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Paying the price for environmentally sustainable and healthy EU diets

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ABSTRACT

We review consumer-side interventions and their effectiveness to support a transition to healthier and more environmentally sustainable diets and identify taxes/subsidies as relevant instruments. To quantify the scope of necessary tax levels to achieve dietary recommendations on EU average, we apply three established economic models. Our business-as-usual food intake projections stress the need for policy intervention to resolve continued divergence from nutrition guidelines. Our findings suggest that food group specific taxes are effective in reaching nutrition and environmental sustainability targets. However, considerable tax levels are required to achieve the targeted consumption shifts, inducing a discussion about alternative policy designs and current model limitations. A coherent policy package is suggested to approach nutrition and sustainability objectives simultaneously.

1. Introduction

Malnutrition is growing across European adults with more than half of the population already being overweight or obese (Marques et al., 2018). Average adherence to dietary recommendations is low (Mertens et al., 2018) and the number of diet-related cardiovascular deaths has increased in the recent past (Meier et al., 2019). Unhealthy diets are one of the main determinants for overweight and related diseases while the intake of important micronutrients is often deficient (Elmadfa and Meyer, 2009).

In the absence of a common European Union (EU) food policy, the Sustainable Development Goals (SDGs) become the effective shared policy commitment at EU level to achieve food security, improve nutrition, and promote sustainable agriculture (SDG2) (Fabbri, 2017). The food system is concerned with further aspects related to social, environmental and economic sustainability (Rutten et al., 2018). The future objectives of the EU Common Agricultural Policy (CAP) overlap with several SDGs (Box 1). Agricultural transformation has great potential to contribute to environmental sustainability objectives as the sector is responsible for 10% of EU overall greenhouse gas (GHG) emissions in 2017 (EEA, 2019) and for reactive nitrogen (N) losses to the biosphere which pose a risk to the quality of air, soil and water (Sutton et al., 2011). Changes in EU dietary patterns will likely have significant implications with respect to achieving several SDGs and thus to contributing to the shared commitment adopted with the 2030 Agenda for Sustainable Development by all United Nations Member States (UN, 2015).

Given the observed gap between recommended and actual intakes in EU member states (Mertens et al., 2018), we focus on the scope for steering diets through consumer policies to support an integrated approach to healthy diets and environmentally sustainable food systems in the EU. The novelty of our approach is to combine the implementation of a dietary target derived from nutritional insights with what is deemed effective given the intervention evidence found in the literature (section 2). We apply three economic models that are able to incorporate the overall socio-economic context and return food system's implications of such diet policies. We enforce two kinds of dietary targets, a healthy dietary pattern and a reduced total calorie intake (section 3). The models solve for the necessary price changes to reach these dietary shifts at EU population level. We discuss the resulting price changes and evaluate these in terms of their efficiency in reaching nutrition and environmental sustainability objectives compared to the business-as-usual (BAU) development without food policy intervention (section 4 and 5).

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2. Effectiveness of interventions for dietary changes

2.1. Literature review and freedom of choice assessment

While there is already an extensive body of literature on how dietary changes may serve health and environmental objectives (e.g. Springmann et al. (2018, 2017); Tilman and Clark (2014); Tukker et al. (2011); Westhoek et al. (2014); Wolf et al. (2011)), these existing modelling studies tend to neglect the discussion about the required instruments. We target our contribution on finding more solid ground for defining policy instruments for the large-scale behavioral change demanded from a future European food policy. Therefore, we place diet policies into perspective of established theories of behavioral change from the public health domain and structure a review of existing evidence on the effectiveness of diet interventions.

Instruments that rank high from a political economy point of view as they allow freedom of choice may not be sufficient in terms of achieving the desired large-scale diet transformation. Griffiths and West (2015) propose a balanced scheme for ranking public health interventions under consideration of their impact on consumption choice autonomy. Interventions can either compromise or enhance (e.g. via information provision) the liberty of the consumer. We extend this scheme by the freedom of supply chain actors to assess the desirability of health-motivated interventions from a food systems perspective, reflecting both demand- and supply-side autonomy (Table 1).

Numerous review studies assess dietary, health and welfare impacts as well as strengths and weaknesses related to different food policy types (e.g. Brambila-Macias et al. (2011); Capacci et al. (2012); Garnett et al. (2015); Hyseni et al. (2017); Mazzocchi (2017); Mozaffarian et al. (2018); Sassi et al. (2009); Thow et al. (2014)). Due to the divergence in study types, variations in policy set-ups and regarding the consideration of substitution and distributional effects, the results of these studies differ and are partly even contradictory.

Mazzocchi (2017) reviews evidence on the effectiveness of different types of health and nutrition policies implemented at national level. While information measures are most prevalent, also school food interventions and more restrictive policies like labelling or bans are increasingly taken up. Hyseni et al. (2017) find that multi-component and price interventions as well as product reformulations appear to be effective policies in terms of stimulating healthier eating patterns and perform better than food labelling or food restrictions.

Darmon and Drewnowski (2015) discover a tendency for healthy diets to be relatively expensive. Economic instruments adjusting food prices based on their contribution to healthy diets could rebalance relative price levels. Brownell et al. (2009) identify imperfect information, time inconsistent preferences and externalities as food consumption related market failures. The occurrence of these market failures can - to a certain extent - justify government intervention and the restriction of agents' freedom of choice. Taxation and subsidization are market-based interventions that can be applied to internalize externalities and to resolve occurring market failures.

