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Promoting climate-friendly diets: What should we tell consumers in Denmark, Finland and France?

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ABSTRACT

We investigate ex-ante the effects of promoting simple climate-friendly diet recommendations in Denmark, Finland and France, with the objective of identifying cost-beneficial recommendations that lower greenhouse gas emissions and improve public health. The simulation approach combines a behavioural model of consumption adjustment to dietary constraints, a model of climate impact based on the life-cycle analysis of foods, and an epidemiological model calculating health outcomes. The five recommendations considered in the analysis focus on consumption of fruits and vegetables, red meat, all meat and all animal products, as well as the greenhouse gas emissions arising from the diet. The results show that trade-offs between climate and health objectives occur for some recommendations in all countries, and that substitutions may result in unintended effects. However, in all countries, we identify some recommendations that would raise sustainability in both its climate and health dimensions, while delivering value for money and increasing social welfare. In particular, promoting consumption of fruits and vegetables through campaigns of the "five-a-day" type is found to be cost-beneficial in all three countries. By contrast, targeting consumption of meat, consumption of all animal products, or the climate footprint of diets directly through social marketing campaigns is only found to be desirable in some country-specific contexts.

1. Introduction

The impact of the food system on climate-warming greenhouse gas (GHG) emissions has now been convincingly established. In most high-income countries which form the focus of this paper, the production, processing and retail of foods account for 15–30% of all GHG emissions (Esnouf et al., 2013; Garnett, 2011), which makes the sector one of the top three contributors to global warming together with housing and transport (Guinée et al., 2006). Given that emissions should decline drastically to prevent catastrophic climate change, as reflected in the EU's emissions reduction target for non-ETS (Emissions Trading Systems) sectors such as agriculture of 30% below 2005 level by 2030, the contribution of the food sector to mitigation efforts is a mathematical necessity rather than a matter of opinion. The magnitude of the challenge to keep GHG under control also makes it unrealistic to think that the problem will be solved by new technology alone (de Bakker and Dagevos, 2012). Thus, it is clear that changes in food consumption patterns are required as part of the transition to a low-carbon society.

In response to this diagnostic, research on the climate effect of food consumption in high-income countries has made much progress and produced important insights. It has been established that, with the foods available to modern consumers, it is possible to compose diets that are nutritionally adequate but have a significantly smaller GHG impact than existing diets (e.g. Macdiarmid et al., 2012; Westhoek et al., 2014; Green et al., 2015). Typically, studies based on optimization techniques suggest that, in different EU countries, 25–30% reductions in food-related GHG emissions are compatible with nutritional adequacy and affordability (Horgan et al., 2016 for the UK; van Dooren and Aiking, 2016 for the Netherlands; Perignon et al., 2016 for France; Vieux et al., 2018 for five EU countries). Those studies have also revealed, in broad terms, what climate-friendly diets look like: compared to existing diets, they contain relatively more plant-based products, in particular those rich in proteins such as legumes and nuts, and less animal products, in particular those from ruminants. The climate-friendly diet target and direction of travel towards it are therefore reasonably clear.

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Unfortunately, it is also likely that the benefits of climate-friendly diets are challenging to realise because they require large changes in food consumption: in the case of five EU countries, for instance, Vieux et al. (2018) establish that about half of the daily diet (in quantity) should be modified to achieve a 30% reduction in diet-related GHG emissions. Looking at the same issue from a different perspective, the economics literature has also established the difficulty of inducing large dietary changes. Thus, studies assessing the climate and health impacts of a carbon tax applied to foods have shown that reductions in GHG emissions tend to be low, even for significant tax rates (Briggs et al., 2013 for the UK case; Edjabou and Smed, 2013 for Denmark; Bonnet et al., 2018 for France; Springmann et al., 2016 for the world). However, that literature suggests a similar direction of dietary change, with carbon taxes inducing an increase in consumption of plant-based products and a decrease in consumption of animal products.

In turn, large-scale changes in food consumption patterns are problematic to orchestrate within a population. Fiscal measures such as taxes and subsidies are politically difficult in the current context, so that the provision of information remains the policy of choice to influence consumers (Capacci et al., 2012). Yet, empirically, we observe that informing consumers about the effects of diets on health and the environment typically generates little behaviour change (Traill, 2012). If a variety of explanations for this reluctance to change can be put forward, we wish to highlight two particularly significant ones: First, eating responds to a variety of needs, both individual and cultural, and offers multiple rewards beyond the provision of adequate nutrition (Wright et al., 2001). Although seemingly obvious, the importance of taste, culture and the food environment has too often been ignored in discussions of dietary change (Irz et al., 2016a); Second, consumers are subject to an informational overload, which, in the food area, tends to confuse them and reduce responsiveness to new information (Verbeke et al., 2007).

In this context, for information to be effective in changing behaviours, it needs to be embodied in simple messages that appeal to the food culture and preferences of the target population. Yet, identifying such messages is difficult because preferences are not directly observed, and simplification of the information conveyed to consumers comes with the risk of generating undesirable substitutions and unintended effects. Further, it has also been demonstrated that in self-selected diets, lower GHG emissions do not always go hand-in-hand with healthier consumption patterns (see a survey by Perignon et al., 2017), and care therefore needs to be taken to ensure synergies across sustainability dimensions when designing policies. A first practical implication of this state of affair is that it is unclear whether, say, promotion of fruits and vegetable (F&V) consumption should be prioritised over measures targeting the consumption of meat, dairy products, or any other food category. A second possible implication is that the recommendations to prioritize may vary across countries. Indeed, as consumers' preferences and current dietary patterns differ across countries, it is likely that the same recommendations would result in different dietary adjustments, and consequently would have different effects on health and the environment across countries.

