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“Sustainable diets: are nutritional objectives and low-carbon-emission objectives compatible?"

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Abstract

Food systems in developed countries face one major challenge, namely the promotion of diets that are both healthy and generate less greenhouse gas emissions (GHGE). In this article, we review papers evaluating the impact of a change in diets on both health and GHGE. We address the following questions: How big are the health and environmental impacts that could be induced by a switch to healthier diets? What is, in monetary value, the relative importance of the health impact and the environmental impact? Is it possible to design an economic policy that increases global welfare taking into account externalities on both health and the environment? Since the way the change in diet is modeled is a key issue, we classify papers according to the methodology used for simulating diet changes: ad-hoc scenarios, optimized diets and economic modelling. We find that it is possible to design economic policies that have positive impacts on both dimensions. Because the substitutions / complementarities between food products are complex, it is not granted that a policy targeting one dimension will generate positive effects on the other dimensions. However, given the diversity of substitution and complementarity possibilities between products, it is possible to design a policy that does improve both dimensions. A carbon-based policy that targets the products with a high GHG content (e.g. meat products) and reinvests the revenues collected with the tax to subsidize the consumption of fruits and vegetables is likely to have positive effects on both dimensions.

Key words: food, consumer, diets, nutritional policy, health, climate change, greenhouse gas, environmental policy

JEL codes: I18, Q18, Q54.

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Sustainable diets: are nutritional objectives and low-carbon-emission objectives compatible ?

1 Introduction

It is now well recognized that low-quality diets are an important risk factor for contracting a non-communicable disease (WHO, 2010). As a consequence, most developed countries have put in place nutritional policies that take various forms, such as healthy eating guidelines, information campaigns, food taxes or food reformulation (e.g. Traill et al., 2013). Another important hurdle that countries face is climate change, which is linked to greenhouse gas emissions (GHGE) (IPCC, 2013). According to recent estimates, food systems are responsible for 15 to 28% of the totality of GHGE in developed countries (Garnett, 2011). To limit the increase in temperature to 2 degrees Celsius, ambitious goals of reduction have been designed. For example, the European Commission set the target to cut GHGE by 40% in the European Union by 2030, requiring a reduction in the emission burden represented by non-ETS (Emissions Trading System) sectors of 30% as compared to 2005.[1] In the specific case of agriculture, the objective of reduction in 2030 is 20% as compared to 2005.[2] Thus, food systems in developed countries face one major challenge, namely the promotion of diets that are both healthier and generate less GHGE.

There already exist some surveys in the literature addressing the compatibility between health and environmental goals. Joyce et al. (2014) focus on the link between dietary

[1]https://ec.europa.eu/clima/policies/strategies/2030_en. Accessed 2017, June 20.

[2]Ref to 'A Roadmap for moving to a competitive low carbon economy in 2050' Table 1. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0112&from=EN. The document also points out the importance of achieving the reduction of emissions in agriculture, as the importance of the latter in the overall EU emissions scenario will progressively increase as a consequence of higher reductions in the other sectors.

choices and GHGE. The main conclusion that emerges is the following: ‘diets containing a higher ratio of plant to animal products are generally associated with lower GHGE’.

Auestad and Fulgoni (2015) address the relation between dietary patterns and environmental sustainability. This survey reviews the impact of diets on various environmental indicators, including GHGE, land-use and water resources. From a methodological point of view, the authors highlight the importance of distinguishing the studies on the basis of the way the changes in diet are modeled. Finally, the authors conclude (p. 35) that ‘... shifts in eating patterns across the population occur slowly and the reduction potential in GHGE in developed countries may be greater in other sectors, such as transportation, rather than in the case of population-based shifts in eating patterns’.

Hallstrom et al. (2015) study the impact of dietary changes on GHGE and land use. Moving from the observed diet to a healthier diet, mostly based on dietary guidelines or on partial substitution of meat with plant-based foods, is likely to lead to a reduction in GHGE in the range 7 to 18% (11 simulations over 14). Adopting a vegetarian diet allows a larger reduction in GHGE (in the range 18-35%).[3] The authors conclude that ‘the reduction potential seems mainly to depend on the amount and type of meat and animal products included in the diet ... the amount of red meat, and especially ruminant meat, seems to be a decisive parameter...’. From this analysis, it appears that, unless diets radically change in the future, the reduction potential in GHGE through a change in consumer behavior exists, but is relatively limited, lower than the 20% reduction objective for agriculture.

Payne et al. (2016) investigate the link between low GHGE dietary patterns and health-related outcomes. They uncover significant heterogeneity in the results of the 100 dietary

[3]Finally, adopting a vegan diet would allow reducing GHGE even to a larger extent (range 25-35% in 4 studies over 6, and about 50% in 2 studies).

patterns reported in sixteen studies. They confirm 'an inconsistent relationship between reduced GHGE and positive health outcomes'. For the main macronutrients that need to be reduced (saturated fatty acids (SFA), salt, sugar), lower GHGE are more frequently associated with lower SFA intake, lower salt intake, but higher sugar intake. Finally, in most scenarios, they report 'lower levels of essential micronutrients in lower GHGE diets'.

Aleksandrowicz et al. (2016) review the environmental and health impact of dietary changes. They provide a comparison of the impact of 210 scenarios, classified into 14 groups, on GHGE, land use and water use. They point out that 'health and environmental priorities may not always converge: for example, sugar may have low environmental impacts per calorie relative to other foods, and some fruits or vegetables may have higher GHGE per calorie than dairy and non-ruminant meats'. Their overall conclusion is that, in high-income countries, the strategy 'to reduce dietary-related environmental impacts should focus on reducing animal-based foods'.

Perignon et al. (2017) focus on studies based on individual consumption. They review 10 studies that they classify into two categories: 'those that analyze the compatibility ... of environmental impact and nutritional quality, on the basis of subclasses of self-selected diets' and 'those that identify the primary dietary contributors to environmental impacts of diets and then simulate the effect of their reduction on ... environmental indicators and nutritional quality'. Analyzes based on subclasses of self-selected diets reveal that healthy diets are not systematically associated with low levels of GHGE. However, there exist diets consumed by a significant proportion of the population that are both healthy and generate less GHGE. From the other set of studies (simulation studies), it appears that the reduction in meat consumption is a potential driver of healthier diets and lower

GHGE. This, however, depends on which foods are selected to replace meat. The survey also reveals the importance of energy intake, or its change, in the analysis of the relation between health and GHGE.

In our view, an important drawback of the existing surveys is the absence of references to economic analyses. None of the above-cited surveys consider contributions from the economic literature. A significant part of our survey is, thus, devoted to review this economic literature and to compare its results with the results extrapolated from other studies. There are at least three major aspects addressed in economic analysis that are worth developing further. The first one is related to how consumer preferences are taken into account in the different approaches. The second one refers to the evaluation of benefits, but also costs, that are associated with alternative scenarios or policies. The third one consists in triggering a discussion on how to implement the desirable changes in practice, that is to define an economic policy. Since, in this survey, we study the health and climate impacts of adopting modified diets, the issue of consumer preferences is central. To better understand the results and the limits of the alternative approaches developed in the literature, we propose a classification of the different approaches and discuss how to interpret their respective results. In particular, we distinguish papers in which the change in diet is defined by the modeler in an ad-hoc manner from papers in which the change in diet results from a formal model. In the latter case, two classes of models are used. The first class of models, mainly developed by nutritionists, is based on mathematical programming. The model defines a new diet that integrates various nutritional and environmental constraints and minimizes an objective function that measures a departure from the current diet. The results are frequently designed as 'optimized diets'. The second class of models is based on the economic theory of rational consumers. Consumer preferences are summarized thanks to a matrix of elasticities that depicts how consumers react when facing a price change.