Thow et al. (2014) review 38 studies analyzing the effectiveness of taxes and subsidies on food consumption and find a consistent effect on improved intakes in terms of obesity and chronic disease prevention. Nutrition-targeted taxes have become a popular measure in the recent past, due to their comparative effectiveness in influencing consumption behavior (Mazzocchi, 2017).

We summarize the evidence on diet change by intervention in Table 1 based on studies that review the effectiveness of various instrument types. The most preferred options from a freedom of choice perspective show limited impact, while often modelled taxes and subsidies can be effective but risk undesirable substitution effects (Garnett et al., 2015). Some non-price interventions reveal promising effects, however, dependent upon their implementation, the intervention setting, or restricted to a target group. Large-scale impacts of these measures are difficult to gather and long-term effects are rarely investigated. Despite that the assessed interventions target consumers' food consumption behavior directly, they restrict freedom of choice of supply chain actors in nearly all cases. The implementation of consumer interventions affects the producer surplus which can be interpreted as impacts on suppliers in marketing activities, product formulation and in selling their products.

We conclude that taxes and subsidies can be effective instruments to steer diets. Various kinds of food tax modelling studies can be found in the literature. Most of these studies focus on the effects on nutrition and health (e.g. Nnoaham et al. (2009); Springmann et al. (2018); Veerman et al. (2016)). Some studies model the impact of GHG emission taxes on health (Briggs et al., 2013; Springmann et al., 2017). A thorough analysis of impacts on environmental sustainability arising from the implementation of nutritionally motivated financial instruments is so far missing.

2.2. Modelling dietary changes

The spectrum of available modelling instruments to simulate diet interventions is limited. In Table 1 we link typically applied modelling instruments to the discussed interventions. For some interventions, there is insufficient knowledge to model their quantitative relationships. In these cases, the result of the intervention (i.e. the changed diet) is modelled with a 'preference shift'. Preference shifts are usually modelled as costless changes in consumer behavior, which means that the parameters in the demand system are exogenously changed to impose the desired behavior. Preference shifts remain silent on how these changes in behavior can be achieved and ignore the cost of the

Box 1
Proposed objectives of the future CAP overlap with several SDGs.

Selected CAP objectives (European Commission, 2020)	Related SDGs (UN, 2015)
Climate change action	**SDG13** Take urgent action to combat climate change and its impacts
Environmental care	**SDG15** Protect, restore and promote sustainable use of terrestrial ecosystems (…) and halt and reverse land degradation (…)
Preserve landscapes and biodiversity	**SDG15** Protect, restore and promote sustainable use of terrestrial ecosystems (…) and halt biodiversity loss
Protect food and health quality	**SDG2** (…) Achieve food security (…), **SDG3** Ensure healthy lives (…)
Vibrant rural areas	**SDG11** Make human settlements inclusive, safe, resilient and sustainable
Rebalance power in the food chain	**SDG9** (…) Promote inclusive and sustainable industrialization and foster innovation
Ensure fair income	**SDG8** Promote (…) decent work for all, **SDG10** Reduce inequality within and among countries

Table 1
Intervention effectiveness – Evidence of diet change.

Freedom of consumer choice
Freedom of supply chain actor choice

Intervention	Brambila-Macias et al. 2011	Capacci et al. 2012	Garnett et al. 2015	Hyseni et al. 2017	Mazzocchi 2017	Mozaffarian et al. 2018	Sassi et al. 2009	Modelling instruments
Information campaigns/ dietary guidelines	Absent for short-lived interventions, awareness raised	Suggestive, small	Unclear long-term effects, awareness increase	Small effect size, uncertain long-term effects	Strongly effective	Limited overall direct effectiveness	+18.4g V&F	Preference shifters
Compulsory information on products (e.g. labelling)	Uncertain, more promising for simple labels, contributing to informed choice	Mixed	Inconsistent consumer responses	Effective, but interpretation difficulties	Suggestive, slightly effective	Mixed, effectiveness depending on knowledge and attention	+9.9g V&F -0.4% fat%E	
Food advertising regulations	Weakly effective	Suggestive, uncertain long-term	Significant	Appears effective	Suggestive, short-term, effective if comprehensive	Sustained, effective if implemented across formats	+0.4% fat%E	
Ensuring choice availability (e.g. school food programs)	Effective, limited to target group	Suggestive	Positive impacts on diets in intervention setting	Modest to small effect size, uncertain long-term effects	Suggestive, strongly effective in intervention setting	Sustained, effective	+38g V&F -1.6% fat%E	
Financial (dis-) incentives through taxes/ subsidies	Effective, but intrusive and potentially regressive	Suggestive, mixed, uncertain regarding distributional impacts	Combinations of taxes and subsidies effective	Consistently effective, diet change price dependent, substitutions can offset improvements	Suggestive, strongly effective	Effective, most promising as combination of incentives and disincentives	+8.6g V&F -0.8% fat%E	Taxes/ subsidies
Restricting/ eliminating choice	Seems effective, limited evidence	Suggestive	Positive impacts on diets in intervention setting	Appears powerful, but neglected	Suggestive, mixed effects	Promising, but neglected	-	Trade/ production quota

Note: The presented effectiveness statement follows the terminology used in the respective study. We rank policy instruments based on the balanced intervention ladder by Griffiths and West (2015) extended by supply chain actor freedom of choice and review selected literature regarding the evidence of diet change. Related modelling instruments are linked to the interventions. (V&F = vegetables and fruits, fat%E= % as total energy from fat).

measures behind it. Financial incentives are implemented by taxes and subsidies. The hereby targeted behavioral change is achieved endogenously driven by resulting price adjustments. A restriction of product choice in the market could be modelled as production and trade interventions (e.g. quotas) reducing the products available in the market.