This article tackles these issues by developing an ex-ante analysis of the effect of complying with climate-friendly eating messages, given the current state of consumer preferences. Building on the assessment of dietary recommendations previously conducted in one country (Irz et al., 2016b), the novelty is to carry out a cross-country comparison by considering three EU countries, namely Denmark, Finland and France. A model of adjustment to dietary recommendations is used to identify, for each country, the messages with the largest potential effectiveness to reduce GHG emissions and/or raise the healthiness of diets, the messages most compatible with consumer preferences by imposing minimum adjustment costs on consumers, and the messages that deliver the highest levels of cost-effectiveness.

Previous studies in this area have used programming-based models of diet optimization that make arbitrary assumptions about food preferences, either explicitly by imposing "palatability constraints" (Henson, 1991) or implicitly, through the choice of an arbitrary objective function (Shankar et al., 2008 or Darmon et al., 2008). However, such a mechanistic approach to modelling behavioural responses tend to ignore consumer preferences, for example by assuming the same proportional reduction in consumption of all animal products as a response to the promotion of fruit and vegetable consumption, with a large potential of producing misleading conclusions about climate or health impacts. As compared to other studies, we argue that our model is based on more theoretically consistent and realistic food preferences and hence would lead to more realistic results as regards dietary adjustments as well as health and climate impacts.

2. Material and methods

2.1. The theoretical model

The analytical core of the study is a preference-consistent model of dietary adjustments to requested changes, and subsequent effects of these dietary changes on public health and GHG emissions. More specifically, our approach is based on the combination of three analytical components:

- An economic behavioural model (Irz et al., 2015) simulates how whole diets would change if consumers complied with a given recommendation, and how this would affect utility in the short run.
- An epidemiological model (Scarborough et al., 2012) estimates the health impact, expressed as a number of deaths avoided (DA), of the dietary change simulated by the economic model.
- A life-cycle analysis (LCA) model computes the climate effect (GHG emission reduction) of the simulated dietary change.

In a last step, monetization of the health and environmental effects allows calculation of the benefits from compliance (to a diet recommendation) in a form that can be compared to the consumer loss of utility and public cost of developing measures to ensure compliance in an integrated efficiency analysis. We now turn to each component of the model.

The behavioural model – The economic behavioural model is designed to simulate how a consumer would adjust his diet when facing dietary constraints, whether those constraints relate to nutrition or environmental issues. To be more explicit, a message such as 'eat less meat' is interpreted in the context of the model as a constraint on the consumption of meat. Then, the model describes how consumers in a rational and preference consistent way make trade-offs and substitutions in consumption to satisfy that constraint. Hence, the behavioural model describes how the consumption of other products will change, if the consumption of a particular good is restricted. The approach is based on the generalised rationing theory of Jackson (1991) and presented in much more detail in Irz et al. (2015). We assume that an individual chooses the consumption of H goods in quantities $\boldsymbol{x} = (x_1,\dots x_H)$ to maximize a strictly increasing, strictly quasi-concave, twice differentiable utility function $U(x_1,\dots x_H)$, subject to a linear budget constraint $\boldsymbol{p}.\boldsymbol{x} \leq M$, where $\boldsymbol{p}$ is a price vector and M denotes income. To deal with a dietary constraint (here for ease of presentation, we assume that only one constraint applies, e.g. a constraint on meat consumption; the general case can be found in Irz et al., 2015), let us assume that the consumer faces an additional linear dietary constraint, imposing, a maximum permissible consumption of meat. Denoting by a_i the constant environmental or nutritional coefficient for any food i, the value of which is known from LCA databases or food composition tables, the dietary constraint is expressed by: $\sum_{i=1}^{H} a^i x^i \leq r_n$. We first solve the model in a Hicksian framework. In this context, the consumer minimizes the cost of his diet to reach a given level of utility, which itself relates to his consumption. We distinguish two versions of this program, constrained and non-constrained. We denote the compensated

(Hicksian) demand functions of the non-constrained problem by $h_i(p, U)$, and those of the constrained model by $\tilde{h}_i(p, U, A, r)$, where A is the H-vector of technical coefficients, and $\boldsymbol{r}$ the level of the constraint. To solve the model, we introduce the shadow prices $\tilde{p}$, defined as the prices that would have to prevail for the unconstrained individual to choose the same bundle of goods as the constrained individual: $\tilde{h}_i(p, U, A, r) = h_i(\tilde{p}, U)$. It is important to understand that introducing shadow prices in the analysis does not mean that we analyse a taxation scenario. Rather, as it is well known in economic analysis, a restriction in quantity space has an equivalent in price space. For example, if the consumption of a good is constrained, the consumer will adjust the composition of his basket of goods as if the constrained good had become more expensive (i.e., shadow price greater than actual price). This would imply that the consumption of goods which are close substitutes to the constrained good will increase relatively more than the consumption of goods that are less substitutable with (or are complements of) the constrained good. In the case of a single dietary constraint, Irz et al. (2015) showed that the changes in shadow prices resulting from a marginal change in the constraint level are:

$$\frac{\partial \tilde{p}_i}{\partial r} = a^i / \left(\sum_{i=1}^{H} \sum_{j=1}^{H} s_{ij} a^i a^j\right) \qquad i = 1, \ldots. H \tag{1}$$

where $s_{ij} = \partial h_i / \partial p_j$ denotes the Slutsky coefficient of good i relative to price j. The corresponding adjustments in Hicksian demand induced by compliance with the constraint follow:

$$\frac{\partial \tilde{h}_k}{\partial r} = \left(\sum_{i=1}^{H} s_{ki} a^i\right) / \left(\sum_{i=1}^{H} \sum_{j=1}^{H} s_{ij} a^i a^j\right) \qquad k = 1, \ldots. H \tag{2}$$

Equations (1) and (2) express the changes in shadow prices and compensated demands as functions of two sets of parameters only: first, the Slutsky coefficients, which describe consumers' preferences and the relative difficulty of substituting foods for one another; and, second, vector A, which gathers the technical coefficients measuring the properties of each food in the environmental and/or nutritional domains.

