How does Carbon Pricing Matter for a Climate-friendly Food Consumption?

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Carbon pricing and climate-friendly food consumption: The new challenges of environmental taxation

Abstract
From the climate change perspective, carbon taxation is a major option for emissions mitigation, and it relies on carbon pricing. This article designs several carbon taxation scenarios at the consumption level. It includes reallocation proposals and evaluates the policy impacts of intermediate to high carbon prices. It measures greenhouse gas emissions and several associated costs.
The food system is the 2nd highest contributor to climate change after the energy sector. It is estimated to contribute 30% of the total greenhouse gas emissions (GHGE), particularly due to emissions from the meat and dairy sector. Although the food system is less studied than the energy sector, a carbon tax on food could also contribute to emissions mitigation as a strong signal to economic actors. A carbon tax based on the differing emission potentials of disaggregated food groups gives a rationale for targeting different sets of products, especially foods rich in animal proteins, and including a revenue-neutral policy. In taxation design, carbon pricing is a strategic issue. While introducing a variation in the carbon price just transfers the same variation in tax rates, the effect on the associated nutritional and equity costs are unknown. Scanner data from French households in 2010 were analyzed. Several GHGE indicators and related nutritional impacts, such as diet quality scores and the shift from animal to plant proteins, were also evaluated. Distributional effects, estimated for continuous distribution, were also measured through an inequality index.

Policy relevance

- Taxing all food purchases at a high carbon price (140€/t CO2eq) would reduce GHGEs 15% to 17% according to indicators.
- A revenue-neutral carbon taxation scenario may have nutritional and distributive co-benefits, combining GHGE reduction with a better adherence to nutritional guidelines and a slightly improved distribution of the food expenditure.
- Comparing the effect of high *vs* intermediate carbon prices, the impacts on the tax revenue, nutritional improvements and equity gains are non-proportional to the price gap.
- Higher carbon pricing may provide stronger mitigation effects and increase co-benefits, which should encourage policy-makers to consider this option with more urgency.

Keywords: carbon tax; carbon pricing; revenue-neutral; environmental public policy; food consumption.

1. Introduction

A recent report by over 15,000 scientists (Ripple, 2017) emphasized the urgent need for action to preserve the planet from further adverse effects of climate change. At its current pace of change, the temperature is expected to increase 2.7°C before the end of the century, far exceeding the 2015 Paris agreement. The global food system is the 2nd highest contributor to climate change after the energy sector. It is estimated to contribute 30% of the total greenhouse gas emissions (GHGEs), with the livestock sector as a major emitter (14.5% of total emissions) (Wellesley, Happer, & Froggatt, 2015). Because the world demand for proteins and meat is expected to grow at a steady pace due to the increase in the population and preference for animal proteins, the unsustainability of this demand threatens the global environmental resources. If meat and dairy consumption continues to rise at their current rates, the agricultural sector alone will produce 20 of the 23 GtCOeq yearly limit in 2050, leaving just 3 GtCOeq for the rest of the global economy (Wellesley et al. 2015). Restrictions on meat overconsumption in developed countries are also supported by nutritional recommendations, which encourage lower protein and meat consumption levels than those currently observed (World Cancer Fund, French Nutritional and Health Plan). Therefore, protein consumption is a key issue for GHGE mitigation. A carbon tax on food could be an incentive to help consumers modify their diets from a climate-friendly perspective, which would result also in health benefits by lowering the calories consumed from total proteins and/or increase the importance of plant proteins relative to animal proteins. However, as food taxes involve difficult and politically sensitive trade-offs, governments focused mitigation interventions in other sectors, mainly the energy sector, as they are less challenging or controversial. “Sin taxes” on meat and cheese are currently being discussed in German, Danish and Swedish parliaments but are not yet implemented.

