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Deliverable D4.4

Report on the impacts of increased fish consumption on economic, health and environmental attributes

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Executive Summary

In recent years, concerns over the sustainability of food consumption patterns in high-income countries have emerged due to the now well-documented negative effects of some diets on both health and the environment. Research seeking improvements generally supports a move away from animal-based products towards plant-based products, but the role that fish and seafood might play in sustainable diets remains unclear. In particular, little is known about how promotion of fish consumption through generic advertising and other informational measures might affect the environmental and health properties of whole diets, nor whether that type of promotion would be cost-effective; that is, represent money well spent from a societal point of view.

This study analyses those questions by adapting a model of whole-diet adjustment to dietary constraints to simulate how French and Finnish consumers would change their diets if urged to raise their consumption of fish at the margin (that is, by a small amount from currently observed levels). The behavioural model, which is based on a rationality assumption and preferences estimated from observations on actual food purchases, captures the relationships of substitutability and complementarity among foods, and produces a quantitative estimate of the difficulty for consumers to modify their diets in a given way (for instance by eating more fish). The whole-diet adjustments simulated by the behavioural model are then linked to an epidemiological model to estimate health effects and a life-cycle analysis model to estimate climate effects. Monetization of the health and environmental benefits then permits the development of a cost-effectiveness analysis of the dietary change. The sustainability effects of raising consumption of fish by an arbitrarily-chosen 5% is compared to that of decreasing consumption of all meat and meat from ruminants by 5%.

The empirical results indicate that the patterns of adjustments to those exogenous changes differ between the two countries, although the broad substitutability of fish for other animal products is confirmed and, in both cases, consumers respond through complex modifications of their diets. The taste cost of increasing fish consumption, which measures the loss in hedonic rewards (taste, convenience) experienced by consumers in the short run, is small, suggesting that the barriers imposed by habits and taste/preferences to increasing fish consumption are limited. In both countries, we estimate that raising fish consumption by 5% would generate larger health benefits than either of the two meat constraints (i.e., reductions of 5% of all meat and red meat), and that most of the health improvement would results from a lower energy intake of the modified diet, suggesting that fish naturally belongs to less caloric meals. The increase in fish consumption also delivers climate benefits which, although only limited in magnitude, confirm that raising fish consumption enhances sustainability in both its health and environmental dimensions.

Placing monetary values on the environmental and health benefits, and taking into account the costs imposed on consumers, industry (for generic advertising) and the public sector (for implementing policies), we find that promoting fish consumption is cost-effective and socially desirable. That promotion should also be prioritised over measures aimed at reducing consumption of meat. Thus, rather than stigmatising meat consumers, we suggest that sustainable diet recommendations may more effectively send a more positive message urging consumers to raise their consumption of fish and seafood.

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Introduction

Owing to their impacts on health and the environment, food consumption patterns currently observed in developed countries are generally considered fundamentally unsustainable. It is for this reason that international organizations such as the Food and Agriculture Organisation (FAO) recommended to develop policies promoting "sustainable diets," defined as those with high-nutritional quality and health benefits, limited environmental impacts, especially related to climate change, and acceptable and affordable to all, including low-income groups (FAO, 2010).

Indeed, regarding the environmental dimensions, it has been established that around 30% of the aggregated environmental impact of final consumption in the EU is related to the consumption of food products (Tukker et al., 2011). Animal products, particularly meat from ruminants, have higher greenhouse gas emissions (GHGE) than plant products as well as a more negative impact on food security due to the requirements in land and water that their production entails (Steinfeld et al., 2006; Gonzalez et al., 2011; Nijdam et al., 2012). Consequently, environmental experts argue that switching to diets containing reduced amounts of animal-based foods would preserve the environment and reduce GHGE.

On the health side, diets currently observed in developed countries are strongly associated with adverse outcomes. In addition to excess intakes of fatty, salty and sugary foods and beverages, 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). For this reason, nutritional guidelines promoted by the World Health Organisation (WHO) include recommendations to limit intakes of foods with high contents in fat, salt and sugar, as well as to reduce consumption of fresh and processed meats.

If the literature on sustainable diets supports unambiguously a move away from animal-based diets towards plant-based diets, it is much less explicit about the position that fish/seafood consumption should have in sustainable diets. Nevertheless, available studies tend to show that increasing fish and seafood consumption has positive effects on both nutritional health and the environment.

First, increasing fish consumption is a way of raising intake of omega-3 (n-3) fatty acids and protect against risks of cardiovascular diseases (Raatz et al., 2016). Diets including a high level of fish consumption appear to be particularly healthy, as is the case of the Mediterranean diet, which includes at least two portions of fish per week. Such diets have been found to be associated with superior health outcomes, both in terms of mortality and morbidity. Hence, Sofi et al. (2013) showed that a two-point increase in the score of adherence to the Mediterranean diet resulted in an 8% reduction in overall mortality and 10% reduction in the risk of CVD.

Second, diets rich in fish seem to be preferable from an environmental point of view when compared to diets rich in meat. A recent study compared dietary GHGE between self-selected meat-eaters, fish-eaters, vegetarians and vegans in the UK (Scarborough et al., 2014). The age-and-sex-adjusted mean GHGE in kilograms of carbon dioxide equivalents per day (kgCO2e/day) were 7.19 for high meat-eaters, 5.63 for medium meat-eaters, 4.67 for low meat-eaters, 3.91 for fish-eaters, 3.81 for vegetarians and

2.89 for vegans. In Norway, Abadie et al. (2016) analysed price policies favouring the adoption of sustainable diets. They estimated the optimal taxes and subsidies to be applied to different foods in order to change consumption patterns and hence reduce diet-related GHGE while complying with some nutritional guidelines. The results showed that nearly all food categories should be taxed except for poultry, fish, milk, eggs, vegetables and fruits. These last categories would have to be subsidized in order to encourage consumption.

Despite those recent investigations, knowledge about the place of fish and seafood in sustainable diets remains partial. Some limitations are due to the fact that current studies take into account too few criteria. On the environmental side, most of the indicators used to estimate environmental impacts are biophysical, with a strong focus on greenhouse gas emissions, but few studies consider biological or ecological impacts. Differences in production methods, notably between aquaculture and fisheries, would also need to be integrated into research on the impacts of diets. On the health side, the characterization of the risks and benefits of consuming seafood requires a balanced assessment of contaminants and nutrients found in fish and shellfish. Studies on diets that balance negative and positive health impacts are still few and far between, mainly due to a lack of data.