In the study at hand, we focus on tax- and subsidy-based instruments to achieve diet changes in line with nutrition recommendations. Our literature review indicates that these instruments can be effective and their model implementation allows to identify the necessary scope of price changes for the envisaged consumption shifts.

3. Methods

3.1. Model approach

We apply three established global economic models to take advantage of individual model strengths in our analysis and to reduce uncertainties inherent to modelling studies. The Common Agricultural Policy Regionalized Impact (CAPRI) modelling system is a comparative-static, partial equilibrium agricultural sector model developed for policy and market impact assessments from global to regional and farm type scale. The modelling system contains a spatial, non-stochastic global multi-commodity model. It is defined by a system of behavioral equations differentiated by commodity and geographical units. Food consumption is derived at country level based on FAO food balance sheets and Eurostat (Britz and Witzke, 2014). Consumer demand is based on generalized Leontief expenditure functions (Ryan and Wales, 1999). Resulting indirect utility functions depend on prices and increase in income. The Global Biosphere Management Model (GLOBIOM) is a partial equilibrium model that covers global agricultural, bioenergy, and forestry sectors (Havlík et al., 2014; Frank et al., 2015). Prices are endogenously determined at the regional level to establish a market equilibrium to reconcile demand, domestic supply and international trade. Land and other resources are allocated to production and processing activities following the objective to maximize the sum of producer and consumer surpluses. The Modular Applied GeNeral Equilibrium Tool (MAGNET) is a multi-regional, multi-sectoral, applied general equilibrium model based on neo-classical microeconomic theory (van Meijl et al., 2006; Woltjer and Kuiper, 2014). The core of MAGNET is an input-output model, which links industries in value added chains from primary goods, over intermediate processing stages, to the final assembly of goods and services for consumption. On the consumption side, a dynamic constant difference of elasticities expenditure function allows for changes in income elasticities in response to changes in model variables (e.g. gross domestic product (GDP)). While MAGNET and CAPRI use the 'Armington (1969) approach' to represent international trade and to differentiate imported from domestically produced products, in GLOBIOM imported and domestic products are assumed homogenous. Further differences between the models exist regarding the definition of consumer prices and the usage of cross-price elasticities.

Technically these models are all able to impose a desired consumption pattern. The implications, however, vary across models. CAPRI and GLOBIOM are partial equilibrium models implying there is no feedback loop from changes in the agri-food system to household incomes and they capture food related household expenditures only. Simulated choices between products are driven by changes in product prices and consumer preferences. MAGNET uses a similar approach but, being a general equilibrium model, total household income is affected by changes in the agri-food system. Furthermore, MAGNET endogenously models non-food expenditures and covers processed food explicitly. In contrast, CAPRI and GLOBIOM express demand for food products in primary equivalents (Appendix A, product mapping of target foods).

3.2. Scenario design

The BAU reference scenario assumes a continuation of the global food system's past development. Among the macro drivers, population and GDP have the most direct impact on consumer decisions simulated in the models. Global population and GDP developments are aligned with the widely used Middle of the Road projections in the Shared Socioeconomic Pathway (SSP2) (see Kc and Lutz (2017); Appendix B). These drivers have a direct effect on consumer purchases, per capita food availability and accessibility. All scenarios are run with global coverage, while the diet intervention is limited to the EU population.

In our model assessment we combine two types of tax scenarios, one focused on food groups and the second on total calorie intake. This way we address concerns on both nutritional adequacy and overweight. The food-based approach is chosen because increasing evidence points out that specific foods have a substantial role in the prevention of chronic diseases (Mozaffarian and Ludwig, 2010). Mertens et al. (2018) show considerable variation in food patterns across four European countries and a low adherence to food based dietary guidelines, with a wide variation regarding dietary patterns within populations. Using population averages for the scenario definition thus has limitations.

For the scenario definition, we focus on three groups of food products which are important markers of diet quality: vegetables and fruits, red and processed meat, and sugar (Mertens et al., 2018). Population adherence to fruit and vegetable intake recommendations of at least 200 g/day is low for Denmark, France and Czech Republic. Mean intakes of red and processed meat exceed the recommended upper limit of 71 g/day for these countries (Mertens et al., 2018). Red and processed meat intakes are related to increased risks of cardiovascular disease, diabetes and colorectal cancer (Ekmekcioglu et al., 2018). In Denmark, Czech Republic and France mean intakes of 108–224 ml/day of sugar sweetened beverages exceed the suggested intake limit of 71 ml/day (Mertens et al., 2018). A reduced sugar intake aligns with the WHO target to reduce obesity by decreasing added sugars, since sugar is related with risks of diabetes and increases in body mass index (BMI) (Singh et al., 2015; WHO, 2000). On EU average about 53% of the adults are overweight (BMI $\geq$25 kg/m^2) of which 16% count as obese (BMI $\geq$30 kg/m^2) in 2014 (Marques et al., 2018). Overweight and obesity are the result of an imbalance between energy intake and energy use for maintenance, growth and physical activity. Due to missing data and model representation we have to ignore physical activity while acknowledging its importance. Working towards a population level policy which is rough by design, we average variations in age, weight, physical activity, and sex. Since we are missing information on the distribution of the BMI among the obese, we approximate a 10% average calorie reduction target based on the energy requirements provided by FAO (2004) in order to reach an average EU BMI below 25 kg/m^2 also among the overweight population groups (Appendix C). Table 2 summarizes the diet scenario specifications. For simplicity we assume a linear implementation over the projection period until 2050. We derive the envisaged food pattern changes based on current divergencies to recommended consumption quantities stated by Mertens et al. (2018). As these food intake recommendations are maximum and minimum suggestions, we accept their potential overfulfillment in the scenarios for some of the countries. The dietary targets are set in a way that they are deemed feasible given past trends in European diets and achievable based on observed current diets of population subgroups. We run the food pattern and total calorie intake changes in a combined mode and perform a sensitivity analysis testing both scenario elements which allows us to disentangle the effects of each component.