The food taxation literature indicates that food consumption is price-sensitive and could respond to the internalization of environmental costs in food prices through virtuous food substitutions and changed consumption patterns, thereby reducing GHGEs (Wirsenius, Hedenus, & Mohlin, 2011; Briggs, Kehlbacher, Tiffin et al., 2013; Caillavet, Fadhuile, & Nichèle, 2016; Revoredo-Giha, Chalmers, & Akaichi, 2018). However, a major drawback to food taxation policies is their regressivity, since lower-income households spend a higher budgetary share on food. At the same time, food taxation can bring substantial revenue to implement compensation policies. A strategic issue relates to the allocation of revenue with a combination of taxes and subsidies (Edjabou & Smed, 2013; García-Muros, Markandya, Romero-Jordan, & Gonzalez-Eguino, 2017). Valuation methods for carbon pricing and their subsequent results are still under debate (Stiglitz & Stern, 2017), underlying the importance of carbon price for the establishment of emission-based taxes. In this perspective, this paper assesses the effects of high carbon prices on a major GHG emitting sector, the food sector, and studies in detail their benefits/costs in the environmental, nutritional and equity fields.

The challenge of this article is to show that a high carbon price for environmental taxation is key to obtaining substantial emissions mitigation. Concerning its application to food consumption, important distributional and nutritional drawbacks of this policy can be avoided with a specific taxation design. Indeed, reallocation scenarios could alter diet quality and distributional outcomes.

This paper puts forth several contributions. First, it studies the incidence of a mid-range *vs* a high-range carbon pricing on environmental taxation. Second, on an emission basis, it compares taxation on the whole food consumption with taxation targeting some high-GHG-emitting foods, such as animal-based products. Third, a revenue-neutral scenario implementing subsidies is developed, comparatively, to control for distributional and nutritional issues. In this study, the outcomes of two alternative carbon prices are assessed for GHGE reduction. Moreover, associate tax costs are measured, since the regressive effects on food budgets and the nutritional impacts on diet quality are key to food policies. Scanner data from French households in 2010 are analyzed, and taxation simulations are based on demand elasticities. The environmental effects are computed through climate change, air acidification, and eutrophication indicators. The nutritional effects include diet quality scores, total protein intakes and plant protein shares. Finally, as individual values are computed, distributional effects are provided, allowing an inequality index, such as the Gini index, to be calculated.

The remainder of this article is organized as follows. Section 2 presents the data and methods applied to French household food consumption. Section 3 provides the outcomes of the simulated tax scenarios with different carbon prices. Section 4 discusses the results. The last section contains the conclusions.

2. Material and methods

2.1. Empirical model

To evaluate the effects of setting a carbon tax, we use an ex ante framework. It is based on the estimation of a flexible demand system, which enables the computation of demand elasticities, i.e. the household sensitivities to carbon taxes. This requires two steps: the estimation of a household's sensitivity and the implementation of a proportional tax system.

First, for household purchase decisions, the Exact Affine Stone Index (EASI) demand system (Lewbel & Pendakur, 2009) is retained. This demand system has linear parameters and enables aggregation over preferences, such as the currently used AIDS (Deaton & Muellbauer, 1980). It also adds interesting properties. Implicit Marshallian demand functions are specified with flexible Engel curves that depend on each food group of the entire food bundle purchase, modeling the complementarities and substitutions. The polynomial degree is empirically chosen to fit the data and thus captures the unobserved heterogeneity. Moreover, the implicit utility is expressed as the log of the food expenditure deflated by the log of the Stone price index. Therefore, this specification uses an exact deflator and not an approximated expenditure. Thus, changes in food purchase costs are computed as the ratios of the log-cost function at the pre-tax and post-tax price levels to measure how taxation would impact the cost function of households and the purchasing power.