Based on this classification, we first present the main conclusions of each approach. That is, we provide a synthetic view of the impact on health and GHGE of modifying diets. In addition, we discuss the main advantages and weaknesses of the different approaches developed in the literature. Then, based on the insights from the economic analysis, we address the following complementary questions: How big are the health and environmental impacts that could be induced by a switch to healthier diets? What is, in monetary value, the relative importance of the health impact and the environmental impact? How is it possible to design an economic policy that increases global welfare taking into account externalities on both health and the environment?

Our main conclusions can be summarized as follows. Approaches based on ad-hoc changes in diets or optimized diets show that adopting healthier diets might be accompanied by a reduction in GHGE, but this is not systematic. They also reveal that diets with a lower impact on climate might also be healthier, but this is not systematic. Economic models show that carbon-based taxes lower the impact of diets on climate, but might have negative impacts on health. They also demonstrate that it is possible to design policies that lead to improvements in both dimensions. Considering that the substitutions / complementarities between food products are complex, it is not granted that a policy targeting one dimension will generate positive effects on the other dimensions. However, given the diversity of substitution and complementarity possibilities between products, it is possible to design a policy that does improve both dimensions. Roughly, a carbon-based policy that targets the products with a high GHG content (e.g. meat products) and reinvests the revenues collected with the tax to subsidize the consumption of fruits and vegetables is likely to have positive effects on both dimensions.

The paper is organized as follows. Section 2 covers the selection and the classification of papers that are included in the survey. Section 3 discusses the results of the studies based on ad-hoc changes of diets. Section 4 does the same for the studies based on optimized diets. Thereafter, section 5 discusses in detail the impact of economic policies on health and GHGE. Finally, section 6 compares the health and the GHGE reduction benefits, whilst section 7 analyzes the main results and foregrounds some directions for future research.

2 Selection and classification of papers

We use two strategies to retrieve and select the papers included in this survey. For 'non-economic' papers, we mainly use the reference section of the existing surveys. For economic papers, we search in EconLit all papers containing the following words: ('greenhouse' OR 'GHG' OR 'carbon' OR 'CO2') AND 'health' AND ('food' OR 'diet'). In both cases, we also use the reference section of the selected papers, particularly the most recent ones, to check any omission. To be included in this survey, the papers should meet the following criteria: i) they are published in peer-reviewed journals between 2009 and November 2017;[4] ii) the analysis concerns the EU in general or specific EU countries in particular;[5] iii) the dietary scenario analysis is performed for the complete diet; iv) quantitative estimates of the impact of a change in diet on GHGE are provided; v) estimates of the impact of a change in diet on health or on health-related indicators are provided. The choice of the

[4] We make two exceptions: two papers were in 'revise' and 'resubmit' form; They are now accepted for publication.

[5] Even if the literature displays some regularities, country-specific characteristics have often an impact on the results, which justifies our focus on a specific set of countries.

articles that meet the inclusion criteria is based on the information available in the title and in the abstract.

As papers from the 'non-economic' literature were already reviewed in different surveys, we use these papers in order to provide a comparison with papers from the economic literature. We also use them to discuss some methodological issues and shed light on important results. Moreover, since our goal is to analyze the impact that changes in diets have on health and GHGE, we do not include papers evaluating the link between the healthiness and the associated GHGE of observed diets within the population (referred as self-selected diets in the literature).[6]

The all-encompassing approach that deals with the impact on health and GHGE of changes in diet combines different models as follows:

- A first model predicts the change in diet. Mathematically, the model defines $\Delta X = (\Delta X_1, ..., \Delta X_i, ..., \Delta X_n)$ the vector of variation of intake of the n food products. The change in diet is either imposed by the modeler in an ad-hoc manner or results from a formal model which evaluates the impact of alternative scenarios on the diet. In the latter case, two classes of models are implemented. The first class of models, mainly developed by nutritionists, is based on mathematical programming. The results are frequently designed as 'optimized diets'. The second class of models is based on the economic theory of rational consumers. Consumer preferences are summarized thanks to a matrix of elasticities that depicts how consumers react when facing a price change.

- From the change in diet, more or less sophisticated models are used to assess the

[6] The reader should refer to the review by Perignon et al. (2017) to have a synthesis of those papers.

health impact. At the very minimum, based on the nutrient content of food products, the change in diet is translated into a change in nutrient intake. Denoting N the (n, m) matrix of the content in m nutrients of the n food products, $\Delta N = (\Delta N_1, ..., \Delta N_i, ..., \Delta N_m)$ the vector of variation of intake of the m nutrients associated to the change in diet, we have $\Delta N = \Delta X.N$. From this change in nutrient intake, in some papers, an health impact is deduced thanks to some epidemiological models that link the change in nutrients to a change in the incidence of some diseases.

- From the change in diet, the impact on GHGE is computed taking into account the GHG content of each product. The GHG content is based, in most cases, on LCA.[7] Formally, denoting $E = E_1, ..., E_i, ..., E_n$ the vector of GHG content of the food products, and ΔG the change in GHGE associated with the change in diet, we have $\Delta G = \Delta X.E'$

Based on the way the diet change is modeled, we propose a classification of the papers included in the survey. Table 1 lists the set of papers and indicates if they were included or not in the previous surveys. Among the studies within the category 'ad-hoc changes in diet', we only keep those assuming an isocaloric change. Thus, with reference to this group of papers, already reviewed in different surveys, we aim at answering two precise questions. The first consists in detecting the type of substitution leading to both better health and lower GHGE. The second one refers to getting an order of magnitude of the impact of adopting an healthier diet on GHGE. Since, in this methodological approach, the type of substitution is decided by the modeler and does not result from an in depth analysis of consumer behavior, we do not want to let the analysis be affected by a scale issue. In other

[7] For a more detailed discussion on the issues related to the GHG content of the product, ref to Hallstrom et al. (2015).

Authors [1]	Country	Joyce (2014)	Auestad (2015)	Hallstrom (2015)	Payne (2016)	Aleksandrowicz [2] (2016)	Perignon (2017)
Impact on GHGE and health of ad-hoc changes in diets							
Risku-Norja et al. (2009)	FIN	X	X	X		X	
Tukker et al. (2011)	EU	X	X	X	X	X	
Scarborough et al. (2012)	UK						
Vieux et al. (2012)	F	X	X	X		X	X
Hoolohan et al. (2013)	UK	X		X	X	X	
Meier and Christen (2013)	D	X	X	X	X	X	
Saxe et al. (2013)	DK	X	X	X		X	
van Dooren et al. (2014)	NL	X		X	X	X	
Westhoek et al. (2014)	EU	X				X	
Roos et al. (2015)	SW					X	
Impact on GHGE and health of optimized diets							
Macdiarmid et al. (2012)	UK	X	X	X		X	
Green et al. (2015)*	UK				X	X	
Perignon et al. (2016)	F					X	
van Dooren and Aiking (2016)	NL					X	
Horgan et al. (2016)	UK					X	
Vieux et al. (2018)	EU						
Impact on GHGE and health of economic policies							
Briggs et al. (2013)	UK				X	X	
Edjabou and Smed (2013)	DK					X	
Abadie et al. (2016)	N						
Bonnet et al. (2018)	F						
Caillavet et al. (2016)	F						
Irz et al. (2016)	F						
Springmann et al. (2016b)**	W					X	
Garcia-Muros et al. (2017)	E						

(1): We do not mention et al. for space reasons but all surveys are co-authored.

(2): Briggs et al. (2013) and Edjabou and Smed (2013) papers are cited but not used in the survey.

*: Milner et al. (2015) provide additional information on the health impact of scenarios. Method and scenarios are identical to those developed in Green et al. (2015).

**: W stands for World. However, this paper provides some results for Europe.

Table 1: Classification of the papers reviewed in this survey and comparison with the subset of papers evaluating the healthiness and GHGE of European diets reviewed in previously published surveys.

words, reducing the amount of calories consumed (which is frequently recommended by nutritionists, but difficult to be put in practice by consumers) would automatically lead to lower GHGE. By keeping the calorie intake constant, we only consider the impact of substitutions between food products. We, thus, abstract from a change in calories that is a consequence of consumer choices and that, as such, should be determined in models that integrate explicitly consumer behavior, that is models based on the modeling of consumer choices.