Eq. (1) shows that the marginal change in shadow price of product i with respect to the level of the dietary constraint is the ratio of the content of product i in the constrained quantity and a denominator which is common to all products. Then, shadow prices differ from market prices only for products which enter directly the dietary constraint. By contrast, Eq. (2) shows that a change in the dietary constraint has an impact on the entire diet. This is true even for the goods that do not enter the constraint directly, as long as they entertain some relationship of substitutability or complementarity with any of the goods entering the constraints (i.e., as long as for the set of products i entering the constraint at least one Slutsky term s_{ki} is different from zero). Further, the model indicates that the magnitude and sign of any change in demand for any given product is unknown *a-priori* but depends in a complex way on the product's technical coefficients and its substitutability with other products entering the constraints.

Because real-world consumers operate under a budget rather than a utility constraint, we have to evaluate the uncompensated demands. To do so, we first calculate the compensating variation (CV), which measures the loss of utility due to the imposition of the new dietary constraint. The CV associated with a variation of the constraint r is: $CV = -\sum_{i=1}^{H} p_i \partial \tilde{h}_i / \partial r < 0$. An approximate solution to the change in uncompensated (Marshallian) demand Δx induced by a change in the constraint $\Delta \boldsymbol{r}$ is then calculated by adding to the vector of changes of compensated demands $\Delta h = (\frac{\partial \tilde{h}_1}{\partial r_1} \Delta r, \ldots \frac{\partial \tilde{h}_h}{\partial r_1} \Delta r, \ldots \frac{\partial \tilde{h}_H}{\partial r_1} \Delta r)$ the income effect associated with the removal of the compensation: $\Delta x = \Delta h + \tilde{h}.\ \varepsilon^R CV / p.\ \tilde{h}$, where ε^R denotes the vector of income (or expenditure) elasticities, which is empirically estimable.

The epidemiological and environmental models - Changes in food intakes obtained from the behavioural model are then converted into changes in nutrients using food composition tables. Variations in nutrient intakes are finally translated into changes in mortality due to diet-related chronic diseases using the DIETRON epidemiological model of Scarborough et al. (2012). DIETRON is a macro simulation model which links changes in 10 nutritional inputs (fruits, vegetables, fibres, total fat, mono-unsaturated fatty acids, poly-unsaturated fatty acids, saturated fatty acids, trans-fatty acids, cholesterol, salt, energy) to changes in risk factors for ill health and health outcomes: incidence of diet-related chronic diseases (heart disease, strokes, and ten types of cancer) and related deaths. This is achieved by using age- and gender-specific estimates of relative risks (RR) drawn from world-wide meta-analyses of trials, cohort studies and case control studies. Fundamentally, DIETRON calculates the change in risk for an individual and applies that change to a sub-population to estimate variations in mortality, which is appropriate if we assume that (a) RR are combined multiplicatively, and (b) the relationship between nutritional quality, risk factors and diet-related chronic diseases follows a dose response relationship (Scarborough et al., 2011).

The environmental effects are limited to an analysis of climate impact, which is estimated by applying LCA coefficients to each intake category. The LCA coefficients represent the quantity of GHG emitted by the production, transformation and distribution of the different food products.

Efficiency analysis – To be welfare increasing, a recommendation should generate benefits that are larger than costs. Formally, promotion of a recommendation generates health benefits (denoted B_h) in the form of deaths avoided and reduced environmental externalities (denoted B_e), which can be calculated by valuing the health and environmental effects estimated by the model. The policy also generates two types of costs: the loss of short-run utility experienced by consumers when adopting the recommendation, and the direct cost of the policy (e.g., information campaign). The first cost is provided by the behavioural model and measured by $-CV$. However, the second cost is unknown. Thus, the behavioural model simply assumes compliance with dietary recommendations without considering the policy measures that would be necessary to implement to bring about compliance. To circumvent that problem, we determine an efficiency threshold, defined as the maximum amount that could be invested by public authorities in order to ensure compliance with a given recommendation (denoted C_p). That cost-effectiveness threshold of each recommendation is simply calculated as $Cp = Be + Bh + CV$, giving us a means of comparing the relative efficiency of the selected recommendations.

2.2. Empirical procedure and design of scenarios

For each country, the calibration of the models requires:

- Defining food product categories and associated technical coefficients: contents in nutrients that are inputs of DIETRON, contents in foods used in the constraints (F&V, red meat, meat, and animal products), and GHG impact derived from LCA analysis.
- Estimating a matrix of elasticities of demand for the different food categories and representative households[1] .
- Adjusting the country-specific parameters of the DIETRON epidemiological model.

Annex 1 explains our sources of data and approach to the estimation of demand elasticities. After calibrating the model, we then simulate the

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[1] Behavioural responses can vary within a population in ways that influence sustainability outcomes. For instance, if relatively "unhealthy" consumers respond to a given recommendation by unhealthy substitutions, while relatively "healthy" consumers respond by relatively healthy substitutions, the average substitution pattern in the population may not reflect the actual health impact. Such a situation can be addressed by calibrating the model over several household types distinguished by their "healthiness", although this type of disaggregation is not always possible in practice. We are grateful to an anonymous referee for pointing out this important issue.

adoption by consumers of different recommendations. The empirical procedure is described in greater detail in Irz et al. (2015). Before describing the scenarios, we discuss the assumptions related to the valuation of benefits.