We impose these recommended consumption changes to the models and leave the respective prices to be changed endogenously by the models. We interpret the resulting price changes as consumer taxes. However, if the attempt of introducing price shifts to attain these demand changes reaches the feasibility boundaries of the models, an exogenous preference shift is introduced instead for the respective dietary adjustment. This is the case in MAGNET to increase the intake of vegetables and fruits and in CAPRI to achieve the sugar reduction target (Appendix B, supplementary model information).

3.3. Indicators

Food system implications of consumer interventions are investigated on the basis of food demand, expenditure and price changes. To assess nutrition impacts at the food intake level we establish a top-down link between one of the economic models, MAGNET, and the FoodEx2 intake data from three country-level surveys used in the diet model SHARP (Mertens et al., 2017). The other two economic models have not been linked to the intake data due to their different food representation in primary equivalents and as the FoodEx2 data do not contain recipe information on primary content of products needed to connect the databases. MAGNET does capture processing of food in a very aggregate manner, while the intake surveys register food items at a high level of detail. We thus define the best possible match of products between the aggregate food categories of MAGNET to the 955 FoodEx2 consumer products (including processed products with mixed ingredients) in the SHARP database (Mertens et al., 2019) with an obvious loss of detail at

Table 2
Diet scenario specification for EU average intakes based on recommended % consumption change in 2050 relative to 2010.

Diet target	%-change	Scenario	Sensitivity scenarios
Vegetables & fruits (V&F)	+100	Food pattern & BMI<25	Food pattern
Red & processed meat (REM)	-50		
Sugar (SUG)	-50		
Total calories	-10		BMI<25

Note: Total calorie intake is not fixed in sensitivity scenario 'Food pattern'.

the macro level. The economic models refer to food demand based on average food availability. Despite a deduction of food losses, inedible parts and approximate food waste shares, a divergence between the available food and its actual intake remains (see Appendix B for further details). Given these considerations we rely on the economic models for changes in environmental sustainability, production, demand and trade, while exploiting the actual intake data in the MAGNET-SHARP database link to get a more precise assessment of nutrition metrics. To assess the nutrition improvement arising from these consumption changes, we calculate the Nutrient Rich Diet score based on 9 qualifying and 3 disqualifying nutrients (NRD9.3) following the approach used by van Kernebeek et al. (2014) with a score of 1 representing complete adherence to nutrient recommendations. Demand changes following from the scenario implementations are provided by MAGNET to the SHARP database. Based on the developed product mapping, these changes are translated to the differentiated product range in the SHARP database to derive the nutrient indicator for each scenario at country level. It should be noted that the SHARP database currently only covers three EU member states and has no coverage outside the EU. In order to assess environmental sustainability, we compare the resulting changes in non-CO_2 GHG emissions from agricultural production and trade in the EU and the rest of the world. In addition, we compare N fertilizer application amounts and N surpluses across scenarios.

4. Results

4.1. Food demand, expenditure and nutrition

EU average GDP per capita is projected to grow by about 75% until 2050 in comparison to 2010 levels in the BAU scenario. EU members with below EU average incomes in 2010 are projected to slowly converge towards Western European income levels, reflected in higher per capita growth rates. The income increase in the EU does not imply an equally strong increase in food expenditures.

EU household food expenditures do not change strongly in the BAU scenario from 2010 to 2050 (USD/cap/day +0.5 in CAPRI, -0.01 in GLOBIOM, +0.2 in MAGNET) due to low price and income elasticities. The diet scenarios show an increase in EU household food expenditures. As presented in Fig. 1 achieving two changes simultaneously, diet pattern and total calorie reduction, induces a strong increase in EU average food expenditures (USD/cap/day +20 in CAPRI, +3.3 in GLOBIOM, +6.5 in MAGNET compared to BAU 2050). CAPRI reacts with a stronger increase towards the various simultaneous constraints which exceeds the sum of expenditure increases of each scenario component as shown in the sensitivity analysis. Rising expenditures raise concerns with respect to the affordability of food. Food, however, is only a minor part (11% in 2017) in the average EU household budget (Eurostat, 2019) and this share is expected to decrease further. In the absence of any diet specific intervention (BAU) the share of food in total expenditures is projected to nearly halve by 2050 driven by expected EU GDP growth and population decline raising per capita income. Enforcing the shifts towards recommended diet patterns increases food expenditures as expected, but the share of household budget needed for food remains moderate (up to 12.4% across models and scenarios) as household income is projected to rise much stronger over time.