3 The effect of ad-hoc changes in diets on GHGE and health

Among the papers analyzing the impact on GHGE of ad-hoc changes in diets, a subgroup focuses on the impact of adopting dietary recommendations. In these papers, the health effect of adopting dietary recommendations is not evaluated, but can be assumed to be positive in line with the objective of the recommendations. In Table 2, we report the change in GHGE associated with the adoption of nutritional recommendations, assuming no change in calorie intake. Overall, the results suggest that adopting dietary recommendations is likely to be accompanied by a decrease in GHGE in the range 8 to 26% (average: - 13%). According to these studies, there is compatibility between health and environmental objectives. Interestingly, Tukker et al. (2011) explore two scenarios of recommendations. When recommendations do not include a limit in red meat consumption, then the impact on GHGE of adopting healthy recommendations is positive (+ 1.2%).[8] This result, which is in line with most research analyzing the impact on GHGE of ad-hoc changes in diets, shows the importance of replacing meat products with plant-based alternatives within the scope

[8]Note that the definition of red meat differs among studies. Tukker et al. (2011) include pork in the red meat category which is not the case in some other studies.

Authors	Country	Method	Number of products	GHG baseline t/person/year	Change in GHG	Change in meat intake
Risku-Norja et al. (2009)	FIN	LCA[(1)]	24	1.7	- 16%	-38%
Tukker et al. (2011)[(2)]	EU	IO matrix	21	2.6	- 8%	na
Meier and Christen (2013)	D	LCA	43	2.1	- 11%	-38%
Saxe et al. (2013)	DK	LCA	30	1.9	- 8%	- 18%
van Dooren et al. (2014)[(3)]	NL	LCA	17	1.5	- 12%	-21%
Roos et al. (2015)	SW	LCA	18	1.9	- 26%	n.a.

(1): GHGE from agriculture production only. (2): Scenario 2 with recommendations including a constraint on beef, lamb and pork meat.
(3): The study concerns women only.
n.a.: Not available.

Table 2: The impact of adopting dietary recommendations on GHGE.

of lowering GHGE. Finally, Roos et al. (2015) report a 26% decrease in GHGE, certainly due to a rather large decrease in meat products and an increase in grains and potatoes. An obvious limitation of this approach is to assume that consumers will comply with the nutritional recommendations. In the case of France, Estaquio (2011) studies the adherence of consumers to the nutritional recommendations defined in the 'Plan National Nutrition Santé'. She shows that some recommendations are poorly met by consumers. For example, less than 10% of men has an adequate intake of salt, and 36% has an adequate intake of milk and dairy products. She also ascertains that elder people and women tend to better comply with the recommendations.

A second subgroup of papers analyzes the impact on health and GHGE of predetermined substitutions. All studies simulate a substitution, at constant energy intake, of a set of animal products with a few alternatives (Table 3). The alternatives are either other animal products (substitution within the category) or plant products (substitution between categories). The health impact is evaluated using different indicators. Only one study (Scarborough et al., 2012) evaluates the impact on health on the basis of the number of deaths avoided (DA). The other studies address the change in some nutrients or in an indicator of diet quality.[9] Simulations show that it is possible to design substitutions that lead to improvements in both health and the climate. Briefly summarized, the different studies reveal that:[10]

- Replacing part of meat and dairy products with cereals (or a mix of cereals and fruits and vegetables (F&V)) leads to significant improvements in both dimensions.
- Replacing white meat with cereals (or a mix of cereals and F&V) leads to improvements in both dimensions, but to a lower extent than in the previous case.
- Replacing red meat with white meat reduces GHGE. The aggregate health impact seems positive, although some adverse effects are envisioned.
- When substitution involves mostly F&V, the health impact is positive, although it might be possible that, in some cases, GHGE increase. This is a consequence of the low caloric content of F&V, in a context in which substitutions are decided on the basis of food calories. Thus, F&V have low GHG content when evaluated per kilo of product, but result in higher emissions if evaluated per calorie of product.
- Some studies demonstrate that there exist trade-offs between health objectives and GHGE objectives. A larger improvement in one dimension is accompanied by a lower improvement in the other one.
- The study by Westhoek et al. (2014) suggests that land use change is an important aspect. For example, when cereals replace 50% of beef and dairy, GHGE are reduced by 14% without taking into account land use change and by 38% when land use

[9] Vieux et al. (2012) focuses on the change in the energy density of the diet. A priori, a decrease in energy density indicates an healthier diet.

[10] For a more extensive view, refer to the different surveys mentioned in Table 1.

Authors	Country	Method	Scenarios	Health effect	Change in GHG
Scarborough et al. (2012)	UK	LCA	S1: - 50% meat and dairy products	36910 DA	- 19%
			replaced by cereals and F&V	(30192-43592)	
			S2: - 75% red meat	1999 DA	- 9%
			replaced by white meat	(1739-2389)	
			S3 - 50% white meat	9297 DA	- 3%
			replaced by cereals and F&V	(7288-11301)	
Vieux et al. (2012)	F	LCA	S3: - 20% meat and / or deli meat		
			replaced by F&V	- 13% (ED)	0%
			replaced by dairy	- 9% (ED)	- 1.7%
			replaced by mixed dishes	- 8% (ED)	- 2.8%
			S4: Max 50 g meat and no deli meat		
			replaced by F&V	- 27% (ED)	+ 2.7%
			replaced by dairy	- 17% (ED)	- 3.5%
			replaced by mixed dishes	- 14% (ED)	- 7.2%
Hoolohan et al. (2013)	UK	LCA	- 100% red meat	+ 5% protein	- 18%
			replaced by white meat	0% carbs, + 9% salt	
Westhoek et al. (2014)	EU	Bio-physical	Cereals replace		
		models	50% beef and dairy	- 27% (SFA)	- 14% (- 38%)*
			50% pig and poultry	- 17% (SFA)	- 5% (- 5%)*
			50% meat and dairy	- 14% (SFA)	- 19% (- 42%)*

Note: we only use the subset of scenarios analyzed in these papers that fit our requirements.

*: in (), greening scenario which assumes that arable land previously used in the production of animal feed is converted into perennial bio-energy crops.

Table 3: Impact of ad-hoc changes on GHGE and health.

change is taken into consideration. In their analysis, they adopt a GHGE favorable view, as they assume that the land, made available through the substitution of cereals for animal products, is used to produce bioenergy crops. However, this result suggests that taking into account land use change might improve the climate impact of modifying diets, a subject that is extensively addressed in the discussion section.

- Overall, even with rather large substitutions in the diet, the change in GHGE remains rather modest (from +3% to -19%) as compared to the EU objective to cut GHGE from food chains by 30% by 2030.