Second, for each food group j ($j \in \mathbb{N}$), let ϑ_j represent the emission level and υ represent the extra-cost corresponding to the value of the carbon tax. We define a subset c of the taxed food groups to be proportional to the level of emissions. Let $\tau_{c(j)} = \vartheta_j \tau_j$ if j is taxed in subset c, and 0 if j is not taxed. This enables the computation, for each indicator k, of the post-taxation situation:

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

where $\tau_{c(j)} = \vartheta_{c(j)}/\exp_j$ and q_j is the initial quantity of food group j, exp_j is the household expenditure, and $\varepsilon_{k,j}$ is the indicator elasticity (computed from the first step).

Finally, the revenue generated by the taxes is used to subsidize a selected subset of food groups to reach a revenue-neutral scenario. In this setting, a subsidy is implemented such that the sum of the tax revenue is totally allocated to households.

2.2. The Data

The dataset is constructed by merging several sources. First, purchases are computed from scanner data from the 2010 Kantar Worldpanel. This survey registers household purchases for food-at-home, i.e. quantities and expenditures. The households with complete purchase data were selected, yielding a sample of 7,134 households.

Environmental data are collected by Greenext, an environment consultancy, which assigns the environmental impact of 311 food products in France based on life-cycle analysis (Goedkoop et al., 2009). The final values are illustrated by the following three variables: CO2 gives the carbon dioxide emissions (gCO2eq/100 g); SO2 gives the sulfur dioxide emissions (gSO2eq/100 g), which relates to air acidification; N gives the nitrogen dioxide emissions (gNeq/100 g), which is directly related to water eutrophication.

The calories and nutrient equivalencies of the purchases are based on the food composition CIQUAL data[1] provided by the French Agency for Food, Environmental, Occupational and Health and Safety. The CIQUAL data give the number of calories per 100 g of edible part for each food item and a set of 15 nutrients. They are used to assess a nutritional score, the mean adequacy ratio (MAR, see Darmon, Lacroix, Muller & Ruffieux, 2014). Computed on a daily 2000 kcal basis, this score illustrates the suitability of a diet to nutritional recommendations. The more likely it is to reach 100, the better the household diet.

Finally, foods are grouped into 21 groups, taking into account the environmental emissions and nutritional contents of the products, the consumer preferences and the willingness to substitute products within food categories, as in Caillavet et al. (2016).

2.3. Carbon pricing and tax rates

Taxes are proportional to the amount of GHGEs. Concerning carbon pricing, French carbon social cost estimates are based on the European Commission's commitment (Quinet, 2009). These values range from 56€/t in 2020 to 200€/t in 2050. Here, 2 values are selected: the 2020 value (56€) and a 140€ value derived from a proposal of the Ministry of Ecological Transition that was issued in July 2017, since accelerating the taxation pace is being debated in the European Commission.

[1] Available from: http://www.ansespro.fr/tablecíqual.

Among carbon taxation studies on food, carbon prices have been set at different levels. Revell (2015), for a world estimation, used a level of US$ 80/tCO2eq/t meat (0.06€/tCO2eq/kg meat at 2010 rate). Briggs et al. (2013), for the UK, applied a level of 2.86£/tCO2eq/100 g food (0.32€/tCO2eq/kg food at 2010 rate). Edjabou and Smed (2013) tested two prices, 0.26 and 0.76 DKK/kgCO2/kg food (respectively 35€/t and 102€/tCO2eq/kg food at 2010 rate). In comparison, the rates selected here (56€/t to 140€/tCO_2eq/kg food) fall within intermediate to high ranges. For each of these carbon pricing levels, the evaluation is conducted by assuming an extra-cost in food prices at the consumer level, thus acknowledging that producers and retailers can directly set prices.