Another important limitation of the sustainable diet literature is that, by and large, it seeks to identify diets with superior properties, and the place of fish consumption in those diets, without a proper account of consumers' preferences. Thus, it is implicitly assumed that consumers can adjust their diets without any difficulty, even if the recommendation to improve sustainability requires that they consume more of less preferred foods. Yet, diets will only be more sustainable if, first, they are better from a health and environmental point of view, but also, second, if they are compatible with consumers' preferences and therefore adopted - that is to say, if they are 'culturally' acceptable to consumers and do not generate excessively high costs of adoption. Against this background, the first goal of this article is to assess the sustainability effects of raising consumption of fish and seafood, giving due consideration to consumers' preferences and associated costs of dietary adjustment. More specifically, we intend to, in a first step, characterise the economic, environmental and health impacts of a recommendation to increase fish consumption and, in a second step, balance the health and environmental benefits of the change against consumers' cost of compliance. This allows us to judge the social desirability of raising fish consumption, considering simultaneously its economic, environmental and health effects.

To investigate the effects of an increase in fish consumption, it is important to consider the whole diet, as any variation in fish consumption is likely to alter consumption of other foods. For instance, an increase in the consumption of fish may lead consumers to modify their consumption of meat or dairy products, either because those products are substitutes (e.g., as alternative sources of proteins) or because of an indirect effect due to an income constraint (an increase in fish consumption may raise food expenditure, which may in turn lead consumers to reduce consumption of other foods). Both those direct and indirect impacts of a variation in fish consumption must be taken into account to properly estimate health and environmental impacts.

Finally, other limitations of available studies are due to the fact that they are based on general diet targets without considering existing dietary patterns at the national or regional levels. Yet, current dietary patterns vary significantly across countries – for instance with respect to the type of fish and seafood that is consumed – and it is likely that, given this variability, the consumer cost to comply with sustainable diet guidelines, as well as the health and environmental benefits of compliance with those guidelines, vary significantly across countries. By proposing a similar analysis in two countries, namely France and Finland, we initiate a more realistic assessment of changes in dietary patterns and also investigate the generality of our conclusions.

In the first section, we present the model used to simulate the effects of a change in the consumption of a food group on the entire diet, and estimate the induced impact on public health and the environment. In the second section, we describe the data used in France and in Finland to calibrate the model, as well the scenarios analysed in the two countries. In the third section, we present the results, and the last section offers some conclusions and directions for future work.

Materials and methods

Overview of the model

The overall approach is presented in Figure 1. At its core is a behavioural model using empirically estimated preferences to simulate how a representative consumer complying with one or several new dietary constraints would adjust his/her diet from observed level, considering all possible substitutions among foods. Thus, on the basis of data on actual food purchases, the model calculates a path of least resistance that consumers are most likely to follow in order to comply with an exogenously given dietary constraint. This path of least resistance minimizes the short-term utility loss due to compliance, and the short-term utility loss is in turn attributable to the inferior properties of the complying diet in terms of taste, convenience, and any other attributes. For simplicity, we henceforth refer to the utility loss as a taste cost.

This behavioural model can be used to analyse the effect of any dietary constraint expressed as a linear function of the quantities of the foods consumed. Recent applications to France (Irz et al, 2015, 2016a, 2016b) have focused on food-based constraints (e.g., increase in consumption of fruits and vegetables), nutrient-based constraints (e.g., reduction in consumption of salt), and environmental constraints (e.g., decrease in greenhouse gas emissions from food consumption). Here, we present a different application considering primarily the dietary changes that would take place if consumers decided to increase their consumption of fish, which we envision as resulting from generic advertising or social marketing efforts.

The dietary adjustments are then linked to an epidemiological model to calculate health effects, and a life-cycle analysis (LCA) model to simulate environmental effects. Monetization of the health and environmental effects allows calculation of the benefit from compliance, which can be compared to the private taste cost and public/industry cost of developing measures (e.g., generic advertising) to ensure compliance in an integrated efficiency analysis. The analysis can be carried out for any number of subpopulations for which data and parameters are available, hence allowing for the analysis of the equity effects of dietary constraints (e.g., is compliance more difficult for low-income groups? Which groups derive the largest health benefit from compliance? Etc.).

Although our model starts from an "as if" assumption in the sense that it assumes compliance with a given constraint (or set of constraints), the analysis delivers useful information to compare the sustainability effects of dietary changes and their impacts on social welfare. With reference to an increase in fish consumption, the model provides a tool to answer some complex questions: what effect would it have on mortality due to chronic diseases and diet-related greenhouse gas emissions? Would that increase be socially desirable in the sense that its benefits would outweigh its costs? And how does it compare to other changes (e.g., reduction in meat consumption) commonly proposed in order to raise the sustainability of diets?

We now turn to each sub-components of the model.

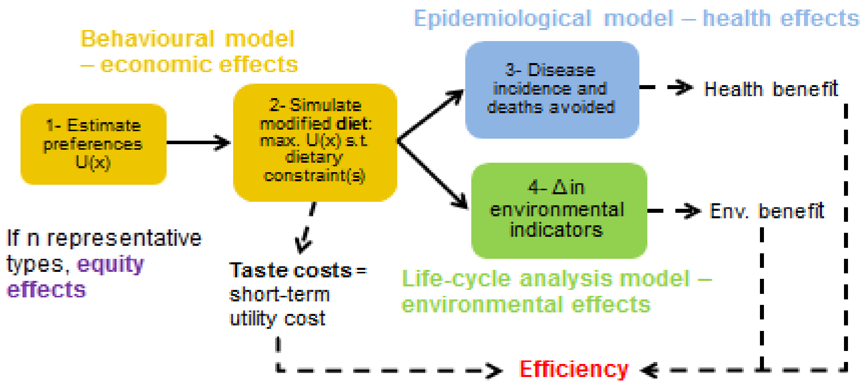

Figure 1: Overall structure of the model

The behavioural model

The starting point is a model of whole diet adjustment to nutritional and/or environmental constraints (i.e., "dietary constraints") presented in more details in Irz et al. (2015) and based on the generalised rationing theory of Jackson (1991). We assume that an individual chooses the consumption of *H* goods in quantities $\boldsymbol{x}=(x_1,\ldots x_H)$ to maximize a strictly increasing, strictly quasi-concave, twice differentiable utility function $U(x_1,\ldots x_H)$, subject to a linear budget constraint $\boldsymbol{p}.\boldsymbol{x} \leq M$, where $\boldsymbol{p}$ is a price vector and *M* denotes income. We further assume that the consumer operates under *N* additional linear dietary constraints, imposing, for instance, a minimum consumption of fish, or a maximum consumption of meat. Denoting by a_i^n the constant technical coefficient for any food *i* and target *n*, the value of which is known from food composition tables, the dietary constraints are expressed by:[4]

$$\sum_{i=1}^{H} a_i^n x_i \leq r_n \ \forall n = 1,\ldots, N \qquad (1)$$

The utility maximization problem is solved first in a Hicksian framework (i.e., maintaining utility constant). 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 (*N x H*) matrix of technical coefficients, and $\boldsymbol{r}$ the *N*-vector of levels of the constraints. The solution requires the derivation of 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: $\tilde{h}_i(p,U,A,r) = h(\tilde{p},U)$. Our empirical application only considers the introduction of a single constraint at a time and, in that