Valuation of benefits – The starting point of the valuation of the health benefit is the threshold value of a Quality Adjusted Life Year (QALY) that is applied in the UK to investigate the cost-effectiveness of medical care. That threshold, discussed in McCabe et al. (2008) and still recommended by the UK National Institute for Clinical Excellence, lies within the £20-30k range, which translates roughly into €24-36k at current exchange rate. Given that epidemiological data show that the average number of Life Years Saved per DA is larger than 10 for most causes of mortality covered by DIETRON, we make the conservative assumption of 10 QALYs per DA, which implies a value of a DA in the €240–360k range. Leaning on the side of caution, we select the lowest value in this range, and the monetized health benefits should therefore be treated as lower bounds. In fact, this valuation of DA is much lower than the values of a statistical life (VSL) typically used in the cost-benefit analysis of public projects, as reviewed by Treich (2015). On the environmental side, there is debate regarding the social cost of GHG emissions (Stratham, 2013). To address this uncertainty, we rely on the meta-analysis of the social cost of carbon developed by Tol (2012). That author, after fitting a distribution of 232 published estimates, derived a median of €32/ton, a value which we adopt in our calculations. Note that Nordhaus (2017) provides an estimate of US$ 31/ton of CO2eq in 2010 US$ for the year 2015 (and also finds in the central case of 3% per year increase of the social cost of carbon from 2015 to 2050). In addition, we will discuss the sensitivity of our results to variations in the social cost of carbon.

Design of scenarios – We analyse the sustainability effects of a number of dietary constraints selected from the literature and public discussions on climate-friendly diets and, to a lesser extent, healthy diets. As mentioned in the introduction, animal products in general and meat from ruminants in particular have been identified as having a disproportionate impact on the climate, that is, in relation to the calories and nutrients that they provide (Wirsenius et al., 2010). Thus, many authors have recommended a reduction in meat consumption (Stehfest et al., 2009), particularly from ruminants, and/or all animal products (Berners-Lee et al., 2012). We therefore test the impact of two recommendations to reduce meat consumption, one for all meat, and the other for meat from ruminant animals only (henceforth referred to as "red meat"), as well as a recommendation to reduce consumption of all animal products, including dairy and eggs. The dietary shift away from animal products towards plant-based products can also be approached by urging individuals to consume more of the latter rather than less of the former, and we therefore include a recommendation to increase consumption of F&V.

For each of the above constraints taken one at a time, there is an expectation of health gains accompanying the climate benefit. High consumption of animal-based products is considered a risk factor for chronic diseases such as type-2 diabetes, some cancers, and cardiovascular diseases (CVD), as reflected in the decision of the World Health Organisation to recommend reductions in consumption of fresh and processed meats (IARC, 2015). Meanwhile, consumption of F&V has been shown in meta-analyses to be negatively associated with risks of CVD (Dauchet et al., 2006; Feng et al., 2006) and all-cause mortality (Wang et al., 2014).

An alternative approach to recommendations targeting specific food groups would rely on the development of carbon labels for foods, as piloted in several countries (Cohen and Vandenbergh, 2012), together with informational measures to persuade consumers to reduce their diet-related climate impact. A constraint on total GHG emissions from the whole diet, measured in terms of CO_2 equivalent (CO_{2e}), is therefore introduced in the analysis.

It should be clear that the analysis of this last case implicitly assumes that consumers have information about the GHG content of foods and are able to take it into account and 'process' it while making decisions. In practice, that might not be so and that analysis is slightly more theoretical, but it was developed for the sake of comparison with the other four recommendations, which are food-based and therefore impose fewer implicit requirements in terms of knowledge of the consumers.

Table 1

Effect of recommendations on greenhouse gas emissions, health and short-term consumer welfare.

	F&V +5%	Red meat −5%	All meat −5%	All animal products −5%	CO2e −5%
CO2 equivalent					
Denmark (kt)	−137	−281	−304	−60	−995
Finland (kt)	−49	−236	−131	−28	−828
France (kt)	−983	−265	−395	179	−958
Denmark (%)	−0.7	−1.4	−1.5	−0.3	−5.0
Finland (%)	−0.3	−1.4	−0.8	−0.2	−5.0
France (%)	−5.1	−1.4	−2.1	0.9	−5.0
DA for DIETRON diseases					
Denmark (total)	338	−125	−175	458	−248
Finland (total)	472	54	−17	71	357
France (total)	778	68	65	−210	266
Denmark (%)	0.7	−0.2	−0.4	0.9	−0.5
Finland (%)	2.2	0.3	−0.1	0.3	1.7
France (%)	4.4	0.4	0.4	−1.2	1.5
Taste cost					
Denmark (€ million)	24	19	60	9	115
Finland (€ million)	12	−10	34	7	181
France (€ million)	145	3	20	19	48
Denmark (% food budget)	0.1	0.05	0.1	0.02	0.3
Finland (% food budget)	0.03	−0.02	0.1	0.02	0.4
France (% food budget)	0.7	0.01	0.1	0.1	0.2

Note: For absolute quantities, the results are expressed for 10 million adults in the 25–74 age range. For that age range, the populations of Denmark, Finland and France are 3.49 million, 3.42 million and 37.10 million respectively.