2.4. Targeted food groups

All food groups have different GHG emitting potentials. Table 1 presents the average values of CO2eq, expressed per 100 g, for each food group (column A) on which the targeted group choices are made. The following scenarios are implemented, according to the level of GHGEs of each food group (see Table 2):

- **TAX_ALL** applies taxes to all food groups; the subsequent emission-based tax rates on all food groups are computed with a pure environmental approach.
- **TAX_ANI** restricts taxes on the 4 highest-emitting food groups rich in animal proteins. Sustainability is coupled with nutrition goals by targeting the set of products most unfavorable for the environment and for health, illustrated by foods rich in animal proteins, and highlighting the desired shift to foods rich in plant proteins. The highest-emitting food groups are mostly animal-based ones, "beef", "other meats", "cooked meats", and "cheese". Taxing other animal-based products appears to be less relevant; the "fish and seafood" group is close to the emissions average and is recognized by the French nutritional guidelines as having good nutritional properties. Similarly, the "prepared mixed dishes" group is close to the emissions average; "animal-based fats" have a low protein content.
- **TAX_SUB** is a revenue-neutral scenario. It uses the TAX_ANI revenue to subsidize 2 food groups rich in plant proteins, "fresh fruits and vegetables" and "starchy foods" (including pulses). This scenario subsidizes healthier and more environmentally friendly foods. For this, foods rich in plant proteins are relevant. A large consensus is found in dietary recommendations on the role of fruits, vegetables and pulses (French PNNS, European EFSA, 2012). Concerning fruits and vegetables, fresh ones were chosen, as they represent a higher contribution to the protein content (4.10%) than processed fruits and

vegetables (2.56%). Moreover, the consumption of fresh fruits and vegetables is socially differentiated, contrary to that of processed ones. In France, recent dietary intake surveys, (ANSES, 2017) or Plessz and Gojard (2013), have shown that low-income households consume less fresh fruits and vegetables. Concerning pulses, the whole group of "starchy foods" had to be considered due to data constraints. Therefore, two food groups are candidates for subsidies. Moreover, subsidizing a restricted set of foods is advantageous to the financial means available in a revenue-neutral approach, and stronger effects can be expected in the environmental and nutritional outcomes. An important additional issue is that the targeted food groups for subsidies are less consumed by lower-income households and meet an explicit nutritional social goal (PNNS), as improvements are more necessary for disadvantaged households.

[Table 1 near here]

3. Results

3.1. Empirical evaluation

Empirically, the impacts of the tax scenarios were measured using the previously published demand system of Caillavet et al. (2016). The demand parameters were used here for computing demand elasticities for 21 food groups. They account for substitutions between food groups and the budget constraints of households.

To precisely evaluate the impact of the carbon tax scenarios described above, individual purchases in 2010 were used, i.e., the individual level of price and quantity for each food group and for food expenditure were considered. These individual values enabled the evaluation of the statistical distributional effects by comparing the distribution of each indicator before and after the taxation scenario effects. Therefore, the confidence interval for each value of the carbon price can be computed.

The scenarios implemented represent different shares among the food-at-home consumption. Compared to TAX_ALL, which concerns all food groups (100% of the food-at-home) 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. It also taxes 64.3% of the animal proteins (Table 2). TAX_SUB concerns 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. It taxes 64.3% of the animal proteins and subsidizes 44.2% of the plant proteins.

[Table 2 near here]

3.2. Tax rates

In the following section, the results will be indicated for the 2 carbon price levels described in the previous section (56€ and 140€/tCO2eq). The induced tax rates reflect the exact gap between the 2 prices at the level of each food group (Table 2). Therefore, when applied to all food groups (TAX_ALL), the 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 of 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". The TAX_SUB rates are the same as the 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.

3.3. Effects of the taxation

Concerning environmental changes, all scenarios predict a significant decrease in emissions (Table 3 and Figure 1). In TAX_ALL, which taxes all foods, variations in the environmental indicators are quite noticeable, with 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, which subsidizes "fresh fruits and vegetables" and "starchy foods", 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, -1.92% to -4.31% for N. Figure 1 shows that some scenarios are not always different, for example concerning SO2 emissions 95% confidence intervals for TAX_ANI and TAX_SUB overlap.