[4] For instance, in the case of a constraint imposing a minimum level of fish consumption, those coefficients are the fish contents of the food aggregates.

simplified framework, the marginal change in shadow prices derived by Irz et al. (2015) are:

$$\frac{\partial \tilde{p}_i}{\partial r_1} = a_i^1 / (\sum_{i=1}^{H}\sum_{j=1}^{H} s_{ij} a_i^1 a_j^1) \qquad i = 1,....H \tag{2}$$

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:

$$\frac{\partial \tilde{h}_k}{\partial r_1} = (\sum_{i=1}^{H} s_{ki} a_i^1) / (\sum_{i=1}^{H}\sum_{j=1}^{H} s_{ij} a_i^1 a_j^1) \qquad k = 1,....H \tag{3}$$

Equation (3) expresses the changes in 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, matrix *A*, which gathers technical coefficients measuring the content of each food aggregate in terms of the target quantities (e.g., fish, meat). Given that the Slutsky matrix is typically estimated empirically from observations on actual purchase behaviours, we claim that the model is based on realistic food preferences, unlike virtually all programming-based models of diet optimization that make arbitrary assumptions about food preferences, either explicitly (i.e., by imposing "palatability constraints", as for instance in Henson, 1991) or implicitly (through the choice of an arbitrary objective function, as in Shankar et al., 2008 or Darmon et al., 2008).

Expressions (3) and (4) show that a change in the constraint level r_1 has an impact on the entire diet. This is true even for the foods that do not enter the constraint directly, as long as they entertain some relationship of substitutability or complementarity with any of the foods entering the constraint (i.e., as long as at least one Slutsky term s_{ki} is different from zero). Thus, when imposing an exogenous increase in fish consumption, consumption of other foods, either substitutes or complements of fish, will be affected. Further, the model indicates that the magnitude and sign of any change in demand for any given food is unknown *a-priori* but depends in a complex way on its technical coefficients (i.e., its composition) and its substitutability with other foods.

Real-world consumers operating under a budget rather than utility constraint, we infer the changes in uncompensated demands by first calculating the compensating variation, which measures the loss of utility due to the imposition of the new dietary constraint. For a change in the constraint levels r_1 , we have: $CV = \sum_{i=1}^{H} p_i \partial \tilde{h}_i / \partial r_1 < 0$. An approximate solution to the change in Marshallian demand Δx is then calculated by adding to Δh 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

Simulation of health effects first 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. Changes in food intakes 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). Based on relative risk ratios derived from world-wide meta-analyses, the model converts variations in ten nutritional inputs (fruits, vegetables, fibres, total fat, mono-unsaturated fatty acids (MUFA), poly-unsaturated fatty acids (PUFA), saturated fatty acids (SFA), trans-fatty acids (TFA), cholesterol, salt, energy) to estimate changes in diet-related chronic diseases (heart disease, strokes, and ten types of cancer) and related deaths. The exact disease pathways are depicted in Figure 2, which shows that the link from dietary input to diseases may be direct, as in the case of the input of fruits of vegetables that lowers the risk of coronary heart disease, or indirect through an intermediate risk factor, as illustrated by the adverse impact of saturated fat intake on the risk of strokes via its influence on blood cholesterol. An important indirect pathway operates through the total energy intake and resulting effect on obesity of dietary changes.

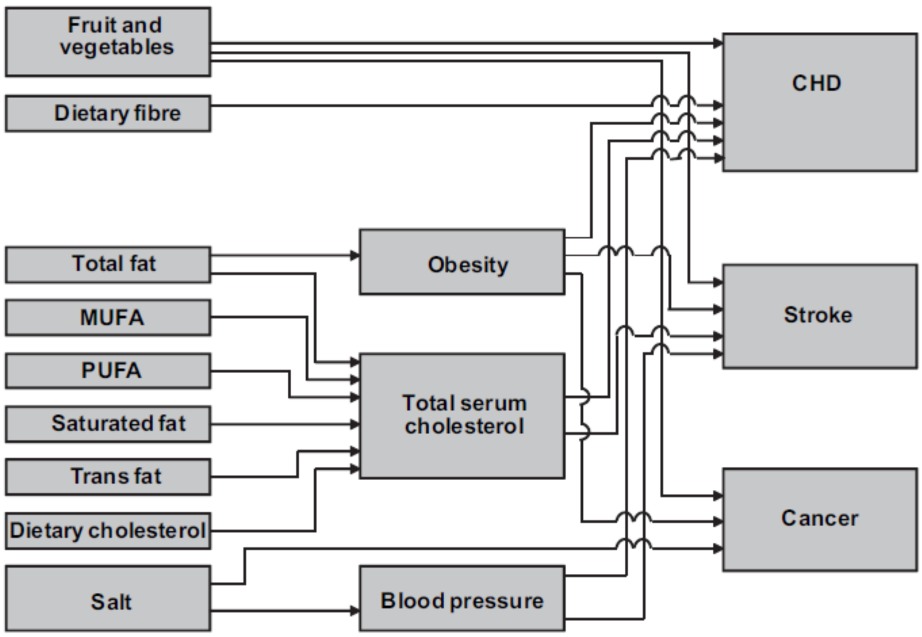

Figure 2: Conceptual representation of DIETRON's disease pathways. CHD= coronary heart disease; MUFA=mono-unsaturated fatty acids; PUFA=poly-unsaturated fatty acid. Reproduced from Scarborough et al. (2012).

The figure also reveals the limitations of the model to analyse the health effects of a dietary change centred on fish consumption. In particular, there are concerns over potential harm to human health from mercury, dioxins, and polychlorinated biphenyls (PCBs) present in some fish species (Mozaffarian and Rimm, 2006 and references therein), but this is not taken into account by the epidemiological model.

The environmental effects are limited to an analysis of climate impact, which is estimated by applying life-cycle analysis coefficients to each intake category.