3. Results

3.1. Climate, health and economic effects of the recommendations

Table 1 describes the climate, health and economic effects of adoption by consumers of the five recommendations taken one at a time. Results are provided in quantities and in percent. For quantities, to ease comparison between countries, results are expressed per 10 million adults. We simulate a 5% decrease for all targets except for F&V, in which case a 5% increase is simulated as F&V consumption should be encouraged. We start with the primary variable of interest, that is, the climate impact of the dietary adjustments simulated by the model. As expected, the imposition of the constraints results in reductions in GHG emissions from the diet ranging from 0.2% to 5%, with one notable exception in the case of France, where it is found that reducing consumption of all animal products would actually have a negative climate impact (i.e., raise GHG emissions), although the effect is small (+0.9%). The result is explained by substitutions operating within the category of animal products: while consumption of milk, cheese and eggs would decrease, as expected, some of the decline would be offset by increases in consumption of meat (+0.7% in total), in particular of the most impacting kind (red meat + 1.8%)[2] . This example demonstrates the importance of the behavioural adjustments captured by the

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[2] The whole set of substitutions is reported in Table A1 in Annex 2.

model, and shows the need to consider whole-diet substitutions when analysing the climate effect of dietary recommendations. A rational French consumer seeking to comply with a recommendation to reduce her consumption of animal products at minimum utility cost to herself would in fact raise her consumption of meat from ruminants. For the other two countries, the simulated substitutions are different both qualitatively and quantitatively. For example, in the case of Denmark, the decrease in consumption of animal products causes a reduction in consumption of all types of meat. These country-specific adjustments are explained by the initial composition of the diet and the substitutability and complementarity relationships among foods that differ across countries. As a consequence, a mechanistic and somewhat naïve approach to modelling the behavioural response to recommendations that would ignore consumer preferences by assuming the same proportional reduction in consumption of all animal products would be inappropriate and produce misleading conclusions about climate impacts.

The climate impact of the different recommendations varies by type of recommendation but also by country[3] . Indeed, the recommendation delivering the largest reduction in GHG emissions is different in the three countries, with F&V in the case of France (−5.1%), red meat in the case of Finland (−1.4%) and all meat in that of Denmark (−1.5%). One consistent result that holds across countries, however, is that a 5% reduction in consumption of all animal products only has a small (< 1%) effect on GHG emissions, while the two recommendations targeting meat are more effective in that respect.

Table 1 also shows that there is no general result about the effect of broadening the scope of the recommendation targeting meat, from the narrowest focus on red meat to the broader focus on all meat. The broadening of the scope raises the reduction in GHG emissions in France but reduces it in Finland, without much change in Denmark. This result highlights the trade-off involved in the broadening of the scope of a recommendation: on the one hand, a 5% reduction in consumption of all meat is larger, in terms of physical quantity, than a 5% reduction in consumption of red meat and thus has a greater potential to deliver climate benefits. On the other hand, a narrower focus on red meat ensures better targeting of the reduction towards the most impacting foods. Table 1 shows that this trade-off plays differently in different countries, depending mainly on consumer preferences.

The health effects of the dietary recommendations are expressed as the number of DA due to the reduced incidence of diet-related chronic diseases. In a majority of cases (10/15), climate-friendly diet recommendations also deliver health benefits, ranging from a few deaths avoided to almost 800 for 10 million people (F&V in France), hence confirming the synergies often mentioned in the literature on sustainable diets (e.g., Macdiarmid et al., 2012). However, in all three countries, and in five simulations out of 15, we also find that compliance with the recommendation may worsen the dietary health of the population. Only the recommendation targeting consumption of F&V would reduce diet-related deaths in all three countries, but the magnitude of the effect varies from less than 1% of all diet-related deaths for Denmark to 4.4% in the case of France. According to the simulations, reducing GHG emissions by 5% would not produce health gains in Denmark but the positive effects on public health in France and Finland would be substantial. Altogether, this analysis reveals that while synergies between the goals of reducing climate impact and improving health by modifying the diet are common, they do not operate systematically and automatically.

Our analysis also measures the difficulty for consumers of complying with each recommendation, as the change in diet has implications in terms of taste, convenience, and other properties impacting consumers' well-being in the short term. The taste cost measuring the short-term loss of hedonic rewards represents in each case less than one percent of the food budget and thus appears relatively small, which is as expected given the limited magnitude of the required changes.[4] However, although the taste cost is small in relative terms, in absolute value it might be substantial. For example, in the case of France and the F&V constraint, the taste cost is as high as 145 million euros annually for 10 million people, which represents a large sum likely to play an important role when examining whether that recommendation may be cost-beneficial. Those substantial costs are typically ignored when assessing the social desirability of measures aimed at promoting healthy eating (e.g., Rajgopal et al., 2002) and climate-friendly diets.

For each country, the ranking of taste costs across recommendations gives an indication of the relative difficulty of adjusting diets to comply with those recommendations. Here again, the results vary across countries: in France, the F&V recommendation is the most difficult for consumers to comply with, although the CO2e recommendation also generates a large taste cost. In Finland and Denmark, it is much harder for consumers to reduce the CO2e from their diet by 5% than to comply with any of the other recommendations. Beyond the ultimate objective of selecting cost-beneficial climate-friendly diet recommendations with health benefits, the model therefore delivers some practical insights, for instance that it should be much easier to encourage F&V consumption in Finland and Denmark than in France.

In all three countries the taste cost of reducing the climate impact of food directly through a recommendation on total CO2e is larger than that of reducing consumption of meat or animal products (abstracting from the fact that reducing the CO2e content of the diet supposes that consumers have the requested information, that is, the knowledge about the CO2e content of each food product and are able to use it). Reducing red meat consumption generates much lower taste costs than reducing all meat consumption, which comes from the fact that cross-category substitutions are more challenging for consumers to achieve than within-category substitutions.

3.2. Cost-benefit analysis

Keeping in mind the objective of identifying win-win cost-beneficial policies, the analysis so far allows us to exclude five recommendations as not delivering either climate benefits (animal products in France) or health benefits (all meat in Finland and Denmark, red meat and CO2e in Denmark). To go further in the selection of recommendations, Table 2 pieces together economic, health and environmental effects to calculate the efficiency thresholds for the ten remaining scenarios (i.e., crossings of country and recommendation). As explained in the methodology section, that threshold represents the maximum amount that could be used by public authorities to promote a recommendation while ensuring that total benefits exceed total costs, assuming that the 5% target for the constrained quantity is attained.