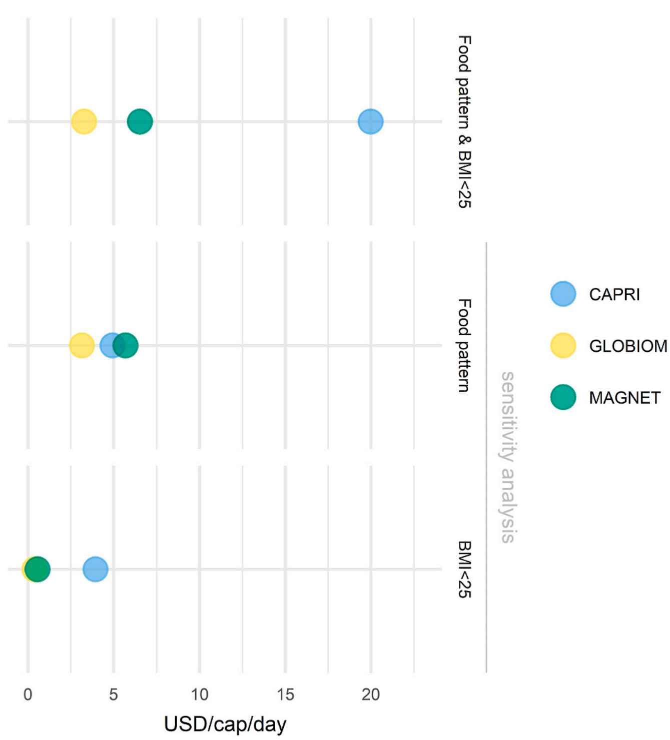

Fig. 1. Absolute change in EU food expenditure in USD/cap/day compared to the business-as-usual in 2050.

For red and processed meat, a consistent increase of average EU household purchases is projected until 2050 without dietary policy intervention (Fig. 2). The average EU demand for vegetables and fruits declines slightly. The projected sugar consumption is more divergent across models with both increases and decreases projected.

We observe considerable differences in the BAU projections regarding per capita consumption developments of the target food groups across models and EU member states. Moreover, calorie accounting diverges between models given differences in product representation, underlying data sources, model calibration and post-model processing (Appendix B). Despite the differences, all models support the conclusion that without interventions directed at consumer purchases and dietary habits, the EU will miss the dietary recommendations on average in 2050 and even deteriorate compared to 2010 (Fig. 2).

The dietary targets are implemented on EU average level. On member state level this results in diverging consumption impacts (Appendix B, D Fig. A1). A consumption shift to non-targeted substitute foods is moderate in MAGNET. The scope of substitutions is limited in GLOBIOM as cross-price elasticities are not captured. CAPRI results project strong substitutions with increases in poultry meat consumption resulting from the price increase in red meat. Considerable price changes are required to achieve the calorie intake reduction and the food pattern shifts as shown for the target food products in Fig. 3. Tax rates of up to several thousand percent for sugar, and red and processed meat are necessary to move consumption 50% away from simulated 2010 consumption quantities in the price- and elasticity-driven modelling systems. For example, assuming a sugar consumer price of 0.8 USD/kg, a tax of 1500% would result in a new consumer price of 12.8 USD/kg. The sensitivity analysis shows that the BMI<25 scenario alone allows the models some leeway to reach the calorie reduction target and that the price increase is largely driven by the taxes on the target food groups.

Moreover, the improvements in nutritional quality represented by the NRD9.3 follow largely from food group specific taxes across the three assessed EU member states (Fig. 4). The reached nutrition scores lie close to the upper boundary of the range of nutritional differences currently observed within these populations and thus imply a considerable improvement of nutritional quality if achieved by population average (Table A3, Appendix B). The simulated tax on total calories alone does not achieve substantial nutrition advances according to the model results, nor does it add additional achievements in the combined tax scenario. Despite the enforcement of recommended dietary targets no perfect score is reached. This is largely due to the top-down MAGNET-SHARP linking, where consumer responses are modelled in MAGNET for 17 aggregate food sectors and then mapped to the 955 FoodEx2 categories. Lacking consumer responses to price and income changes at the FoodEx2 product level, there is no scope for substitution at this finer level which is expected to yield a