[Table 3 near here]

[Figure 1 near here]

Concerning nutritional effects, three indicators are summarized for the different scenarios (Table 3 and Figure 2 at 140€/tCO2eq). First, the MAR illustrates the suitability of food purchases in relation to nutritional recommendations. In TAX_ALL, the MAR improves slightly (+0.16 to +0.38 percentage points). TAX_ANI degrades the diet nutritional quality (-0.08 to -0.21 percentage points), while an improvement is observed in TAX_SUB (+0.12 to +0.33 percentage points). Second, the protein share in total calories measures the impact of protein substitutions following taxation. Regardless of the carbon price used, all scenarios show a decrease in the protein share, with the greatest decrease occurring under the TAX_SUB scenario (-0.28 to -0.71 percentage points), inducing a food-at-home protein content of less than 14% for 140€/tCO2eq pricing. Third, the plant share of the total proteins measures the desired substitution of animal with plant proteins. All scenarios improve the plant protein share, with the highest ratio, 27.59%, in TAX_SUB (+0.92 to +2.54 percentage points). The nutritional impact of the scenarios always significantly differs among scenarios (Figure 2).

[Figure 2 near here]

Finally, in terms of the loss of purchasing power relative to the food budget, incorporating the cost of carbon into all components of food-at-home (TAX_ALL) has the stronger impact, as expected, compared to the scenarios that involve less food groups. TAX_ALL induces a supplementary daily food expenditure cost per household of 4.49% to 11.22%, while TAX_ANI induces costs of 1.59% to 3.98%, and TAX_SUB induces no costs, as it is designed to be revenue neutral (Table 3).

However, the Gini inequality index, based on the distribution of the food expenditures pre- and post-scenario, shows a different trend. The Gini index decreases with TAX_ALL and TAX_SUB, with a very slight decrease after taxing all food groups and a higher decrease after taxing and subsidizing the protein food groups (-0.004/-0.010 points).

4. Discussion

These results give, for the first time in France, an ex ante evaluation for incorporating the carbon cost to all food groups. Setting a high carbon price (140€/t) compared to a mid-range price (56€/t) provides the only opportunity to obtain substantial environmental impacts (emissions indicators at or exceeding a 15% decrease), through the consequent tax rates

(0.9% to 19.4% according to food groups). Previously, nutritional taxation literature has argued that a 20% tax rate was the minimum value to obtain diet change (Mytton, Clarke & Rayner, 2012). At 140€/t, TAX_ALL allows the avoidance of annual emissions of 318 kgCO2eq per household. Note that CO2 emissions, although the main indicator of GHGs used in the literature, do not register the highest variations. SO2 emissions proved to be more sensitive to food carbon tax policies, demonstrating a change of -17.43%.

The TAX_ALL rates logically induce the greatest reductions in emissions among the three scenarios considered, since all food groups are targeted. Nevertheless, the nutritional and equity co-benefits are very moderate; there are slight positive impacts on the overall nutritional quality of purchased food based on the MAR and animal/plant protein shift, and there is a negligible impact on the distribution of the food expenditure, based on the Gini index, with an important loss in the food budget.

Compared to the other scenarios, TAX_SUB is revenue-neutral by introducing compensation subsidies. Here, again, the high carbon price, 140€/t, logically induces a greater decrease in emissions (20 kgCO2eq per household) than with an intermediate one. However, more importantly, the high carbon price is crucial for achieving better compliance with the nutritional guidelines. For emissions mitigation, introducing subsidies results in an additional emissions effect compared to the pure tax scenario. The GHGE reduction is -1.78% for CO2 and -8.24% for SO2 (compared to -5.50% and -9.80%, respectively, under the TAX_ANI scenario). This may be related to a quantity effect, as subsidized products benefit from higher purchases. Therefore, the decrease in total calories purchased remains non-substantial in TAX_SUB (-0.73%), while it reaches -14.85% in TAX_ALL and a lower -2.68% in TAX_ANI. These results are consistent with those of previous works, which noted the relationship between emissions and calorie intakes (Vieux, Darmon, Touazi, & Soler, 2012).