In the case of France, the efficiency thresholds C_p are positive and large for all four constraints, but an increase in consumption of F&V, as well as a direct recommendation to reduce the CO2e from the diet should be prioritised over reductions in meat consumption (all meat, red meat). We note, however, that the thresholds are in all cases large, amounting to more than €70 million per ten million adults for the F&V constraint, and still worth €8 million annually for the "all meat" constraint. Those sums typically exceed the cost of public information campaigns aimed at inducing consumers to change their diets. For instance, Capacci and Mazzocchi (2011) report that the ambitious "5-a-day" UK campaign to encourage consumption of F&V, which was partially successful since it raised consumption by 8%, had a total budget

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[3] The climate effect of the CO2e constraint is an uninformative 5% reduction by construction and we therefore ignore it in this discussion.

[4] We note that the Finnish model produces a small but negative taste cost in the case of the red meat constraint, which is anomalous and inconsistent with the theory. This problem relates to the approximation that is made when switching from the Hicksian constrained model to the Marshallian solution.

Table 2
Efficiency analysis.

	F&V +5%	Red meat -5%	All meat -5%	All animal products -5%	CO2e -5%
DENMARK					
Benefits (€ million)	85	Trade-off	Trade-off	112	Trade-off
Cost (€ million)	24	19	60	9	115
Cp (€ million)	61	–	–	103	–
	(21)	–	–	(36)	–
Ranking	2	–	–	1	–
FINLAND					
Benefits (€ million)	115	21	Trade-off	18	112
Cost (€ million)	12	−10	34	7	181
Cp (€ million)	103	31	–	11	−69
	(35)	(10)	–	(4)	(-23)
Ranking	1	2	–	3	4
FRANCE					
Benefits (€ million)	218	25	28	Loss-Loss	94
Cost (€ million)	145	3	20	19	48
Cp (€ million)	73	22	8	–	46
	(272)	(81)	(30)	–	(171)
Ranking	1	3	4	5	2

Note: All values are expressed for 10 million adults in the 25–74 age range. However, the figures in parentheses give the efficiency thresholds without adjusting for differences in population size.

of less than £3 million (roughly €4 million)[5] . On that basis, our results support the idea that more resources should be allocated to the promotion of sustainable diets in France by informational measures.

In the case of Finland, one efficiency threshold corresponding to the recommendation to reduce the carbon footprint of the diet directly is negative (-€23 million). The result is explained by the large taste cost imposed on consumers. Thus, in spite of the fact that the recommendation would improve public health and reduce GHG emissions, those benefits are too small to justify the costs that the recommendation would also impose on consumers and taxpayers. For the remaining three recommendations, the efficiency thresholds are much more modest than in the case of France, but most of the difference is due to different population sizes. Hence, it turns out that promoting consumption of F&V and a reduction in consumption of red meat would be even more cost-efficient in Finland than in France, when assessed for the same number of consumers.

For Denmark, three of the five recommendations are excluded as generating no improvement in health. The efficiency thresholds for the two remaining recommendations (F&V and animal products) are large, hence suggesting that both measures would also be cost-beneficial.

Altogether, few results hold across all three countries, which points to the need to consider local conditions, in terms of preferences and prevailing dietary patterns, when choosing recommendations to be promoted. In particular, we find that for four of the five recommendations, the recommendation appears cost-beneficial in some country but not in others. The one exception corresponds to F&V, for which encouraging consumption would be cost-beneficial in all three countries according to our simulations.

4. Conclusion

This paper applied a novel approach to the ex-ante analysis of the sustainability effects of climate-friendly diet recommendations in French, Finnish, and Danish contexts. The analysis is motivated by the fact that for information campaigns to be effective, they must convey a simple message, but the simplicity of the message opens the door to unintended effects, as consumers naturally substitute foods for one another in complex and poorly understood ways. As our approach relies on a representation of consumer preferences estimated from actual food purchase data, we claim that it gives a realistic account of substitutions among foods. It also offers a monetary measure of the difficulty for consumers of complying with dietary recommendations, which makes it possible to develop an efficiency analysis of recommendations.

In terms of climate and health effects, the analysis reveals that synergies tend to prevail but that trade-offs are not uncommon and that unexpected outcomes indeed happen due to within-group substitutions. To illustrate, we find that telling consumers to decrease their consumption of animal products in France would likely raise GHG emissions, while a message to reduce meat consumption in Finland and Denmark would likely increase the burden of diet-related chronic diseases. Thus, in spite of their appeal, slogans of the type “Healthy for you, healthy for the planet” (Ornish, 2012) should be taken with caution when devising climate-friendly policies. In fact, the results suggest that a careful empirical investigation taking into account a country’s dietary patterns and food preferences is a necessary preliminary step to establish which dietary recommendation should be promoted.

The taste cost estimates support the view that, in some cases, consumers may not have the incentive to undertake the considered dietary changes, as those changes impose utility losses given the current state of consumer preferences. However, health benefits can also be considered to have private good characteristics that provide utility to consumers. Those health benefits therefore compensate, to some extent, the short-term taste cost. This may especially be the case for the F&V recommendation, which may thus be considered the most incentive compatible recommendation across the three countries, whereas some of the other recommendations may be incentive compatible in some, but not all, countries.

The results also deliver positive conclusions, in the sense that in all three countries, it is possible to find simple messages (e.g., “eat less red meat” in France) that deliver climate benefits, improve public health, and whose promotion is likely to be highly cost-beneficial, thus resulting in an unambiguous rise in social welfare. In all three countries, we note that promotion of F&V consumption fits that description, and that this policy is only outperformed by the promotion of one other recommendation (“animal products”) in the case of Denmark. However, given the variability of consumer preferences and current dietary patterns, the ranking of the other recommendations differs significantly

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[5] The adult UK population in the 25-74 age rage exceeds 40 million (https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalesscotlandandnorthernireland, consulted 21.12.2017).

across countries. This means that, even if some general goal can be determined at the European level, the prioritization of food-based recommendations to promote in pursuit of that goal would have to be conducted at the national level. Nonetheless, a good starting point for the promotion of sustainable diets with climate benefit lies with campaigns of the "five-a-day" type (Castiglione and Mazzocchi, 2019).