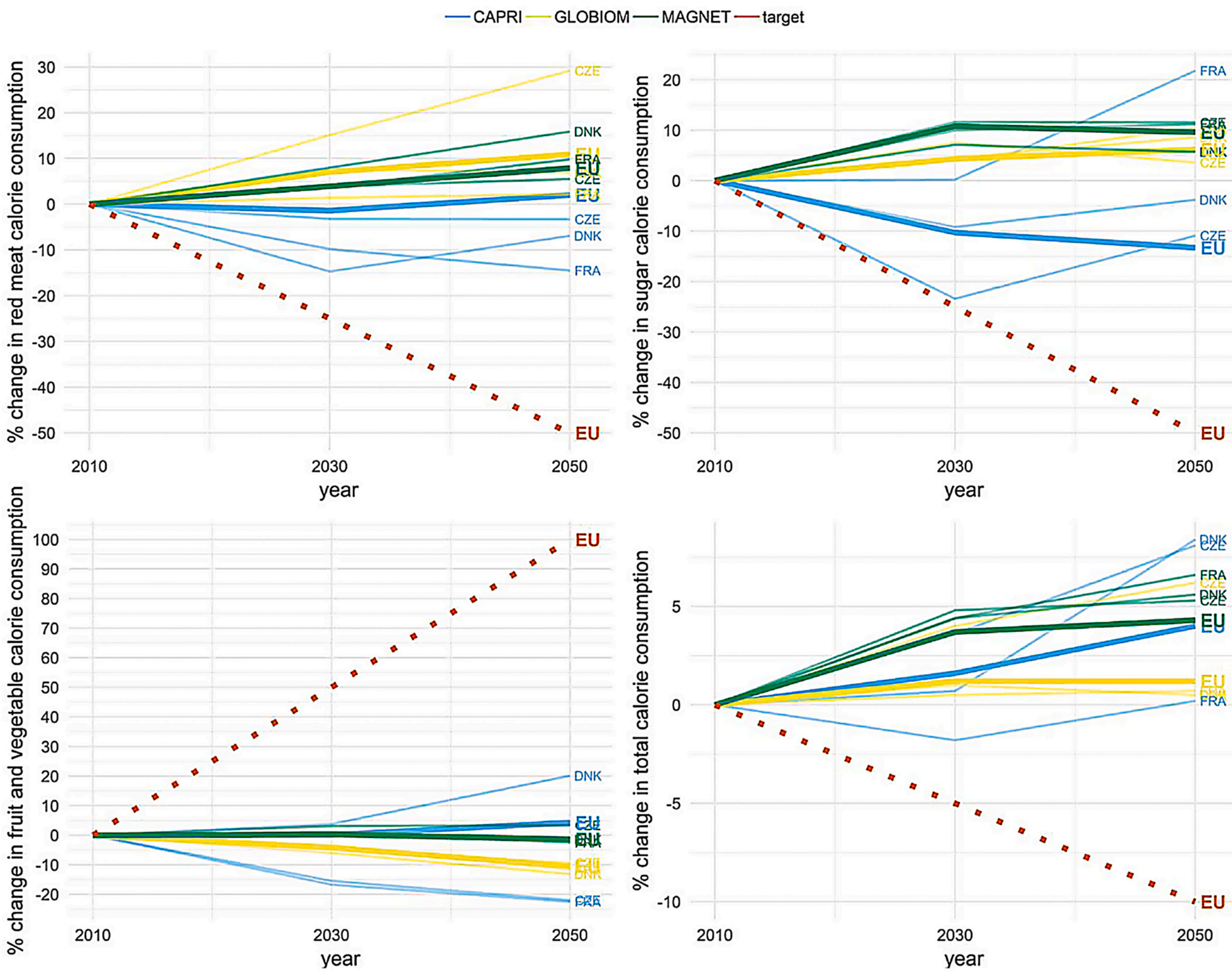

Fig. 2. Percentage consumption changes in the business-as-usual for 2030 and 2050 relative to 2010. Note: Projections are displayed for the EU average and three EU member states (France (FRA), Czech Republic (CZE), Denmark (DNK)).

larger change in nutrient intake due to the broad variety of products associated with a single MAGNET sector. As part of the sensitivity analysis, total calorie intake reduction to achieve a decline in overweight prevalence is enforced separately in the BMI<25 scenario. The results show that without this explicit target, the food pattern adjustment alone (Sensitivity scenario Food pattern) only reduces total calorie intake in one of three model projections (%-change in total calorie intake +10 in CAPRI, -7 in GLOBIOM, +7 in MAGNET in the food pattern scenario).

4.2. Environmental sustainability impacts

In 2011 the European Commission released a roadmap towards a low carbon economy proposing potential reductions of agricultural GHG emissions by up to 49% until 2050 compared to 1990 emission levels which is equivalent to a reduction of about 267 Mt CO_2eq (European Commission, 2011). In 2018, the European Commission even increased its ambitions aiming for a climate neutral economy in 2050 (European Commission, 2018). Between 1990 and 2017, 20% of EU agricultural GHG emissions could be reduced (EEA, 2019). However, since 2011 EU agricultural emissions have been increasing by 3.6% until 2017 (EEA, 2019).

GLOBIOM and MAGNET model results show a substantial decline in EU agricultural non-CO_2 GHG emissions if the diet taxes are applied. EU emission savings arise dominantly in the livestock sector. The reductions appear to be comparatively small in the CAPRI results. The comparison to agricultural emission savings in the rest of the world (Fig. 5) reveals that strong emission reductions are suggested by CAPRI as well, only that these occur mostly in non-EU regions. These differences are reflected in agricultural production and trade pattern changes and are due to different trade responsiveness between models. Therefore, also N surpluses occurring from EU agricultural production are reduced only marginally as consequence of the diet scenarios in CAPRI. Fertilizer application is hardly affected in the CAPRI projection, whereas the decline in agricultural production goes in line with a strong reduction of

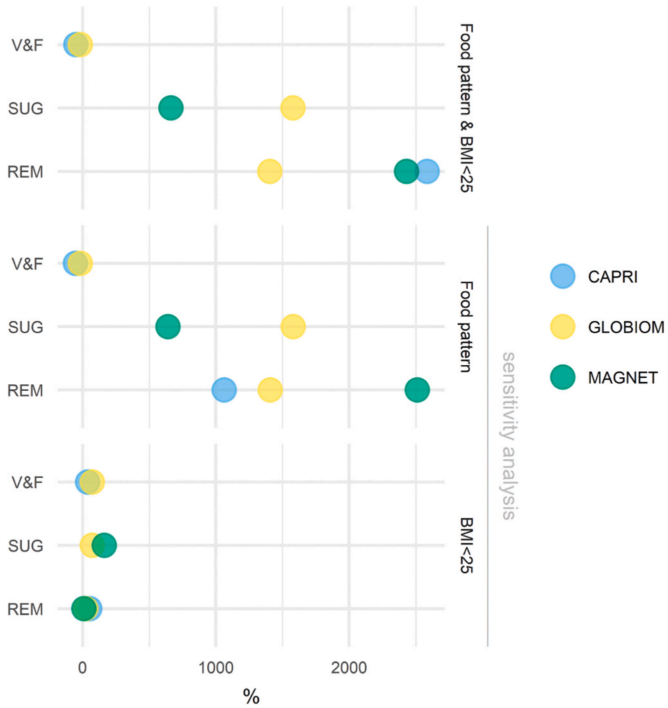

Fig. 3. EU consumer tax rates (%) for targeted food products in 2050. Note: Required subsidies to double vegetable and fruit (V&F) intake are comparably moderate, while consumer prices would need to increase strongly to halve red and processed meat (REM) and sugar (SUG) demand or to reduce total calorie demand on top.