4 The effect of optimized diets on GHGE

Rather than defining a priori the substitution between food products, some studies are based on optimization techniques. The general idea is to minimize an objective function, subject to various constraints. In particular, these models integrate nutritional constraints (i.e. dietary requirements), thus insuring the nutritional adequacy of the optimized diet. Depending on the study, the objective function differs. Macdiarmid et al. (2012) minimize the GHGE of the diet; Perignon et al. (2016), Vieux et al. (2018), Green et al. (2015), and van Dooren and Aiking (2016) minimize a distance function between the observed diet and the modeled diet. By minimizing a distance function, these studies introduce the idea that consumers seek to modify at the minimum their diet when complying with some constraints. This represents a first attempt to integrate consumer behavior into the picture. Thus, van Dooren and Aiking (2016) minimize the absolute changes in terms of portions. Perignon et al. (2016) define the distance function as the sum of the absolute values of the relative deviation of each product and each food group.[11] In this setting, modifying by, say, 10% the consumption of a food product that is marginal in the diet has the same 'cost' as modifying by 10% the consumption of a food product that is consumed in important quantities. Moreover, all food products are considered equally, in that the model does not integrate consumer preferences for the different food products. Alternatively, the distance function defined by Green et al. (2015) integrates some concepts coming from the economic theory. In this case, the distance is given by the weighted sum of the squared relative deviation of each food product. The weight is the ratio of the share of expenditure of a product divided by its own price elasticity. The idea of a weight inversely proportional to its own-price elasticity can be traced back to the taxation theory (e.g. Samuelson, 1951). However, as shown by Irz et al. (2015), in the case of nutritional recommendations, it is more complex to take into account consumer preferences, as they are related to own-

[11] Vieux et al. (2018) use a similar objective function: the distance function is defined as the sum of the absolute values of the relative deviation for each product.

and cross-price elasticities defining the substitutability and complementarity relationships between products. The above-detailed literature provides the main following results (Table 4):

- Satisfying nutritional constraints might lead to significant changes in GHGE. The results seem to be country- and gender-specific. Using the same model for 5 countries, Vieux et al. (2018) find medium to large increases in most cases (7 cases over 10) and small or intermediate decreases in a few cases (3 cases over 10). For instance, for the UK, they find an increase in GHGE for men (+ 31%) and a decrease for women (- 8%). Instead, Green et al. (2015), who use a slightly different objective function, find a reduction of 17% in GHGE for women.

- Satisfying nutritional constraints implies significant changes in the diet. In particular, this implies an increase in the consumption of F&V, cereal products, and, at least in some countries, a decrease in the consumption of meat products.

- Once nutritional constraints are satisfied, imposing an upper boundary on GHGE results in a reduction in animal product consumption, sometimes in significant proportions.

- Once nutritional constraints are satisfied, imposing reductions in GHGE in the range - 20 to - 30% is possible without large additional changes in the diet.

- There exist possibilities to improve both the health and the climate dimensions through a change in diets.

- It is possible to cut diet-related GHGE, without negatively impacting the diet quality.

Authors	Country	Number of food products	Method	Main results
Macdiarmid et al. (2012)*	UK	82	Min GHGE Subject to Nutritional constraints Acceptability constraints	GHGE: - 36% ↗ F&V (about + 15%), cereals, potatoes (about + 40%) ↘ High fat / sugar (about - 50%), meat (about - 50%) Modify the type of dairy products (↗ drinking milk, ↘ fat dairy products)
Green et al. (2015)	UK	42	Min changes in diet Subject to Nutritional constraints	GHGE: - 17% ↗ Cereals, F&V ↘ Red meat, dairy products, eggs, soft drinks
			GHGE Constrains	GHGE: - 20 to - 30% Only small additional changes compared to the healthy diet GHGE: - 40% ↘ Meat, dairy, fruits ↗ Sugary snacks GHGE: reductions of GHGE > 40% involve major dietary changes
Perignon et al. (2016)	F	402	Min changes in diet Subject to Acceptability constraints GHGE constraints	'FREE' scenario (no nutritional constraint): GHGE: - 30% reduction possible without significant impact on diet quality Food products substitution is not reported
			Nutritional constraints	'ADEQ' scenario (includes nutritional constraints and no increase in GHGE): significant changes within the food categories ↗ F&V (+ 30 to + 40%), breakfast cereals (+ 250%), fish (+ 75%) ↘ Deli meat (- 75%), ruminant meat (- 25%), cheese (- 50%) With nutritional constraints, decreasing GHGE by 20 to 30% is possible without additional large changes Larger GHGE reductions (> 40%) lead to larger ↘ (or removal) of meat (ruminant, pork, poultry) of animal based dishes
Vieux et al. (2018) Not yet published	F , UK, I, Fin Sw	151	Min changes in diet Subject to Acceptability constraints Nutritional constraints	'NUTR' scenario (no GHGE constraint): Mostly ↗ GHGE. Men: from - 3 to + 31% depending on the country Women: from - 8 to + 46% depending on the country ↘ Sugared and fat products ↗ F&V, starchy foods
			GHGE constraints	Within food-groups substitution needed Changes in animal-based products but country-specific Reduction of GHGE by 30% possible without large additional changes (compared to nutritional constraints alone)

Authors	Country	Number of food products	Method	Main results
van Dooren and Aiking (2016)	NL	206	Min Changes in diet Subject to Nutritional constraints GHGE constraints	Optimized 'LLD' scenario: $\nearrow$ F&V (+ 19.4%), fruits (+ 91%), legumes (+ 183%), fish (+ 48%) $\searrow$ Meat (- 12.7%), cheese (- 100%) GHGE: - 20%
Horgan et al. (2016)	UK	134	Min changes in diet Subject to Nutritional constraints Acceptability constraints	Healthy diet scenario (nutritional recommendations): GHGE: - 15.4% Sustainable diet scenario (both nutritional and environmental constraints): GHGE: - 26.7%

*: percentage changes in food product consumption are approximated from the results presented in Figure 1 of the paper (pp. 637).

Table 4: The effect of optimized diets on GHGE and the composition of the diet.

Studies using this methodology suggest that significant reductions in GHGE are possible (-20 to - 30%) and compatible with health objectives, as diets satisfy nutritional constraints in this setting. Thus, the results suggest that there exist combinations of food products allowing to reduce GHGE from diets and, at the same time, to improve the healthiness of diets. However, this general result depends on significant changes in the diet at both the food group level and the individual product level. For example, Vieux et al. (2018) report that required changes concern 1.5 to 2 kg of food per day for women. This is a huge change in diet, considering that the initial food intake is between 2 and 3 kg per day depending on the country. Moreover, as shown by Horgan et al. (2016), who develop a similar analysis at the individual level, there is a large heterogeneity across changes in diet that are required to achieve healthier and more environmentally friendly dietary patterns. Finally, as compared to the results discussed in the previous section ('ad-hoc changes'), it is possible to reach larger reductions in GHGE while complying with nutritional recommendations. This is directly linked to the fact that a large number of food products is taken into consideration, which makes possible to design more diverse diets and demonstrates that it is theoretically reasonable to significantly decrease GHGE.

All this taken into account, an interesting feature of this approach is that it allows to consider a large number of food products. As a consequence, one can analyze substitutions between product categories, as well as substitutions within product categories. However, the key issue behind these results is related to the likelihood of such changes in practice. Therefore, the pivotal question to be investigated remains the plausibility of such changes. Since these approaches do not properly take consumer preferences into account, their results should be interpreted cautiously. Finally, another weakness consists in the absence of tools providing incentives for consumers to significantly change their diets.

In the following section, we provide a detailed analysis of the economic studies addressing these two weaknesses: giving more attention to consumer preferences and simulating the impact of economic tools favoring changes in consumer food choices.

5 Impact of economic policies on health and GHGE

Rather than simulating more or less realistic changes in diets and exploring their potential effects in terms of health and reductions in GHGE, economists evaluate how consumers are likely to react to policy scenarios in order to infer the implications of these changes on diet quality, health and GHGE. We found 8 published papers evaluating the impact of policies in the European context (Table 5).[12] Only one paper addresses the impact of policy recommendations, whereas the others analyze price policies. In this latter case, taxes and subsidies are frequently based on the GHG content of the food products. Most papers consider the whole diet distinguishing about 20-25 different food products. In most cases, elasticities are estimated using the AIDS demand model. Given the level of aggregation, these models account for substitution between food product categories ignoring the intra-category substitutions.[13]

In what follows, we discuss in more detail the results of the simulated price policies. To do so, we distinguish between scenarios merely based on the taxation of a set of products and scenarios in which the revenues generated through taxes are used to subsidize another set of products. In the former case, there is no product experiencing a price reduction,

[12] One paper (Springmann et al., 2016b) develops an analysis at the world level; we use the results related to the developed countries in the discussion section.