Regarding the impact on purchase quantities per food group, beef purchases were found to decrease, with little variations among scenarios.[2] Indeed, the taxation rates for the foods rich in animal proteins were the same in all scenarios for a given carbon price (Table 2), while subsidies cause more changes by inducing important increases in purchases of "fresh fruits

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[2]Results are available upon request.

and vegetables" and "starchy foods". Note, however, that these two groups already registered higher purchases due to substitutions after animal protein taxation alone (TAX_ANI) compared to the baseline.

Furthermore, TAX_SUB shows the efficiency of a reallocation of tax revenue to plant-based foods. Briggs et al. (2013), in Britain, showed that taxing the highest-emission food groups (emissions over the average) to subsidize the lowest-emission food groups would induce adverse health effects. In France, the average emissions amount to 360 kgCO2eq per kg of food. Using the approach of Briggs et al., seven food groups would exceed this threshold ("beef", "other meats", "animal foods high in fats", "cooked meats", "cheese", "prepared mixed dishes", and "fish and seafood") and would be candidates for taxation (Table 1). At the same time, with a revenue-neutral approach, subsidies would be allocated to the food groups under this threshold. This favors nutritionally undesirable products, such as "alcohol", "soft drinks" or "foods high in sugar". In contrast, favoring a protein shift from animal to plant-based foods on environmental grounds also induces an improvement in nutritional indicators The highest price obtains a decrease in protein calories under 14% and an increase in the fresh fruit and vegetable purchases that is consistent with the nutritional guidelines (400 g/capita/day for fruits and vegetables in French PNNS). Calculating the household per capita quantities on the basis of equal distributions among household members,[3] an average of 404 g at 56€ *versus* 502 g at 140€ was obtained. However, as fruit and vegetable consumption is known to be heterogeneous and as increasing this consumption for disadvantaged populations is a national priority (PNNS), it is necessary to check whether the TAX_SUB impact holds for lower-income households. For households under the poverty threshold (Burricand, Houdré, & Seguin, 2012), quantities purchased were found to remain well under the nutritional recommendations, with levels of 232 g/capita/day even at a carbon price of 140€/t. In this perspective, a high carbon price is more than adequate.

Combining carbon pricing with food taxation issues, the revenue-neutral scenario TAX_SUB shows strategic co-benefits compared to the other scenarios, and a high carbon price is a necessary condition for its impact. On the one hand, the resulting nutritional indicators of TAX_SUB are favorable, with an improving diet quality score based on the

[3] Available upon request.

MAR, a decreasing total protein content and an increasing share of plant proteins (-0.7 and +2.5 percentage points, respectively, at 140€/tCO2eq). The usual taxation scenarios induce calorie decreases, which raises doubts on the feasibility of the consumer behavior change. TAX_SUB is more credible, with calorie decreases under 1%. On the other hand, the *equity* effects are quite distinct. The average loss of purchasing power, here represented by the increase in the food budget, indicates that the revenue-neutral scenario is the only one that is not regressive. Indeed, the Gini index calculated on the distribution of the food expenditure improves by 0.01 points. While it is interesting to observe that the taxation in TAX_ALL does not worsen the Gini index, this scenario nevertheless induces an important loss of purchasing power (the food budget increases by 11.2%), which calls for compensation, at least for lower-income households.

Finally, comparing the impact of the two different carbon price values does not result only in a difference in the magnitude of the effects that corresponds to the exact difference between the 56€ and 140€ values (2.5 times). While this gap automatically translates to the tax rates, since they are based on emissions, this is not the case when dealing with the absolute revenue derived from the tax. Indeed, the higher the carbon price, the higher the revenue available for public action at a non-proportional rate (here, a multiplicative factor of 2.7 times). As the revenue amount, in a revenue-neutral scenario, determines subsidies, the gap between the subsidy rates at different carbon prices was observed to be higher (3.02 times for “fruits and vegetables”, 3.09 times for “starchy foods”) than the carbon price gap itself.