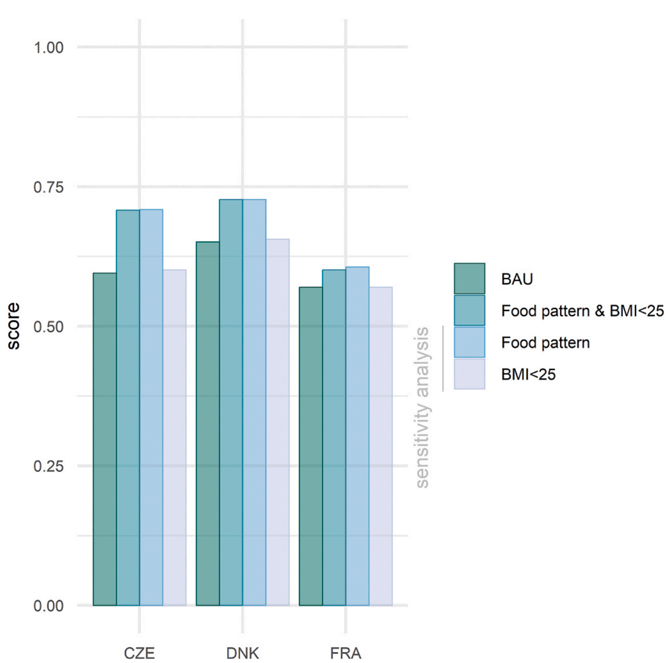

Fig. 4. NRD9.3 for three EU member states (Czech Republic (CZE), Denmark (DNK), France (FRA)) in 2050 based on MAGNET-SHARP. Note: BAU = Business-as-usual.

N fertilizer usage according to GLOBIOM (see Appendix F for further details). Disentangling the tax effects by sensitivity scenarios reveals that reducing total calorie intake alone (BMI<25) causes comparably small reductions in related environmental impacts.

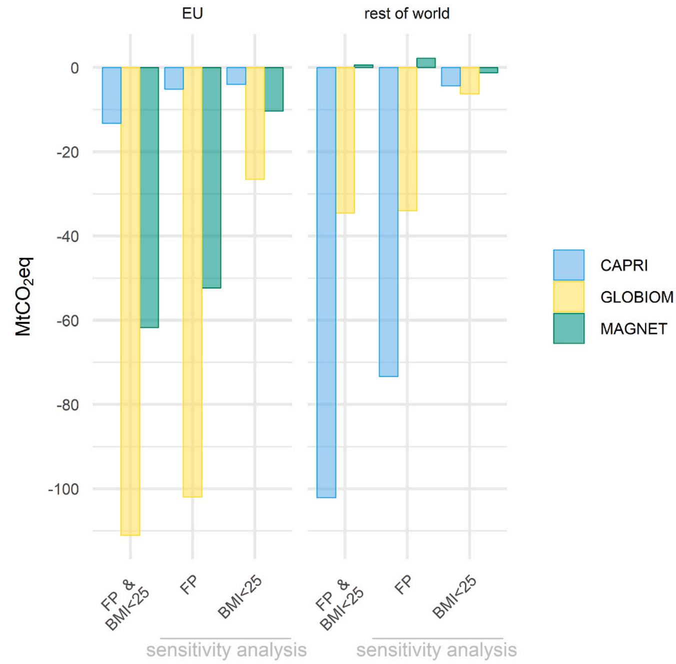

Fig. 5. Absolute change in non-CO_2 greenhouse gas emissions from agricultural production in the EU and in the rest of the world compared to the business-as-usual in 2050. Note: FP = Food pattern.

The drastic consumption changes we enforce to follow dietary guidelines on EU average imply diverse consequences for EU agricultural production in the models. In MAGNET, the EU demand change translates to a domestic production adjustment. A similar observation is made for the CAPRI results, but the effects are much smaller due to the aforementioned stronger trade response. Agricultural production in GLOBIOM decreases strongly for commodities directly affected by taxes. The production of vegetables and fruits however also decreases slightly in GLOBIOM despite the doubling of domestic consumer demand for this food group. This decrease is driven by reduced production of roots and tubers being part of this category which are largely used for animal feed and decline in line with decreasing livestock production. This is also reflected in the slightly decreasing EU imports of vegetables and fruits in the GLOBIOM results.

Despite this exemption, similar import changes occur across models. Products for which EU demand drops are imported less, while imports of vegetables and fruits increase. Strongly increasing exports of red meat in the food pattern scenarios explain that emission reductions occur in EU trading partner countries in the CAPRI results. Emission reductions are in that sense “exported”.

In summary, strong demand reductions for sugar, and red and processed meat affect the respective producers of these products - either in the EU or in countries that are increasingly importing European products. A combination of a general calorie tax and specific food group taxes does not improve nutrition considerably more than the food pattern intervention alone, while emissions are reduced slightly more. The impacts on most indicators are not found to be strictly additive when imposing the food pattern and total calorie changes jointly as these are presenting additional constraints to our non-linear models.