We must also acknowledge that the analysis relies on strong assumptions. For instance, we assume that consumers adopt a given recommendation and, therefore, that public campaigns would be effective in changing behaviours. Further, all but one recommendations are food-based and in that sense easy to formulate (as exemplified by "five-a-day"-type campaigns). The recommendation on carbon foot print would be more difficult to implement as the total footprint is the combination of the carbon footprint of every product which is not perfectly known by consumers. To tell it differently, our results related to the CO_2 recommendation rely on stronger assumptions with respect to the information available to consumers.

At another level, the model only captures behavioural heterogeneity in a limited way, which may introduce biases in the modelled health impacts if preferences vary significantly within sub-populations. The issue can in theory be handled by introducing more representative households in the model, but this would complicate calibration greatly and is therefore left to future inquiry. The simulations also rely on the simplifying assumption that foods have the same climate footprint in all three countries. Thus, we are not able to capture differences in climate impact linked to country-level specificities in trade patterns and production systems. Establishing a better linkage of our model of dietary adjustment to supply-side models able to describe input-output relationships and trade represents a priority for future research.

Finally, the model is deterministic and does not fully capture uncertainty about the values of key parameters. While this is not ideal, previous work based on Monte Carlo simulations and sensitivity analyses (Irz et al., 2016a, b) have shown that, at least in the case of France, the conclusions of the research and ranking of recommendations are robust to the uncertainty surrounding the value of LCA coefficients, relative risk ratios of the epidemiological model, and valuation parameters used in the efficiency analysis. However, more work is needed to address those sources of uncertainty in a more systematic way.

The conclusion that large amounts of public resources should be allocated to social marketing campaigns to promote sustainable diets contrasts with the prevailing pessimism regarding the ability of information to change dietary behaviours. Already two decades ago and with reference to healthy eating, Nestle et al. (1998) were writing that "evidence suggests that providing information about risk does not have much effect on food behavior", a point reinforced more recently by Traill (2012). We suggest that those conclusions are overly negative and that two elements should be taken into account when informing policy making: first, that even though some policies may result in limited dietary adjustments at population level, small changes in consumption are often sufficient to ensure cost-efficiency and it would therefore be desirable to revise expectations about the short-term effects of media campaigns. Second, measures to inform consumers about sustainable diets tend to be few and far between, even if considering the traditional area of nutritional health. This contrasts with the continuous marketing efforts of private food companies to promote their brands and magnitude of the related advertising budgets (Matthews, 2007). Seen from that angle, the suggestion that investing millions of euros annually to promote climate-friendly diets would represent an efficient use of public resources does not seem unreasonable.

Declarations of interest

None

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Annex 1 Detail of model calibration

France – The model's calibration is explained in Irz et al. (2015) so that we only give a brief overview here. Food consumption data originates from a representative panel of French households (KANTAR Worldpanel), which was used previously to estimate matrices of price and expenditure elasticities of demand for food by Allais et al. (2010) for four representative households, corresponding to income quartiles. We have used those behavioural parameters and related product aggregation scheme as reported in the supplementary material of that article. The intake and food composition data come from the French dietary intake survey INCA2.[6] The parameters of DIETRON are not country specific, so that adapting the DIETRON model to France only requires calibration of the initial mortality levels, by relevant causes. This is achieved by using the INSERM data on mortality in France attributable to major diet-related diseases.

Finland – The consumption data originates from the year 2012 Household Budget Survey (HBS), which used diary records of all food purchases destined for at-home consumption in a nationally representative sample of Finnish consumers (n = 3495). This data supported the estimation of an approximate Exact Affine Stone Index (EASI) demand system (Lewbel and Pendakur, 2009), which presents several advantages over more common functional forms (e.g., AIDS). The product aggregation scheme was defined so as to allow both a nutritional assessment and an assessment in terms of climate change impact. The elasticities, average intakes and other technical coefficients for those aggregates and a single representative household were drawn from Irz (2017). The mortality data, which are necessary to calibrate DIETRON, are publicly available from the website of the Finnish Statistical Institute.

Denmark – The consumption data originates from the National Dietary Survey 2011–2013 (Pedersen et al., 2015), which is a representative sample based on 3307 individuals' 7-day records of their intakes. The dietary intake data were disaggregated into more detailed commodity groups by means of household budget survey data from Statistics Denmark and household purchase data from GfK Consumerscan Scandinavia panel (http://www2.gfkonline.dk/). An Exact Affine Stone Index (EASI) demand system was estimated on the basis of monthly data from the GfK panel dataset for the years 2006–2014, in order to obtain estimates of conditional price and budget elasticities for a single representative household and the same 20 commodity categories as for Finland.

For the three countries, the LCA coefficients derive from a systematic review of the grey and academic literature, as explained in detail in Hartikainen and Pulkkinen (2016). Importantly, the LCA coefficients are the same for the three countries and correspond to best estimates for an average European diet. We also limit the study to individuals between the age of 25 and 74 and therefore focus on the effects of dietary changes on premature deaths (i.e., occurring before the age of 75).

Finally, simulations of health effects requires that changes in food consumption at household level, as described by the behavioural model, be translated into changes in individual intakes. This is accomplished under the assumption that (i) the percentage changes in intakes are the same for all the members of a given household, and (ii) the percentage changes are the same for at-home and out-of-home consumption.