Efficiency analysis

The behavioural model simply assumes compliance with an exogenously-given dietary constraint without considering the collective measures that would be necessary to bring about compliance. Although that simplification precludes carrying out a full cost-benefit analysis, we nonetheless derive important insights regarding the relative efficiency of various constraints through calculation of an efficiency threshold, defined as the maximum amount that could be invested by public authorities or industry in order to ensure compliance with a given constraint. 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. In the short-run, there are however costs imposed on consumers (i.e., the taste cost as measured by $-CV$ and capturing a loss of hedonic rewards), as well as (unknown) costs to the public sector or industry (i.e., cost of interventions such as social marketing campaigns or generic advertising, denoted C_p). The cost effectiveness threshold of each constraint is hence calculated as $C_p=B_e+B_h+CV$, giving us a means of comparing the relative efficiency of all the selected constraints.

Data, calibration, and scenarios

Calibration of the behavioural, epidemiological and environmental models

The data on food/fish consumption and related estimates of price and expenditure elasticities for various food and fish categories are presented in detail in PrimeFish deliverabe 4.3, which reported the analysis of household-level demand for fish in France and Finland. Calibration of the model requires additional parameters and data that we now document.

For the French model, the intake data and food composition tables were obtained from the French dietary intake survey INCA2. Those are freely available from the open data platform of the French government at: https://www.data.gouv.fr/fr/datasets/donnees-de-consommations-et-habitudesalimentaires-de-letude-inca-2-3/.

The specific steps involved in the calibration of the French model are explained in greater detail in Irz et al. (2015). In the Finnish case, the intake data and food composition coefficients were derived from a study of demand for food in Finland and its climate impact (Irz, 2017).

The parameters of DIETRON are not country specific, so that adapting the epidemiological model to France and Finland only requires calibration of the initial mortality levels, by relevant causes, in those two countries. This is achieved by using, for the French model, the INSERM data on mortality in France attributable to major diet-related diseases. The corresponding mortality data to calibrate the Finnish model was downloaded directly from the website of the Finnish Statistical Institute. In the two countries, the study focuses on individuals between the age of 25 and 74 and therefore investigates the effects of dietary changes on premature deaths (i.e., occurring before the age of 75).

For both countries, the LCA coefficients measuring the greenhouse gas emissions resulting from consumption of each type of food derive from a systematic review of the grey and academic literature, as explained in detail in Pulkkinen and Hartikainen (2016). Table 1 displays the coefficients used for the meat and fish groups. In the next section, we will first provide the results obtained while using the average values of GHGE (4th column of Table 1). In a second step, a sensitivity analysis will be conducted by considering the coefficients corresponding to the upper boundary of GHGE (last column of Table 1). Here as well, we must acknowledge that the environmental assessment is only partial, as it does not cover other important issues related to, for instance, the sustainability of fish stocks or the biodiversity impact of aquaculture.

	Food category	Used indicator product	GHGE, kgCO_2-eq./kg food	GHGE, lower boundary	GHGE, upper boundary
Meat	Beef	Beef	42,5	36,1	52,9
	Pork	Pork	10,2	7,7	11,2
	Lamb	Lamb	34,3	33,7	67,7
	Livestock meat, other	Avg. Meat	22,2	18,5	27,5
	Poultry	Chicken	5,8	4,7	7,4
	Preserved meat	Ham, sausage	5,6	4,3	6,0
	Sausages	Ham, sausage	5,7	4,4	6,1
	Meat specialties	Ham, sausage	5,6	4,3	6,0
	Pastes, pâtés and terrines	Ham, sausage	5,6	4,3	6,0
	Meat imitates	Tofu	1,5	1,2	2,9
	Meat and meat products (unspecified)	Avg. Meat	22,2	18,5	27,5
	Game mammals	Avg. Meat	22,2	18,5	27,5
	Game birds	Chicken	5,8	4,7	7,4
	Mixed meat	Avg. Meat	22,2	18,5	27,5
	Edible offal, farmed animals	Avg. Meat	22,2	18,5	27,5
Fish and seafood	Fish and other seafood (unspecified)	Avg. Fish	3,6	2,7	4,5
	Fish products	Avg. Fish	3,6	2,7	4,5
	Fish offal	Avg. Fish 5 %	1,1	0,6	1,1
	Crustaceans	Shrimps	9,6	7,2	12,1
	Water mollusks	Mussels	6,7	5,0	8,4
	Amphibians, reptiles, snails, insects	Avg. Fish	3,6	2,7	4,5
	Tuna canned	Thuna canned	4,0	2,9	5,0
	Tuna not canned	Thuna not canned	4,1	3,0	5,1
	Salmon	Salmon	5,5	4,8	6,1
	Cod	Cod	4,5	3,3	5,6
	Other fatty fish	Small pelagics (herring, sardine)	2,1	1,6	2,6
	Other non fatty fish	Ground fish (cod, sole)	2,9	2,1	3,6

Table 1: GHGE coefficients for meat and fish products. Source: Pulkkinen and Hartikainen (2016)

Valuation of costs and 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 (e.g., drugs, procedures). That threshold, discussed in McCabe et al. (2008) and still recommended by the UK National Institute for Clinical Excellence (NICE), lies within the £20-30k range, which translates roughly into €24-36k at the current exchange rate. Given that epidemiological data show that the average number of Life Years Saved (LYS) 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, that valuation of DA is much lower than the values of a statistical life (VSL) typically used in the cost-benefit analysis of public projects (e.g., road improvement), as reviewed in Treich (2015).

On the environmental side, there is much debate regarding the social cost of greenhouse gas emissions. 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 due to its rigour and objectivity.

Choice of constraints

In line with the focus of the PrimeFish project, our analysis is primarily concerned with the effects of raising fish consumption on the sustainability of diets in the two selected countries. Given that the parameters of the model (e.g., elasticities) are only valid at the margin, that is, for small changes from observed consumption levels, we consider the effect of an arbitrarily-chosen 5% increase in fish consumption. Interpretation of the model results, however, is easier by comparison and we therefore also investigate the effects of other exogenously dietary constraints, which are unrelated to fish but hotly debated in relation to the sustainability of diets.

Our specific choice is to compare the sustainability effects of an increase in fish consumption to those generated by a decrease in meat consumption, distinguishing between all meat and meat from ruminants (henceforth referred to as “red meat“). This choice is justified first by the recognition that foods vary widely in terms of their environmental and climate impacts, with greenhouse gas emissions per unit of consumption of animal products far exceeding those of plant-based products, and meat from ruminants imposing a particularly large climate burden due to methane production from enteric fermentation (Abadie et al., 2016; Nijdam et al., 2016).

On the health side, recent meta-analyses have documented a probable link between consumption of different types of meat and negative health outcomes, although much discussion over the issue is ongoing. For instance, Larson and Orsini (2013) reviewed prospective studies to conclude that high consumption of red meat, especially processed meat, may increase all-cause mortality. Another study by Abete et al. (2014) found that processed meat consumption could increase the risk of mortality from any cause and cardiovascular diseases (CVD), while red meat consumption was positively but weakly associated with CVD mortality. In 2015, the evidence was deemed sufficiently strong for the World Health Organisation (WHO) to classify the consumption of red meat *as probably carcinogenic to humans* and the consumption of processed meat as *carcinogenic to humans.* The associated press release (IARC, 2015) also stated that the review of the evidence gave, overall, support for current public health recommendations to limit intake of meat.