[13] Bonnet et al. (2018) focus on animal products and use a random logit model in which the 'outside option' is an aggregate of plant-based products. Their analysis mainly deals with substitutions within the meat-product category.

whereas in the latter, some products undergo a decrease in their price. This difference in the design of the scenarios has important consequences on the results. It is interesting to note that the policies analyzed in this section adopt a tax scheme with a primary focus on climate (except the work on nutritional recommendations), while studies reviewed in the previous sections mainly have a nutritional motivation. This might be because GHGE are seen as an externality that requires public intervention, which justifies the advocacy of carbon taxation. Conversely, until now nutritional policies have mainly targeted information on consumers and, when taxation is envisaged, it is mostly geared towards specific products, such as sugar-sweetened beverages.

Authors	Country	Method	Scenarios	Main results
Briggs et al. (2013)	UK	AIDS model, 3 stage-budgeting 29 food groups	S1: Tax based on GHG content (27.2 €/tCO_{2e}) of products with emissions > 4.1 kg CO_{2e}/kg	- 1.4% energy intake 7770 [7150 to 8390] deaths avoided GHGE: - 7.5%
			S2: S1 + subsidies on products with emissions < 4.1 kgCO2e/kg Tax revenue-neutral scenario	+ 1% energy intake 2685 [1966 to 3402] additional deaths GHGE: - 6.1%
Edjabou and Smed (2013) 2013	DK	AIDS model 23 food groups an other set of elasticities for sensitivity analysis	S1: Tax based on GHG content S1A: 29 $/t CO_{2e} S2A: 85 $/t CO_{2e} All products taxed	Calories: - 2 to - 4 % (S1A); - 5 to - 10 % (S1B) ↘ SFA, and ↗ sugar GHGE - 4.0 to - 7.9% (S1A); - 10.4 to - 19.4% (S1B) ↘ CSurplus 0.36 to 0.39$/kg GHG
			S2: S1+ decrease in VAT Revenue-neutral (ex-ante)	Calories: + 1 to + 2% (S2A); + 3 to + 6 % (S2B) Small ↘ SFA and ↗ sugar GHGE: - 0.7 to - 3.4% (S2A); - 2.3 to - 8.8% (S2B) Almost no impact on consumer surplus
Abadie et al. (2016)	N	LA/AIDS model 19 products Ad valorem taxes and subsidies chosen to minimize DWL with isocaloric diet	S1: GHGE: - 5%	Red meat: - 25% Poultry: + 12% Cheese: - 10% Fat and oil: - 9% Decrease in fat (- 4.9%), SFA (- 10.4%), carbohydrates (- 0.7%) Increase in protein (+ 1.1%)
			S2: GHGE: -10%	Red meat: - 49% Poultry: + 39% Cheese: - 28% Fat and oil: - 10% Decrease in fat (- 2.3%), SFA (- 5.2%), Increase in carbohydrates (+ 0.9%), protein (+ 4.0%)
Bonnet et al. (2018)	FR	Random logit model Focus on animal products (25) Outside good: plant-based products	Tax based on GHG content 56 or 200 €/t CO_{2e} All animal products Only ruminant meats Only beef meats	 - 1.9 / - 6.1% GHGE (low / high CO2 price) - 1.3 / - 3.7 % GHGE - 1.1 / - 3.2 % GHGE Welfare cost << with only beef taxation Compatibility between nutritional and environmental objectives
Caillavet et al. (2016)	FR	EASI demand model 21 food products Estimate elasticities for different households	20% tax ENV: Tax animal-based foods	ENV: - 8.1% calories ↘ Protein, cholesterol, SFA and sodium MAR index: ↘ ; Consumer cost: + 7.6% GHGE - 7.5%, SO2 - 14.5%, N20: - 8.4%
		(income and age classes)	ENV-NUT: tax animal-based foods except fish, other meat, and fresh dairy not taxed	ENV-NUT: - 8.1% and - 5.6% calories ↘ Protein, cholesterol, SFA and sodium MAR index: ↗; Consumer cost:+ 4% GHGE - 7.0%, SO2 - 13.2%, N20: - 6.6%
Garcia-Muros et al. (2017)	E	AIDS demand model 13 food products Distinguish income classes assuming identical elasticities	Tax based on GHG content REF: 25 €/t CO_{2e}	 REF: - 2.2% calories; all nutrients ↘ by 1 to 5% GHGE: - 3.8% Consumer surplus: - 97 €/household Slightly regressive
			HCT: 50 €/t CO_{2e} ExeHT: HCT with 4 products untaxed (cereal, milk, fruits, vegetables)	HCT: impact is about twice the impact of REF Calories: - 2.5%; all nutrients ↘ but fibre GHGE not reported, likely larger than HCT Less costly for consumers than HCT
Irz et al. (2016)	Fr	Elas: AIDS model Consumer model: choice under rationing Cost-Benefit Analysis 22 food products	Nutritional Recommendations Change in consumption by 5% Recommendations tested: ↗ F&V; ↘ salt; ↘ SFA; ↘ meat; ↘ red meat ↘ Added sugar;	In 5 over 7 cases, improve health and reduce GHGE Most recommendations likely to have net > 0 effect Health gains > GHGE gains Best options: ↗ F&V, ↘ salt and SFA Modest impact on GHGE
Springmann et al. (2016b)	World 7 regions	Partial Equilibrium Model IMPACT	Tax based on GHG content $52/t CO_{2e} Different set of products taxed Alternative use of taxes subsidize F and V; income redistribution	Higher rates: beef, oils, milk, lamb Consumption of every product ↘ - 9% GHGE when all products are taxed Only beef taxation: 2/3 of GHG impact $\geq$ 0 impact on health: - 1% deaths

Table 5: The effect of policy scenarios on GHGE and the composition of the diet.

5.1 Scenarios of only taxation

We first review the results of scenarios based on taxation of all products or a subgroup of products (Table 6). We report the results of 6 scenarios from 5 different papers. In most cases, the tax is based on the GHG content of the food products. In what follows, we report the main results assuming the tax is 32 €/t CO_2.[14] Note also that a precise comparison of the results is difficult as the impact of the tax in percentage of the price for a given product varies from one study to another, even when correcting for the value of CO_2.[15]. The main conclusions are the following:

- Consumption of beef (and lamb) is the most impacted and decreases by a low 5% (in Bonnet et al. (2018), in which substitutions between different beef products are allowed) and a high 20%. Consumption of beef products is the most impacted, as the tax is the highest for these products.
- Consumption of poultry products decreases less than consumption of beef products, as a consequence of a lower tax rate, but also of substitution effects with beef products. In one case (Edjabou and Smed, 2013), poultry consumption increases while being taxed.
- Consumption of the majority of products decreases as a reaction to the taxation scheme.

[14]To do so, we linearly extrapolate the results when the tax scenario is based on an explicit value of CO_2. Then, the results from Edjabou and Smed (2013) are multiplied by $32/21.2 \simeq 1.51$; the results from Briggs et al. (2013), Bonnet et al. (2018) and Garcia-Muros et al. (2017) are multiplied by 1.01, 0.57 and 1.28 respectively. As Caillavet et al. (2016) do not base taxation on the CO_2 content, we do not compare their quantitative results with the other studies.

[15]For example, in the case of beef meat, assuming that the tax is based on 32 €/t CO_2, the impact varies from about 4% for some beef products considered in Bonnet et al. (2018)) to about 16% in Edjabou and Smed (2013).