These results can be considered as low estimates, since Kantar scanner data only concern food-at-home purchases. The potential changes due to carbon taxation in the whole food consumption, and the relative variation ranges, could be different because affecting the whole diet would bring higher GHGE reductions. However, food-at-home in France still represents an important share of calories (80%, according to the INCA3 survey, see ANSES, 2017), more than in other developed countries.

5. Conclusions and perspectives

There are still few studies evaluating the effect of a carbon tax applied to food consumption. In this field, carbon pricing represents an efficient tool for discouraging carbon-intensive patterns. Here, the relevance of carbon pricing was studied in relation to several key issues of environmental food taxes, with a specific focus on nutritional and distributional co-benefits/costs. The impacts of several taxation scenarios aimed at GHGE mitigation, including a revenue-neutral scenario, were studied for France. Proportional emission-based tax rates, allowing the discrimination of foods according to their environmental impacts, were designed. Two carbon prices in the mid- and high-ranges were retained (56€/tCO2eq to 140€/tCO2eq). The results showed that carbon pricing needs to be high to obtain substantial impacts. A carbon tax policy could be effective in reducing over 15% of GHGEs when all food groups are targeted. The results note that the reallocation scenario improves the nutritional quality of food, particularly related to the desired substitution of animal with plant proteins. It also slightly reduces the Gini index, leading to favorable results in terms of distributional effects. As demonstrated by different studies in the literature (Briggs et al., 2013; Caillavet et al., 2016) the compatibility of environmental aims, health and society equity remains a difficult task, which leads to necessary trade-offs.

Finally, the results showed the carbon price magnitude matters for food policy. Indeed, a high carbon price could have several benefits for food environmental taxation. Logically, as a stronger signal to consumers, it is more efficient in changing consumption patterns and induces a larger emissions reduction. However, interestingly, the induced impacts are non-proportional to the price gap and were higher for the tax revenue, nutritional improvements and equity gains. Therefore, a higher carbon pricing has large co-benefits, which should encourage policy-makers to consider this option with more urgency.

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Table 1: Summary statistics by food group: Shares, GHG emissions, household expenditure and quantity (on a daily basis per household).

Food groups	Shares (in %)						(A) Emissions (gCO2eq/100 g food)	(B) Food expenditure (€)	(C) Quantity (kg)
	Food Budget	Environment			Nutrition				
		CO2	SO2	N	Calories	Proteins			
Plant-based food groups									
Beverages									
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
Other plant-based products									
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									
Animal-based products									
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
Mixed origin-based products									
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	TAX_ALL		TAX_ANI		TAX_SUB	
Carbon price in €/tCO2eq	**56**	**140**	**56**	**140**	**56**	**140**
Plant-based food groups						
Beverages						
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				
Other plant-based products						
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						
Animal-based products						
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				
Mixed origin-based products						
Prepared mixed meals	3.89	9.72				
Prepared desserts	3.89	9.73				

Table 3: Variations in environmental, nutritional and social 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**	**(%)**
Environmental indicators													
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
Nutritional indicators													
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]
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
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]
Distributional indicators													
Gini	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]
Food expend (€/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

Notes: [a]Percentage point variation; [b]Absolute variation.