Thus, our analysis also presents the assessment of the sustainability effects of reducing consumption of all meat and consumption of red meat by the same arbitrarily chosen level of 5%.

Results

Changes in food consumption

Table 2 describes the simulated behavioural adjustments corresponding to the imposition of three constraints on French and Finnish consumers, in each case considering a 5% variation from current levels. For each country and each constraint, the table presents two columns: the left one reports the contribution of each food group to the constrained quantity (e.g., total consumption of fish), hence giving a depiction of current diets in relation to the targeted foods. Thus, in the case of France, the consumption aggregate "fish" unsurprisingly accounts for 96% of total fish consumption, but the table also shows that 4% of fish consumption originates from other consumption aggregates (ready meals). Meanwhile, for each constraint, the right column reports the change in consumption resulting from the imposition of the constraint. Thus, in the French case, requiring a 5% increase in consumption of fish results in a slightly more than proportional increase (+5.3%) in consumption of the aggregate fish because, at the same time, product categories containing some fish decrease (e.g., ready meals -2.9%).

The simulations reported in Table 2 allow us to highlight several characteristics of the dietary adjustments that would take place if consumers were encouraged to increase their consumption of fish in France and Finland. Starting with France, we note that consumption of most of the non-fish categories respond to the imposition of the fish constraint. Conform to intuition, some substitutions occur with other animal products such as meat (-0.3%), particularly from ruminants (-0.9%) and eggs (-1.0%), while consumption of dairy products is not affected. The adjustments with plant-based products reflect substitutions with starchy foods but complementarity with fruits and vegetables (+0.4%), although the disaggregated results for the "F&V" categories reveal that the adjustments are not uniform across types of fruits and vegetables – for instance consumption of fresh fruits increases with the 5% increase in fish consumption, while that of processed fruits actually declines (by 0.5%). Among the remaining food products (i.e., "Other" aggregate), we note the particularly large decrease in consumption of ready meals (-2.9%).

This first set of French results demonstrates complex behavioural responses involving significant substitutions among product groups, implying that simulating the effect of an increase in fish consumption under a *ceteris paribus* assumption (i.e., holding constant all other components of the diet) would be inappropriate. The results also cast doubts over the ability of researchers to devise "reasonable" substitutions ex-ante, for instance by imposing ad-hoc palatability constraints as is often done in diet modelling.

France (2^{nd} income quartile)	Constraints: Fish +5%		All meat -5%		Red meat -5%	
All meat	**0.0**	**-0.3**	**93.7**	**-5.2**	**89.7**	**-0.7**
Red meat	0.0	-0.9	22.7	-8.2	89.7	-5.5
Other meats	0.0	-0.1	38.8	-6.4	0.0	0.7
		0.0				
Cooked meats	0.0	-0.2	32.2	-1.3	0.0	0.8
Dairy	**0.0**	**0.0**	**0.0**	**3.4**	**0.0**	**0.6**
Milk products	0.0	0.0	0.0	3.3	0.0	0.7
Cheese/butter	0.0	0.1	0.0	4.2	0.0	0.1
		0.0				
Other animal prod.	**0.0**	**3.2**	**0.0**	**3.5**	**0.0**	**0.7**
Fish	96.1	5.3	0.0	7.5	0.0	1.7
Eggs	0.0	-1.0	0.0	-3.3	0.0	-0.8
Starchy foods	**0.0**	**-1.2**	**0.0**	**-2.2**	**0.0**	**-0.9**
Grains	0.0	-1.4	0.0	-0.3	0.0	-1.0
Potatoes	0.0	-1.0	0.0	-4.5	0.0	-0.8
F&V	**0.0**	**0.4**	**0.0**	**0.6**	**0.0**	**0.6**
F - Fresh	0.0	1.0	0.0	2.7	0.0	1.5
F - Processed	0.0	-0.5	0.0	-3.2	0.0	0.2
F&V juices	0.0	0.4	0.0	-0.3	0.0	0.8
V - Fresh	0.0	0.0	0.0	-0.3	0.0	-0.5
V - Processed	0.0	-0.4	0.0	-2.7	0.0	0.0
F - Dry	0.0	1.5	0.0	11.7	0.0	1.4
Other						
Ready meals	3.8	-2.9	6.3	-3.6	10.1	-1.1
Oil, margarine	0.0	0.1	0.0	-1.2	0.0	0.1
Salt-fat prod.	0.0	-0.3	0.1	10.3	0.1	1.2
Sugar-fat prod.	0.0	-0.2	0.0	0.3	0.0	0.1
Soft drinks	0.0	-0.1	0.0	5.3	0.0	0.7
Water	0.0	0.1	0.0	10.0	0.0	1.8
Alcohol	0.0	-0.5	0.0	-0.4	0.0	0.3

Finland (whole population)	Constraints: Fish +5%		All meat -5%		Red meat -5%	
All meat	**0.0**	**0.0**	**94.3**	**-4.9**	**76.1**	**-0.9**
Beef/lamb	0.0	0.1	4.9	-4.0	51.2	-8.5
Pork	0.0	-0.2	21.5	-6.2	0.0	1.2
Poultry/other	0.0	0.1	37.8	-2.8	0.0	-0.7
Processed	0.0	-0.2	30.0	-7.7	24.9	-1.6
Dairy	**0.0**	**-0.3**	**0.0**	**1.2**	**0.0**	**0.4**
Milk/other dairy	0.0	-0.3	0.0	0.7	0.0	0.4
Cheese	0.0	-0.2	0.0	3.0	0.0	0.5
Animal fats	0.0	0.0	0.0	4.9	0.0	0.9
Other animal prod.	**97.6**	**5.1**	**0.0**	**0.5**	**0.0**	**-0.2**
Fish	97.6	5.1	0.0	0.5	0.0	-0.2
Starchy foods	**0.0**	**-0.5**	**0.0**	**0.7**	**0.0**	**0.4**
Grains	0.0	-0.4	0.0	1.8	0.0	0.9
Roots, tubers etc.	0.0	-0.6	0.0	-1.8	0.0	-0.8
F&V	**0.0**	**0.1**	**0.0**	**0.9**	**0.0**	**0.4**
Fruits	0.0	0.2	0.0	0.7	0.0	0.4
Vegetables	0.0	-0.2	0.0	1.2	0.0	0.2
Other						
Composite dishes	2.4	-1.0	5.7	-1.5	23.9	-1.1
Plant based fats	0.0	-0.3	0.0	4.6	0.0	1.1
Snacks	0.0	-0.1	0.0	-0.6	0.0	0.7
Sugar	0.0	-0.3	0.0	0.5	0.0	0.0
Soft drinks	0.0	-0.4	0.0	0.9	0.0	-0.8
Tea/coffee/water	0.0	0.0	0.0	1.5	0.0	-0.1
Residual category	0.0	-0.2	0.0	0.5	0.0	-0.1

Table 2: Simulated impacts of an increase in fish consumption and decreases in consumption of meat and red meat on total food consumption in France and Finland.