	Briggs et al. (2013)	Edjabou and Smed (2013)	Abadie et al. (2016)	Bonnet et al. (2018)	Caillavet et al. (2016)	Garcia-Muros et al. (
Carbon Tax	£27.2 ≃ €31.6	\$29 ≃ €21.2		56	-	€25
(/t CO_2)						
Taxation rule	Pdts GHGE > 4.1 CO_2/kg	All	Endogenous	All**	Anim Pdts	All
Tax level						
Beef	2.0 (€/kg)	11.1%	9%	6 - 12%	20%	6.0%
Pork	0.1 (€/kg)	2.0%	- 5%	2 - 5%	20%	4.2%
Poultry	0.05 (€/kg)	2.5%	- 15%	3 - 9 %	20%	2.2%
Cheese	0	4.9%	0%	7%	20%	4.4%
Sugar	0	1.4%	40%	n/c	0	2.1%
F&V	0	1.0 to 2.7%	F: -7% V: -10%	n/c	0	2.1 to 4.4%
Δ Consumption						
Beef	- 14.2%	- 13%	- 25%	- 8.3%		- 7.5%
Pork	- 1.2%	- 2% 6%		- 0.5%		- 2.5%
Poultry	- 0.2%	+ 1%	12%	- 3.8%		- 3%
Cheese	- 0.2%	- 3%	- 10%	- 1.8%		- 5%
Sugar	- 0.2%	3%	6%	n/c		- 1%
F&V	F: + 0.2%; V: - 0.4%	F: + 4%; V: 0%	0%	n/c		- 4%
Nber pdts Δ cons ≥ 0	3 (of 29)	10 (of 23)	2 (of 30)		0 (of 13)	
Δ Nutrients						
Calories	- 1.4%	- 2.0 %	iso	- 0.7%	- 8.1%	- 2.2%
SFA	- 2.8%	- 4.0%	- 10.4%	- 1.6%	- 15.7%	- 3%
Carbohydrates			- 0.7%		- 3.0%	- 1.2%
Sugar	- 0.4%	0.3%	- 1.2%		- 3.2%	- 2.7%
Aggregate impacts						
Δ GHGE	- 7.5%	- 7.9%	- 5%***	- 1.9%	- 7.5%	- 3.8%
Diet quality Index					- 0.3	
DA	7770 (3.4%)*					
Δ Consumer Surplus		- 29 €/pers/year		- 0.9%		- 97 €/hh/year

*: Based on a total number of deaths from the modeled diseases of 226 743 in 2008, cf. Scarborough et al. (2012).
**: This paper considers 21 meat products, 7 other animal products, a dairy product aggregate and a plant-based aggregate substitute.
***: The reduction of GHGE is imposed. The tax scheme is determined endogenously to reach the imposed reduction in GHGE.

Table 6: Comparison of the impacts of environmental taxation on consumption, health and GHGE.

- As the consumption of most products decreases, the calorie intake decreases in the range - 1.5 to - 3% for models that are based on the whole diet.

- Consumption of SFA and carbohydrates decreases, whereas consumption of sugar might increase. The aggregate health impact might be positive as the number of DA is positive (although evaluated in only one study). However, the diet quality index might decrease as shown in the 'ENV' scenario in Caillavet et al. (2016).

- GHGE are reduced by 5 to 12% for models that are based on the whole diet.

- A significant part of this reduction is linked to the reduction in beef (lamb) consumption. Another part is linked to the overall decrease in calorie consumption.

- Consumer surplus, ignoring health or climate impacts, decreases by €45 to 50 per person per year.

An important conclusion that emerges is that the reduction in GHGE through a tax based on the GHG content of products (assuming a value of 32 €/t CO_2) is smaller than the ones reported in the previous sections of this paper. This reduction is mainly the consequence of a decrease in the consumption of beef (and lamb) products as well as of a 'scale' effect following a reduction in the calorie intake. For example, Bonnet et al. (2018) get very small decrease in GHGE as well as low changes in calorie intake. On the contrary, Caillavet et al. (2016) find a reduction in GHGE that is as large as the reduction in calorie intake. Net of the scale effect, the reduction in GHGE is between 2 and 9% for models based on the whole diet. With respect to the health dimension, only one study evaluates the aggregate health impact, which is positive. However, a significant part of the positive health effect is linked to a reduction in calorie intake. Contrarily, Caillavet et al. (2016)

find a negative impact on the diet quality. In sum, the results on the health impact of GHGE taxation are mixed. This is an important finding that will be discussed in depth in section 7.

Finally, it is important to note that, for these scenarios, the consumption of most products decreases, which mainly depends on the fact that the models used only consider food demand, rather than a complete demand system also integrating demand for non-food products. That is, a reallocation of the consumer budget between food products and non-food products is not taken into account.[16] In other words, it is likely that these models over-estimate the decrease in consumption of animal products induced by the tax policy. As a consequence, they certainly over-estimate the decrease in GHGE driven by taxation.

5.2 Scenarios of revenue-neutral price policies

In a few papers, the simulated scenarios include revenue-neutral schemes of taxation. The revenues from the carbon tax allow subsidizing some products or decreasing the VAT (Table 7). Briggs et al. (2013) define a revenue-neutral scenario in which products with GHGE above a given threshold are taxed and products with GHGE below the threshold are subsidized. Edjabou and Smed (2013) use a different rule: all products are taxed proportionally to their GHG content and all products benefit from the same abatement in VAT. In what follows, we report the main results assuming the tax is 32 €/t CO_2 :[17]

- As a consequence of supporting the highest tax, consumption of beef (and lamb) is

[16] The impact of ignoring this effect becomes particularly visible when exploring high levels of tax. For example, Edjabou and Smed (2013) simulate two levels of carbon tax: the one reported here and another one based on a carbon price of 62 €/t CO_2. In the latter case (scenario 1B), they report a decrease in calorie consumption as high as 5.3%, which is huge.

[17] As in the previous section, we linearly extrapolate the results to 'estimate' the impact considering such a carbon price.

the most impacted item.

- Consumption of some products decrease (meat products in particular), whereas consumption of other products increase (fruits, as well as some energy-dense products).
- Calorie consumption increases by 1 to 3%. This is linked to the increased consumption of energy-dense products benefiting from net subsidies which counter-balances the decreased consumption of meat products.
- Consumption of SFA might decrease by a small amount whereas consumption of sugar, as a nutrient, increases by about 4%. The impact on health is likely to be negative.
- Due to substitutions between food products, GHGE are reduced by 4.5 to 6%.
- Consumer surplus, ignoring health or climate impacts, is almost unaffected.

There are three subsets of results that derive from these analyzes. First, the results suggest that the reduction in GHGE is smaller than the one reported in the case of taxation only, about 5% for a 32 €/t CO_2 carbon tax. As a consequence, unless taxation is based on higher values of CO_2, the reduction in GHGE through a change in consumption is rather limited, well below the objective of cutting GHGE from food and agriculture by 20%. It also appears that taxing products with high GHG content and subsidizing those with low GHG content is likely to have negative impacts on health, as a consequence of increased calorie consumption and increased consumption of sugars. This is due to the fact that the policy assigns subsidies to energy-dense products, such as soft drinks and sugary products, thus leading to adverse health effects. This is a very important conclusion that sheds light

	Briggs et al. (2013)	Edjabou and Smed (2013)	
		S-2A	S-2B
Carbon Tax (/t CO_2)	£27.2 ≃ €31.6	\$29 ≃ €21	\$85 ≃ €62
Tax /Subsidies	Tax on Pdts GHGE > 4.1 CO_2/kg Subsidies for pdts GHGE < 4.1 CO_2/kg	All products: carbon tax and decrease in VAT	
Beef	2.0 (€/kg)	8.5%	25.3%
Pork	0.1 (€/kg)	- 0.6%	- 1.4%
Poultry	0.05 (€/kg)	- 0.2%	0.0%
Cheese	- 0.07 (€/kg)	2.3%	7.1%
Sugar	- 0.13 (€/kg)	- 1.2%	- 2.9 %
F&V	- 0.08 to - 0.1 (€/kg)	F: - 1.6%; V: + 0.1%	F: - 4.3%; L: + 0.9%
Δ Consumption			
Beef	- 13.7%		- 32%
Pork	- 0.7%		- 6%
Poultry	- 0.3%		+ 2%
Cheese	+ 0.9%		- 9%
Sugar	+ 5.0%		+ 8%
F&V	F: + 3.5%; V: + 2.4%		F: + 9%; V: - 1.5%
Nber pdts Δ cons ≥ 0	19 (of 29)		13 (of 23)
Δ Nutrients			
Calories	+ 1.0%	+ 2.2 %	+ 6.1%
SFA	- 1.2%	- 0.1%	0.0 %
Carbohydrates			
Sugar	+ 4.2%	+ 3.1%	+ 8.9%
Aggregate impacts			
Δ GHGE	- 6.1%	- 3.4%	- 8.8%
Diet quality Index			
DA	-2685 (- 1.2%)		
Δ CS		+1 €/pers/year	-2 €/pers/year

Table 7: Comparison of the impacts on consumption, health and GHGE of revenue-neutral price policies.

on the non-existence of an automatic convergence between a health objective and a climate attenuation objective. Finally, the impact on consumer surplus is very small, which means that the revenue-neutral policies improving both the health and the climate dimensions are likely to be highly cost-effective and welfare-improving.