5. Discussion and conclusions

The objective of this research was to apply a multi-modelling approach in order to determine the required level of consumer taxes and subsidies to steer recommended dietary shifts and to compare their effectiveness in contributing to EU nutrition and environmental sustainability objectives. Our findings show that food group taxes contribute effectively to these objectives. Total calorie intake reduction does not automatically end up in a more balanced diet since calories are reduced where it is cheapest in the applied models. Even with food group targets though, we do not perfectly hit the nutrition objectives by 2050. In part this is due to limitations of the top-down linking in this application, as discussed above. More generally, micro-managing nutrient intake (by consumers or governments) may be challenging with nutrients being supplied in varying combinations through a wide variety of products. Also, care needs to be taken that changes in targeted food groups are balanced in their nutritional implications. Despite that overconsumption of certain foods represents a health risk, moderate intake amounts can be a source of valuable nutrients like protein and iron in the case of red meat.

High taxes are imposed to achieve substantial changes in food purchases and these may push the models beyond the range of validity of their implemented consumer price responsiveness. The price elasticities are estimated based on observed data (for further details see Appendix B). The large-scale diet shift, however, deviates strongly from the model calibration points and likely implies too rigid model behavior. Therefore, the resulting tax levels should be interpreted with caution, focusing rather on the order of magnitude than on the exact values. Nevertheless, also Springmann et al. (2018) find that a price change of more than 100% is needed in high-income countries to reduce processed meat intake by 25%. Whether in reality comparably high tax rates would be necessary to reach substantial demand changes remains speculative as validated price elasticities for this size of demand shift are missing. Changes in preferences and substitution behavior towards vegetarian diets would likely require less drastic price incentives. Increased awareness due to the implementation of the fiscal diet interventions may increase consumer response beyond the elasticities in the current modelling analysis. Overall, the effectiveness of non-price interventions at large scale is difficult to measure as the literature review in Table 1 suggests. Further research on the interactions of price and non-price measures is needed. Still, our results indicate that likely more ambitious interventions are required to reach nutrition and sustainability objectives than those often under public discussion.

High tax rates as suggested by the model simulations raise concerns regarding the intervention design. Alternative to our approach, a budget-neutral tax design could be chosen balancing subsidies and taxes in a way that consumers following a healthy diet are not worse off (e.g. Briggs et al. (2013)). Also, a redistribution of tax revenues via income-dependent or lump-sum transfers like recurrently discussed and partly implemented for carbon taxes (e.g. Carattini et al. (2018); Klenert and Mattauch (2016)) could be an option to reduce social equity concerns. The models rely on a single representative consumer for each country or region and thus cannot address the food accessibility of poor subgroups in the population. Additional assessments using micro level data would be needed to address these distributional issues, while also taking differences in diets and thus exposure to diet-related health risks into account.

In our scenario design broad food group diet targets are defined as percentage changes and implemented at EU level. As dietary patterns and obesity rates diverge also between countries, a uniform relative diet target across EU member states might not be the most efficient way to achieve healthy diets on a regional level as some countries could do with less stringent targets if their current diet is healthier than the EU average.

Reducing total calorie intake alone does not go along with decreased demand for the most emission intensive products. The food pattern taxes though clearly promise a contribution to reducing agricultural GHG emissions - either directly from EU production or from reduced production in trading partner countries. It should be noted that strong consumer price changes might affect food waste behavior and thus the intake share of products purchased. This could result in further environmental benefits which are not accounted for in the present study.

Model results differ with respect to whether EU producers or producers in trading partner countries would be affected mostly. Opportunities for increasing profitability may arise by focusing more on quality, extensive production, and animal welfare standards (Dawkins, 2017). Fiscal incentives may also initiate product reformulations in the food industry and thus change the product line offered to consumers (Vandevijvere and Vanderlee, 2019).

The size of the envisaged shifts towards healthy diets is well beyond the reported order of magnitude of diet changes from any single intervention in our literature review. Acknowledging the previously mentioned modelling limitations, it nevertheless appears that monetary instruments alone will not suffice in order to reach nutrition and sustainability objectives. Complementary measures able to change behavior of large consumer groups are needed alongside price signals. These could be a mix of the non-fiscal interventions contrasted in Table 1 like information campaigns, product labelling or target group specific interventions to increase awareness, acceptability and willingness of consumers to change to sustainable and healthy diets. Future research could reveal further insights into how large and persistent dietary changes can be achieved at population level. Supply side measures targeted at producers and the entire value chain are required in addition to further push food production towards environmental sustainability goals within the EU. A coherent policy package incentivizing the consumption, production and trade of certain foods identified beneficial should be designed to reach nutrition and sustainability objectives simultaneously and thereby restricting freedom of choice to the least possible extent.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Product mapping

The product mapping for groups of food products targeted in the diet scenarios by model is provided in the online supplementary material.

Appendix B. Supplementary model information

Additional information on the baseline scenario construction and model details are provided in the online supplementary material.

Appendix C. Calorie reduction target calculation

Additional information on the calculation of the 10%-reduction target for EU calorie intake in the scenario design are provided in the online supplementary material.

Appendix D. Meat consumption changes

Figure A1 "Percentage consumption changes for red and processed meat in EU member states relative to the business-as-usual scenario in 2010" is provided in the online supplementary material.

Appendix E. Supplementary data description

The description of the supplementary data provided with this article can be found in the online supplementary material.

Appendix F. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2020.100437.

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