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[6] Available at https://www.data.gouv.fr/fr/datasets/donnees-de-consommations-et-habitudesalimentaires-de-letude-inca-2-3/

Annex 2 Substitution patterns

Table A1: Impact of each recommendation on consumption (% change).

	Denmark					**Finland**					**France**					
	F&V +5%	Red meat -5%	All meat -5%	An. Prod. -5%	CO2e -5%	F&V +5%	Red meat -5%	All meat -5%	An. Prod. -5%	CO2e -5%		F&V +5%	Red meat -5%	All meat -5%	An. Prod. -5%	CO2e -5%
All me ats	−1.4	−0.3	−4.9	−0.5	−1.1	−1.2	−1.6	−6.1	−0.7	−5.7	**All me at**	−0.4	−0.7	−5.1	0.7	−3.2
Beef/lamb	−2.1	−6.0	−5.2	−0.1	−19.3	−2.7	−15.4	−5.1	0.2	−31.8	Red meat	−10.5	−6.0	−8.1	1.8	−20.7
Pork	−2.3	−0.7	−10.5	−1.5	−6.3	−1.6	2.1	−7.9	0.2	5.1	Other meats	7.1	0.8	−6.4	−1.0	0.4
Poultry/other	−0.9	2.1	−3.2	−0.3	7.7	−1.0	−1.2	−3.5	−0.4	−11.1		0.0	0.0	0.0	0.0	0.0
Processed	−0.9	1.5	−3.5	−0.3	5.4	−0.9	−2.9	−9.7	−2.2	0.7	Cooked meats	−3.8	0.9	−1.3	2.4	4.3
Dairy	−0.7	0.5	3.1	−7.4	0.1	−1.3	0.7	1.5	−6.2	−4.5	**Dairy products**	−4.6	0.6	3.4	−10.1	0.2
Milk/other dairy	−0.8	0.5	3.2	−9.4	0.0	−1.1	0.6	0.9	−7.7	−5.7	Milk products	−4.9	0.8	3.2	−12.3	0.0
Cheese	−0.6	0.3	2.4	3.6	0.3	−3.4	0.8	3.8	0.4	−2.0	Cheese/butter	−3.4	0.1	4.1	−0.9	0.9
Animal fats	1.3	0.4	2.8	−0.1	0.0	−1.7	1.6	6.2	3.9	6.4		0.0	0.0	0.0	0.0	0.0
Othe r animal prod.	−1.6	−0.5	0.7	0.9	−0.2	−0.6	−0.4	0.6	0.3	2.4	**Other animal prod.**	3.7	0.8	3.4	−3.3	3.7
Fish	−1.6	−0.5	0.7	0.9	−0.2	−0.6	−0.4	0.6	0.3	2.4	Fish	11.2	1.8	7.4	−1.6	9.3
											Eggs	−8.8	−0.9	−3.2	−6.2	−5.6
Starchy foods	0.6	0.3	2.1	1.1	0.7	−0.3	0.7	0.8	−0.5	0.3	**Starchy foods**	−18.5	−1.0	−2.2	6.2	−3.7
Grains	−0.4	0.3	2.1	1.0	1.0	0.3	1.7	2.2	0.6	4.6	Grains	−7.1	−1.1	−0.3	7.1	−3.6
Roots, tubers etc.	2.6	0.3	2.1	1.4	0.1	−1.7	−1.5	−2.3	−2.9	−9.3	Potatoes	−31.7	−0.9	−4.4	5.1	−3.9
F&V	5.2	0.3	2.1	1.4	1.4	6.2	0.7	1.1	1.4	7.2	**F&V**	6.3	0.7	0.6	1.8	2.5
Fruits	6.3	0.3	2.1	1.4	1.3	6.6	0.8	0.9	1.4	7.1	F - Fresh	−1.3	1.6	2.6	0.5	6.2
Vegetables	4.0	0.3	2.1	1.4	1.5	5.7	0.4	1.5	1.3	7.4	F- Processed	31.0	0.2	−3.2	12.1	−0.3
											F&V juices	4.6	0.9	−0.3	4.5	2.7
											V - Fresh	10.9	−0.5	−0.3	0.3	−1.1
											V - Processed	21.2	0.0	−2.7	4.9	−0.8
											F - Dry	−6.9	1.6	11.5	−13.7	7.9
Other											**Other**	0.0	0.0	0.0	0.0	0.0
Composite dishes	−4.4	−0.5	1.3	14.9	15.0	0.5	−1.9	−1.9	1.9	−7.4	Ready meals	−13.5	−1.2	−3.6	4.9	−4.5
Plant-based fats	1.1	0.3	2.4	−0.1	1.5	−3.9	1.9	5.8	2.9	16.7	Oil, margarine	13.8	0.1	−1.2	0.0	−0.7
Snacks	−1.8	0.0	0.0	0.0	3.2	−3.0	1.3	−0.7	3.3	3.2	Salt-fat products	−23.8	1.3	10.1	8.0	6.6
Sugar	−1.7	0.0	0.4	0.4	1.0	−0.7	0.0	0.6	1.5	−0.9	Sugar-fat products	2.4	0.2	0.3	−0.2	0.5
Soft drinks	−0.4	0.0	0.2	0.3	−0.5	−0.3	−1.5	1.1	3.5	0.5	Soft drinks	−21.2	0.8	5.2	12.4	7.8
Tea/coffee/water	−1.3	0.1	0.8	1.1	−2.2	−1.8	−0.2	1.8	1.9	−6.9	Water	−23.0	2.0	9.9	5.3	8.6
Residual	6.8	0.1	0.7	0.6	−3.9	−1.9	−0.2	0.7	0.2	3.2	Alcoholic beverages	14.9	0.4	−0.4	−0.1	1.0

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