The French simulations of the effects of decreases in meat consumption confirm the substitutability of meat and fish, but the relationship appears quantitatively stronger in that direction. Thus, according to the simulations, French consumers would compensate a 5% reduction in all meat consumption by raising their consumption of fish more than proportionally (by 7.5%). In the case of a 5% reduction in red meat, the response of fish consumption is still positive but quantitatively much smaller (+1.7%), as consumers would also offset the decrease in red meat consumption by raising their consumption of other meats (+0.7%).

Table 2 further reveals that the patterns of adjustment are specific to each country both qualitatively and quantitatively. Hence, in the case of Finland, the simulations confirm the substitutability of fish and other animal products, in line with the French results, but the main effect now occurs through dairy products (-0.3%) rather than meat (no aggregate change). We note in particular a marginal increase in consumption of red meat as a result of the imposition of the fish constraint in Finland, a result to which we will return when discussing the climate impact of those dietary adjustments. The other consumption changes related to the rise in fish consumption in Finland are broadly consistent with those depicted for France: there is evidence of substitutability between fish and starchy foods (-0.5%) as well as composite dishes (-1%), but complementarity between fish and F&V (+0.1%). However, the overall adjustment in the entire food consumption basket appears relatively more limited in the case of Finland as compared to France.

The adjustments to variations in consumption of all meat and red meat in Finland confirm the limited substitutability between those two food categories and fish. In fact, the results suggest that fish consumption would actually decrease, albeit only marginally (-0.2%), if red meat consumption was curtailed by 5% in Finland.

Overall, the simulations reveal country-specific patterns of adjustments to the imposition of dietary constraints. This level of heterogeneity in response is, of course, not unexpected as it is known that current diets vary across EU countries (Slimani et al., 2002) and that there are strong cultural influences on food preferences (Tiu Wright et al., 2001).

In order to better understand the functioning of the model, Table 3 reports the shadow prices calculated from application of formula (2). The column highlighted in yellow and to the left of the table shows that inducing French consumers to raise their purchases of fish by 5% would require a fairly small decrease in price (-3.3%). The shadow prices of the products that do not contain fish are equal to their market prices, which is a result that follows from the theory (i.e., for a product category *i* that does not contain any fish, the technical coefficient a^1_i in equation (2) is simply equal to zero). Ready meals containing a small amount of fish, their shadow prices differ from market prices but only by a small margin (-0.1%). The corresponding results for Finland indicate a wider gap between shadow and market prices for the fish constraint.

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	France (2nd income quartile)			Finland (whole population)			
	Constraints				Constraints		
	Fish +5%	All meat -5%	Red meat -5%		Fish +5%	All meat -5%	Red meat -5%
All meat				**All meat**			
Red meat	0.0	9.8	3.8	Beef/lamb	0.0	5.5	10.3
Other meats	0.0	13.3	0.0	Pork	0.0	7.4	0.0
				Poultry/other	0.0	7.8	0.0
Cooked meats	0.0	10.6	0.0	Processed	0.0	9.4	1.4
Dairy				**Dairy**			
Milk products	0.0	0.0	0.0	Milk/other dairy	0.0	0.0	0.0
Cheese/butter	0.0	0.0	0.0	Cheese	0.0	0.0	0.0
				Animal fats	0.0	0.0	0.0
Other animal prod.				**Other animal prod.**			
Fish	-3.3	0.0	0.0	Fish	-6.0	0.0	0.0
Eggs	0.0	0.0	0.0				
Starchy foods				**Starchy foods**			
Grains	0.0	0.0	0.0	Grains	0.0	0.0	0.0
Potatoes	0.0	0.0	0.0	Roots, tubers etc.	0.0	0.0	0.0
F&V				**F&V**			
F - Fresh	0.0	0.0	0.0	Fruits	0.0	0.0	0.0
F - Processed	0.0	0.0	0.0	Vegetables	0.0	0.0	0.0
F&V juices	0.0	0.0	0.0				
V - Fresh	0.0	0.0	0.0				
V - Processed	0.0	0.0	0.0				
F - Dry	0.0	0.0	0.0				
Other				**Other**			
Ready meals	-0.1	3.3	0.5	Composite dishes	-0.2	2.2	1.6
Oil, margarine	0.0	0.0	0.0	Plant based fats	0.0	0.0	0.0
Salt-fat prod.	0.0	0.2	0.0	Snacks	0.0	0.0	0.0
Sugar-fat prod.	0.0	0.0	0.0	Sugar	0.0	0.0	0.0
Soft drinks	0.0	0.0	0.0	Soft drinks	0.0	0.0	0.0
Water	0.0	0.0	0.0	Tea/coffee/water	0.0	0.0	0.0
Alcohol	0.0	0.0	0.0	Residual category	0.0	0.0	0.0

Table 3: Percentage difference between shadow and market prices.

Sustainability effects

Table 4 presents the simulated economic, health and climate effects resulting from the imposition of the three constraints in each country. The taste cost measuring the short-term loss in hedonic rewards represents in each case less than 0.1% of the food budget and thus appears small, although it is worth keeping in mind that we only test small/marginal changes in the constraint levels. More informative, the ranking of those taste costs captures the relative difficulty of adjusting diets to comply with the exogenous constraints. On that basis, Table 4 indicates that, in both countries, the difficulty of raising fish consumption by 5% is comparable to that of diminishing consumption of red meat by 5%. Both changes are much less difficult for consumers than a 5% decrease in consumption of all meat. The fact that, in both countries, the taste cost of reducing consumption of all meat is significantly larger than the taste cost of only reducing consumption of red meat was expected, as it is intuitive that cross-category substitutions are more difficult for consumers to achieve than within-category substitutions (i.e., among relatively close substitutes).

Although the taste costs are small relative to the food budget, they still account for millions of euros when expressed annually for whole populations (e.g., €10 million for France and the fish constraint). Those costs are typically ignored when assessing the social desirability of measures aimed at promoting consumption changes (e.g., Rajgopal et al., 2002), but will be included in the efficiency analysis of the three recommendations below. However, the main insight from the calculation of the taste costs is that the barriers imposed by habits, tastes and preferences to increasing fish consumption appear relatively limited in both countries, which hints at the potential effectiveness of generic advertising and other informational measures to boost fish consumption.