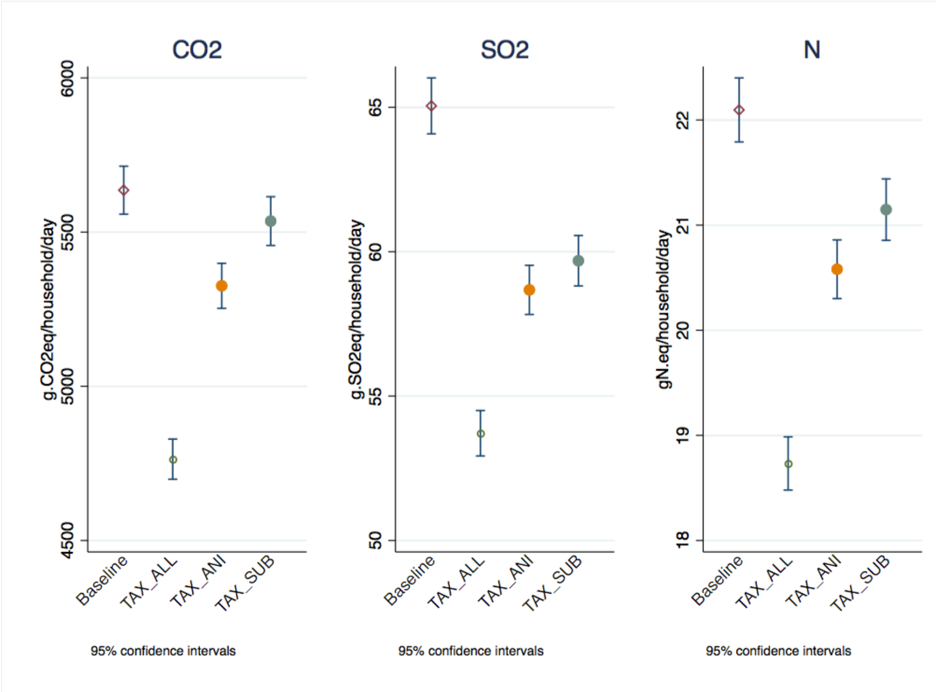

Figure 1: Environmental values for CO2, SO2 and N by scenario at 140€/tCO
values and 95% confidence intervals).

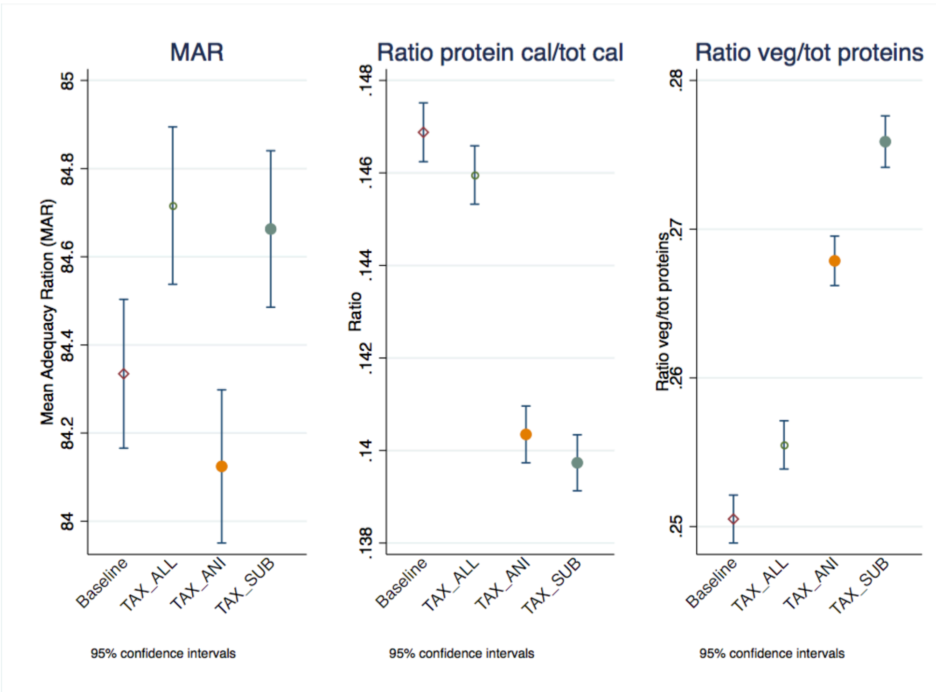

Figure 2: Nutritional values for MAR (2000kcal basis), proteins share in total
plant share in total proteins by scenario at 140€/tCO2eq (average values and 95
intervals).