6 Comparison of health and climate benefits

As discussed previously, changes in diets impact both the health and the climate. The objective of this section is to compare, in monetary terms, the relative importance of these two effects. To do so, among the different studies reported in the previous sections, we keep the ones that provide both an estimate of the health impact (number of DA or number of disability-adjusted life years (DALY)) and an estimate of the impact on GHGE. Although, as already discussed in the previous sections, these studies rely on a different array of methodologies, they provide information on health and GHGE for a sound scenario of consumption change. To assign a monetary value to these impacts, we avail ourselves of conventional values that are extensively used in cost-benefit analysis. For the health impact, we use the monetary value of a statistical life (VSL), defined as the effort, in terms of resource usage, that society is willing to make in order to reduce the risk of death. The VSL is commonly adopted in economic and policy analysis.[18] For instance, in the transportation sector, the VSL reported by Anderson and Treich (2011) ranges from 1.8 million USD 2005 for New-Zealand to 3.3 million USD 2005 for the United States, with the three represented EU countries displaying values in the order of 2 million USD 2005. Valuing the benefit of reduced externalities proves difficult also on the environmental side. In the case of carbon emissions, we rely on the meta-analysis of the social cost of carbon developed by Tol (2012). The author, after fitting a distribution of 232 published estimates, derives a median of 32 €/ton, which we adopt in this analysis. We also present results in the case of a higher value of the social cost of carbon (56 €/ton), following some recent policy debates that suggest higher values for the cost of carbon in order to provide higher

[18] For a review, see Treich (2015)

incentives for GHGE reduction.

In table 8, we report the health impact (in DA or DALY), the avoided GHGE for 15 scenarios from 5 different studies in the UK (4 studies) and France (1 study). In most cases (12 cases over 15), the scenarios have a positive impact on both dimensions. Given the VSL and the social cost of CO_2, we compute the health and climate benefits as well as the ratio of climate benefits and health benefits. In the majority of cases, it appears that the climate impact (as measured by the benefit of avoiding GHGE only) is generally small as compared to the health impact, as the ratio of climate benefits over health benefits lies between 0.01 and 0.21 with a CO_2 value of 32 €/ton.[19] These results have an important consequence on the design of climate policies targeting food products. When evaluating these policies, one should verify that the impact on health is not negative. Otherwise, it is likely that the policy would result in a negative welfare impact.

[19]Springmann et al. (2016a) found similar results when analyzing the potential impact of diet changes at the world level.

Authors	Country	Scenario	Deaths Avoided (nber/year)	Avoided GHGE (Million t / year)	Economic Value (billion €) Health (a)	Env (b1)	Env (b2)	Ratio (b1)/(a)	(b2)/a
Briggs et al. (2013)[(1)]	UK	Scenario A	7770	18.7	15.5	0.6	1.0	0.04	0.07
		Scenario A bis	1 207	15.5	2.4	0.5	0.9	0.21	0.36
		Scenario B	- 2 685	15.3	- 5.4	0.5	0.9	< 0	< 0
		Scenario B bis	2 536	17.6	5.1	0.6	1.0	0.11	0.19
Scarborough et al. (2012)[(2)]	UK	Scenario 1	36 910	13.0	73.8	0.4	0.7	0.01	0.01
		Scenario 2	1999	7.3	4.0	0.2	0.4	0.06	0.10
		Scenario 3	9297	2.7	18.6	0.1	0.2	0.00	0.01
Irz et al. (2016)	F	F&V + 5%	2507	1.57	5.0	0.05	0.09	0.01	0.02
		Na - 5%	2852	0.46	5.7	0.01	0.03	0.00	0.00
		SFA - 5%	2140	- 0.26	4.3	- 0.01	- 0.01	< 0	< 0
		Added sugar - 5%	941	- 0.34	1.9	- 0.02	-0.04	< 0	
		Red meat - 5%	230	0.27	0.5	0.01	0.02	0.02	0.03
		All meats - 5%	245	0.51	0.5	0.02	0.03	0.03	0.06
			DALY or YL						
Aston et al. (2012)[(3)]	UK		70 142	27.8	5.4	0.9	1.6	0.17	0.29
Green et al. (2015)[(4)]	UK	.	132 910	26.1	10.2	0.8	1.5	0.08	0.14

(1): Scenario A and B are defined in the paper. Scenarios bis assume no change in calorie intake.
Note that we recomputed the impact on GHGE for the 'bis' scenarios, as there was a mistake in the original paper.
(2): Amount of GHGE avoided is taken from the Committee on Climate Change study.
(3): The impact on health is measured by the number of DALY (Disability-Adjusted Life Years) saved.
(4): The impact on health is measured by the number of YL (Years of Life) over a period of 20 years for all diseases. We assume an equi-repartition over the 20 years. The paper provides the impact on GHGE in percent (- 17.2%). To compute the impact on quantity, we use the estimate of GHGE emissions in the UK from Audsley et al. (2009).
(a): VSL: €2M; (b1): CO_{2e}: €32/t; (b2): CO_{2e}: €56/t.

Table 8: Estimates of the value of the health and environmental impacts of modifying diets.

7 Discussion - research needs and policy perspectives

Several important conclusions emerge from this survey. There are broadly three groups of studies addressing the impact of modifying diets on health and the climate.[20] It is crucial to make this distinction, as the results must be interpreted in line with the main assumptions that are inherent to each of the methodologies dealt with in this survey.

From the studies based on ad-hoc changes, it appears that adopting dietary recommendations is likely to reduce GHGE by about 8 to 16% suggesting a convergence between health and climate objectives. The analysis of pre-determined substitutions also suggests that there is room for substitutions that are both healthy and climate-friendly. The largest impacts are obtained by replacing animal products with plant-based products. In addition, the substitution of red meat, rather than white meat, generates a higher reduction in GHGE. The results also indicate that the type of plant-based substitute matters. In particular, if the substitute is mainly F&V, the impact on GHGE is likely to be relatively small. Finally, even with large substitutions, the impact on GHGE remains smaller than the EU objective to cut GHGE from the agricultural sector by 20% by 2030. Since the substitutions are chosen by the modeler and not by the consumers, these results should be interpreted with great cautious. In our opinion, the results offer some general directions that could help in the design of policies. They deliver both a positive message, that is the plausible convergence between health and climate objectives, and a less optimistic message, related to the fact that large decreases in GHGE from diet changes are unlikely.

The studies based on optimized diets also provide some important insights. First, they confirm the possibility to design diets that are both healthy and climate-friendly. They

[20] A fourth group of studies, which is not reviewed in this survey, focuses on the analysis of the heterogeneity of self-selected diets (see Perignon et al., 2017).

also suggest that reaching substantial reductions in GHGE, while satisfying nutritional recommendations, is not impossible. According to Vieux et al. (2018), it is possible to reach 20 or 30% reduction in GHGE while abiding by nutritional guidelines. In these cases, diet changes mainly involve substitutions between product categories. However, these changes are significantly large, as the consumption of some food categories vary by more than 50%. For example, the consumption of animal-based products and, particularly, the consumption of ruminant meat, needs to be significantly reduced, whereas the consumption of plant-based products needs to be significantly increased.