The health effects are calculated as the annual number of deaths avoided due to the dietary changes induced by each constraint and vary from two to four hundred for France and from none to 29 for Finland. Those health effects are deemed small but significant as they account for up to 0.6% of the diet-related deaths captured by the epidemiological model DIETRON (keeping in mind the marginal 5% exogenous change in constraint levels). More importantly for PrimeFish, when comparing the results for the different constraints, the analysis reveals that, in both countries, raising fish consumption by 5% would achieve significantly larger health benefits than a 5% decrease in meat consumption. The surprising finding that, in the case of Finland, a decrease in meat consumption would actually *raise* mortality from diet-related chronic diseases (i.e., negative DA in Table 4) illustrates that the inclusion of whole-diet substitutions is paramount for the calculation of health effects, and that well-intended recommendations ("eat less red meat") may generate undesirable effects.

	FRANCE			FINLAND		
	Fish +5%	All meat -5%	Red meat -5%	Fish +5%	All meat -5%	Red meat -5%
Taste Cost						
Total (€M)	10	76	10	0.3	9	-2
% food budget	**0.01 %**	**0.10 %**	**0.01 %**	**0.002 %**	**0.07 %**	**-0.01 %**
DA for DIETRON diseases						
Total	394	245	229	29	-4	10
% Dietron disease	**0.6 %**	**0.4%**	**0.3%**	**0.4 %**	**-0.1 %**	**0.1 %**
% CHD	35 %	21 %	28 %	53 %	41 %	66 %
% Stroke	20 %	22 %	19 %	28 %	75 %	13 %
% Cancers	45 %	57 %	53 %	19 %	-15 %	21 %
CO2 equivalent						
Total (Kt)	-400	-1487	-892	-14	-36	-44
% change	**-0.6 %**	**-2.1 %**	**-1.3 %**	**-0.2 %**	**-0.6 %**	**-0.8 %**

Table 4: Economic, health and climate effects of the simulated dietary adjustments

Table 4 further documents the pathways to better dietary health, and we observe differences both across countries and constraints. In France, the fish constraint as compared to the meat constraints reduces mortality relatively more due to its effect on the incidence of cancers, although a similar result is not observed in the case of Finland.

Table 4 provides additional elements quantifying the relative contribution of the variation in energy intake (i.e., calories) to the reduction in mortality[5]. It turns out that, for France, the reduction in energy intake induced by the adoption of the three recommendations is the main driver of the health benefit. That statement is also true in Finland for the fish recommendation, but not in the case of the meat recommendations. Altogether, the simulations indicate that fish is typically included in less caloric meals than alternatives, and that this reduction in calories represents a key mechanism by which fish consumption improves dietary health.

France

	RedMeat -5%	AllMeat -5%	Fish +5%
DA	229	245	394
DA except energy effect	63	8	14
DA energy effect	167	237	380
% energy effect	73%	97%	96%

Finland

	RedMeat -5%	AllMeat -5%	Fish +5%
DA	10	-4	29
DA except energy effect	11	20	-4
DA energy effect	0	-24	33
% energy effect	-4%	544%	114%

Table 5. Relative contribution of the reduction in dietary energy to the number of DA.

The climate impacts of the dietary adjustments simulated by the model are presented in the lower part of Table 4. In both countries, we find that increasing fish consumption would induce a reduction in GHG emissions from food consumption, although the effect is quantitatively small (-0.6% in France and -0.2% in Finland). The larger reduction simulated for France is in line with the greater substitutability of fish for red meat in France than in Finland, as mentioned above in relation to Table 2. In both countries, we also find that curtailing consumption of all meat and red meat would have a significantly larger climate impact than raising fish consumption. Finally, Table 4 brings to light the more general point that while healthier diets also tend to be more climate friendly, the possibility of

[5] The other contribution is that of diet quality.

trade-offs in sustainability dimensions is very present when considering real-world consumers and their preferences. Indeed, as shown in Table 4, the ranking of the three recommendations differ depending on the country and the type of impact. Hence, for health (number of DA):

- 'Fish' > 'All meat' > 'Red meat' in France
- 'Fish' > 'Red meat' > 'All meat' in Finland

For GHG emissions:

- 'All meat' > 'Red meat' > 'Fish' in France
- 'Red meat' > 'All meat' > 'Fish' in Finland

Thus, a careful account of substitutions and preferences in each country is necessary when assessing the sustainability effects of dietary adjustments.

Cost effectiveness

To carry out the cost-benefit analysis, we first need to monetise the health benefit (deaths avoided) and environmental benefit (reduction in GHGE) described in Table 4, using appropriate valuation parameters. As explained in the methodology section, this was achieved by relying on the economic values of a ton of carbon and a Quality-Adjusted Life Year as reported in the relevant literature. The column labelled "Benefits" in Table 5 then displays the sum of the monetised health and environmental benefits, expressed in millions of euros, while the column labelled "% health" quantifies the share of the health benefit in the total benefit from the dietary adjustment. Thus, in France, the simulations indicate that inducing consumers to raise their consumption of fish by 5% would generate a total benefit worth €107 million, 88% of which would accrue from better health, and the remaining 12% from a reduction in greenhouse gas emissions.

The column labelled "Cost" simply replicates the taste cost reported in Table 4 and therefore estimates the loss of rewards, mainly in terms of convenience and taste, which consumers would experience in the short run due to the dietary adjustment. In turn, the column before last presents the threshold values C_p measuring the maximum amount of resources that could be used by industry or government to bring about the assumed dietary change while ensuring that the benefits exceed the costs. Thus, still in the case of France, we estimate that it would be socially desirable to spend up to €98 million annually to boost fish consumption through generic advertising and/or social marketing, provided that it resulted in an increase in consumption worth 5% from currently observed levels. The last column simply provides the ranking of the different constrains based on the value of the threshold C_p.

The results indicate that, in both countries, the value of the efficiency threshold are relatively large (€98 million and €7 million respectively) and likely to exceed the cost of measures that could bring about the targeted dietary change (+5% in consumption of fish). Although it is difficult to anticipate the effectiveness of information provision in modifying dietary behaviours, some academic studies have been published on the subject, albeit not specifically about fish. For instance, Capacci and

Mazzocchi (2011) reported that the ambitious "5-a-day" UK campaign to encourage consumption of fruits and vegetables, which was partially successful since it raised consumption by 8%, had a total budget of less than £3 million (roughly €4 million). On that basis, our results support the idea that the promotion of fish consumption in France and Finland through provision of information to consumers is likely to represent money well-spent (i.e., to raise social welfare).