However, there is no consensus regarding the impact of adopting nutritional recommendations on GHGE. As reported in Table 4, a recent study suggests that complying with nutritional recommendations might lead to higher GHGE, whereas other studies state the contrary. This conclusion is consistent with analyses developed in the case of self-selected diets. Thus, Vieux et al. (2013) show that 'high-nutritional-quality diets have significantly higher GHGE than do low-nutritional-quality diets'. In our view, this variability in the results might be explained considering the heterogeneity across countries, which makes the comparison difficult. Nonetheless, it could also be related to the methodology itself. Models differ in their objective function (as discussed in section 4), but also in the presence or not of 'ad-hoc' non-nutritional constraints. These constraints are frequently referred to as 'palatability' or 'acceptability' constraints, although their role is not detailed (for example, it is difficult to know which of these constraints is binding at the optimum). Therefore, it is difficult to understand precisely what drives the diverging results. Finally, the results from this class of models also suggest that within-food group substitutions are an additional way to reduce GHGE from diets. This is an important take-away, as, from a consumer's perspective, it is certainly easier to substitute between products within a product category rather than between categories. This distinction between within and between categories is made possible because LP-based models consider a large range of food products. To sum-up, the results from this class of models tend to show that a convergence between the two objectives is possible and that significant decreases in GHGE are achievable at the cost of large changes in diet. These models also instruct us on which substitutions to prioritize. Nonetheless, the main limitation of this class of models lies in the fact that consumer preferences are not properly taken into account. The main concern that emerges from this strand of literature is related to the need of designing policies that could provide consumers with the incentives to modify their diets in the 'desired' direction.

The economic studies provide a less optimistic view. First, the order of magnitude of the decrease in GHGE is much lower, frequently lower than 10% unless high levels of taxation are put into force. A second conclusion that emerges is that a carbon tax policy, which consists in taxing products with a high GHG content and subsidizing those with a low GHG content, is likely to have negative health impacts. This is mainly due to the fact that such a policy subsidizes energy-dense products that have a negative impact on health. As shown by Springmann et al. (2016b), in order to achieve convergence between the two objectives in a revenue-neutral policy, one has to tax products with high GHG content (ruminant meat in particular) and invest the revenues to subsidize healthy products, such as F&V. In this case, it is more likely that consumers will choose diets that are healthier and more climate-friendly. This rises the problem of defining which products to include in a price policy. On the one hand, Bonnet et al. (2018) consider scenarios with taxation only and show that, by taxing beef products rather than all meat products, one gets most of the impact of the taxation policy at a much lower cost for consumers. On the other hand, in a revenue-neutral scenario, Springmann et al. (2016b) conclude that 'the greater the tax coverage, the greater the tax revenue, the more revenue could be used to subsidize F&V consumption and the greater the associated health benefits'. The results of the different studies also show that, when there is convergence between the two objectives, the health effect is higher in monetary terms, sometimes in very large proportions, as compared to the environmental impact. This is an important take away for policy design. In particular, it means that the design of environmental policies should take into account the induced health impact of policies. More generally, because the substitutions / complementarities between food products are complex, it is not granted that a policy targeting one dimension will generate positive effects on the other dimensions. Notwithstanding, given the multiple possibilities of substitution and complementarity between products, it is possible to design a policy that does improve both dimensions. Roughly, a carbon-based policy that targets products with a high GHG content (e.g. meat products) and use the revenues of the tax to subsidize the consumption of F&V is likely to have positive effects on both dimensions.

There are still a lot of aspects that need to be better analyzed. First, since the economic models consider a small number of product categories, the economic analysis mostly ignores the problem of substituting within a product category. This represents a limit as, from the consumer's point of view, substitutions between categories are likely to be more difficult to realize than substitutions within product categories. As shown by Bonnet et al. (2018), a product category (e.g. red meat) includes different products with very different prices. A tax that applies to a certain category will have a larger impact on the price of relatively cheap products, rather than on that of more expensive products. As a consequence, it is likely that the demand for the different types of products will be differently affected. This remains a difficulty that, at present, cannot be assessed in the models developed so far, unless they focus on a specific group of products.

Second, one should keep in mind that, in most cases, a significant proportion of the health benefit derives from the change in calorie consumption.[21] The change in calorie consumption is a fundamental factor that needs to be better understood. Simulations of taxation policies (non-neutral schemes of taxation) generally lead to a decrease in calorie consumption, following a decrease in the consumption of most products. As discussed in section 5, this result might be linked to a bad accounting of budget reallocation between food and non-food products. This issue is a priori much less important in the revenue-neutral simulations, in which there is a rebalancing of consumption between products. However, anticipating calorie changes induced by a change in the diet remains key, as it conditions the relative importance of the health and climate impacts.

Third, with respect to the environmental impact of diets, we have focused on GHGE since, globally, the location of GHGE does not matter. In other words, there is additivity in the quantities that are emitted wherever it is emitted. The GHG content of each product is derived from the LCA method, which intends to take into account the emissions generated throughout the whole cycle of production. However, as mentioned in other surveys, there is a large variability in the values that are used in the reported studies. This is clearly a limitation in the empirical results of all the reported studies. From a

[21] The study by Briggs et al. (2013) provides some quantitative elements. In Scenario A (see 8), the number of DA is 7770, but is reduced to 1207 when adjusting for the change in calories. That is, 85% of the number of DA is due to the change in calories, whereas the remaining is due to the change in the composition of the diet. Moreover, in Scenario B, which leads to an increase in calorie consumption, the number of DA is actually negative. When corrected for the change in calories (Scenario B bis), the impact on health is positive. Irz et al. (2015) also show that most of the health impact is due to a change in caloric intake.

more methodological side, another drawback consists in the lack of integrating some key consequences of modifying the level of production of an ‘activity’.[22] In our case, a major difficulty relates to the change in land use. As exemplified by the case of biofuels, taking into account or not changes in land use is not neutral (Searchinger et al., 2008).[23] In the case of changes in diet, integrating land use changes in the analysis might improve the environmental impact. For example, Westhoek et al. (2014) evaluate the impact of diet changes on GHGE, taking into account or not the change in land use. In their case, any land removed from production is converted in perennial bio-energy crops, which is a favorable option for the land made available. However, their results clearly show that, when changes in land use are taken into account, the reduction in GHGE associated with a change in diet is larger and, sometimes, in significant proportions. More generally, since, in most cases, the recommended diets are more plant-based oriented, it is likely that the demand for land decreases overall. For example, Aleksandrowicz et al. (2016) demonstrate that switching from current diets to healthy guidelines leads to lower land usage (median value: - 20%). As a consequence, it is possible that integrating land use changes in the analysis will improve the climate impact. This is an important aspect that needs to be better assessed in future studies.

Fourth, a frequently ignored issue, is the so-called ’rebound effect’. If consumers modify their diets for any reasons, their food expenditure will be affected. As a consequence, their other expenditures will also be affected, and the GHGE associated to the non-food

[22]The development of the so-called consequential LCA is a way to deal with this type of problem (Zamagni et al., 2012).

[23]In the case of biofuels, taking into account land use changes leads to estimate much lower gains in GHGE from biofuel production. This is because biofuel production induces an increase in the quantity of land used for agriculture, which puts into production areas that were rich in carbon (deforestation for example).

expenditures will also vary. Tukker et al. (2011) integrate this effect and find that it has a limited impact on the results. However, there is room for a better integration of the rebound effect in the economic evaluation of policies.

Overall, this survey points out that there are possibilities to design and provide consumers with the incentives to adopt healthier and more climate friendly diets. However, since food consumption habits change slowly, it is likely that the associated reduction in GHGE will be small as compared to the EU target of reducing GHGE. This endorses the necessity to improve the performance of the production systems in a way that limits GHGE. In other words, one cannot relies only on the change in consumption to tackle the climate change challenge. Similarly, it is interesting to note that, from an health point of view, the content of food products and how to ameliorate it through a reformulation of policies is also crucial to improve the healthiness of diets.

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