	Benefits (M€)	% Health	Cost (M€)	C_p Max Campaign		Ranking
FRANCE						
Fish +5%	107	88 %	10	98		1
All meat -5%	106	55 %	76	30		3
Red meat -5%	84	66 %	10	73		2
FINLAND						
Fish +5%	7	94 %	0.3	7	(87)	1
All meat -5%	0.1	-	9	-9	(-113)	3
Red meat -5%	4	63 %	-2*	4*	(47)	2

* Theoretically inconsistent negative cost not included in calculation

Table 6: Efficiency analysis

The difference in magnitude of the efficiency thresholds between the two countries is explained to a large extent by differences in population size, as France features about 12 times more inhabitants than Finland. To facilitate the comparison, the efficiency threshold is also calculated for Finland assuming a population of the same size as the French one, resulting in the adjusted figures presented in parentheses in Table 6. This exercise reveals that, once accounting for population size, the values of the efficiency thresholds corresponding to the fish constraint in the two countries are of the same order of magnitude and large. In both cases, the bulk of the benefit derives from improvements in health rather than reductions in greenhouse gas emissions.

The comparison of the efficiency results for the fish and meat constraints also generates valuable insights. Most importantly, in both countries we find that raising consumption of fish by 5% results in higher efficiency thresholds than decreases in meat consumption, with the exact same ranking of the three constraints. The least attractive option would be to seek to reduce consumption of all meat by 5%, and for both countries the result is explained by the significant taste costs that this reduction would impose on consumers in the short run. This provides additional confirmation of the importance of including a realistic representation of consumer preferences when assessing measures to raise the sustainability of diets.

Sensitivity analysis

We now examine the robustness of the results presented in the previous sections in relation to the uncertainty surrounding the CO2 coefficients derived from LCA. Table 7 depicts the variations in GHGE induced by the adoption of the three recommendations for two different levels of CO2 coefficients for fish/seafood, corresponding to the average and upper-boundary values of those coefficients reported in Table 1. Overall, shifting from the average to the upper-boundary values results in 20% and 16%

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increases in the CO2 coefficients of the 'fish basket' in France and Finland respectively. However, Table 7 shows that such an increase in CO2 coefficients has a very low impact on the GHGE of the whole diet. This is explained first by the modest place that fish products occupy in the French and Finnish diets overall. A second reason is that, even with a 20% increase in the average CO2 coefficient of the fish category, that category remains much less impacting than meat products. In fact the CO2 coefficients of the fish group would have to be higher by several orders of magnitude to modify our conclusions, which are therefore deemed robust in that dimension.

	France (average CO2 coefficients for fish)			France (upper boundary CO2 coefficients for fish)			Finland (average CO2 coefficients for fish)			Finland (upper boundary CO2 coefficients for fish)		
	RedMeat -5%	AllMeat -5%	Fish +5%	RedMeat -5%	AllMeat -5%	Fish +5%	RedMeat -5%	AllMeat -5%	Fish +5%	RedMeat -5%	AllMeat -5%	Fish +5%
Δ eq. CO2 (Kt)	-892	-1487	-400	-886	-1 460	-380	-45	-36	-14	-44	-35	-13
% Δ eq. CO2	-1.3%	-2.1%	-0.6%	-1.2%	-2.0%	-0.5%	-0.8%	-0.6%	-0.2%	-0.8%	-0.6%	-0.2%

Table 7: Variations in GHG emissions induced by the adoption of the three recommendations for two levels of CO2 coefficients of the fish aggregate

Conclusion

This study has quantified the sustainability impacts of several food-based recommendations, including that to increase fish consumption, by combining a model of rational behaviour under dietary constraints, an epidemiological model of diet-related mortality and a life-cycle-analysis model of environmental impact. The strength of this approach is, first, that it permits the *ex-ante* assessment of dietary recommendations related to fish and meat consumption in multiple dimensions: taste cost borne by consumers, welfare effect on the whole society, mortality avoided and reductions in greenhouse gas emissions. This contributes to improving the evaluation of the sustainability effects of those dietary recommendations by actually considering possible convergence, or trade-offs, across sustainability dimensions. Second, the analytical approach takes into account consumers' preferences (expressed by own- and cross-price elasticities) and the complex relations of substitution and complementarity between food groups within the whole diet. Third the analysis was conducted in a similar way in two different countries, France and Finland. This is important to interpret results and derive robust conclusions, as consumption patterns vary widely across countries, as do the incidence of diet-related chronic diseases as well as tastes and preferences.

In spite of its advantages, the analytical approach also presents some limitations, which must be acknowledged and should be kept in mind when interpreting the results:

- Important health and environmental impacts of dietary changes were not taken into account, mainly because of the lack of data. For instance, we did not quantify the biological and ecological effects of wild fisheries and aquaculture, and did not address the issue of marine resource depletion. Food safety issues related to the possible presence of contaminants in fish and seafood products were also ignored. Thus, the proposed assessment is only partial and other sustainability dimensions will have to be integrated in the future, as corresponding data and key parameters become available.

- To precisely characterize the impact of variations in fish consumption, it would be desirable to consider more disaggregation of the fish category so as to take account of substitutions between types of fish products and species.

Thus, future work will have to capture other health and environmental effects and refine the analysis to the level of species and groups of fish products. Nevertheless, keeping in mind those limitations, some key results can be highlighted:

- In both countries, the taste cost of increasing fish consumption is quite small. This suggests that the barriers imposed by habits, tastes and preferences to raising fish consumption are relatively small, and that informational measures such as generic advertising could be successful in boosting that consumption.

- The simulations for both countries show that an increase in fish consumption generates larger health benefits than a reduction in meat consumption of the same relative magnitude. Most of the health benefit from raising consumption of fish is due to a decrease in energy intake, pointing to the fact that fish naturally belongs to relatively less calorific meals than alternatives.

- Regarding the climate impact, the recommendation to eat more fish appears to have a positive effect, even if that effect is smaller than those induced by recommendations to decrease meat consumption.

- Altogether, encouraging fish consumption would raise the sustainability of the French and Finnish diets, at least in the two measured dimensions (dietary health and greenhouse gas emissions). Further, promoting fish consumption appears to be socially desirable as the health and environmental benefits of the associated dietary change would exceed the associated cost imposed on consumers, industry and the public sector.

- Given the balance of benefits and costs, the recommendation to eat more fish should be prioritized over the recommendations to eat less meat. Thus, rather than stigmatising meat consumers, we suggest that sustainable diet recommendations may more effectively send a more positive message urging consumers to raise their consumption of fish and seafood.

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