# Improved food intake in OECD countries as a key global climate mitigation driver

**Bruno S. L. Cunha**[1], Angelo Gurgel[2], Rafael Garaffa[1,3]

*[1] Graduate School of Engineering, Universidade Federal do Rio de Janeiro (COPPE/UFRJ), Brazil*

*[2] Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology (MIT), USA*

*[3] Joint Research Centre – European Commission (JRC-Seville), Spain*



## Abstract

There is more evidence than ever before that food systems are intimately connected to major contemporary global challenges, from malnutrition to climate change. Food systems are struggling to deliver nutritious diets equitably, but became key drivers of environmental change. A food system transformation that operates within planetary boundaries towards healthy, culturally appropriate, and available diets for all requires an urgent shift in mindset to recognize the importance of consumers' choices to meet the United Nations Sustainable Development Goals (SDGs) targets for the coming decade. Healthy diets emerge as a solution both to human and planet health. To address these issues, we use a computable general equilibrium model (CGE) to explore how a voluntary improved food intake in OECD countries contributes to global greenhouse gas (GHG) emissions reduction. The mitigating role of behavioral changes and the effects of ambitious market-based climate policy are assessed by comparing future scenarios. A climate-related cost of the global food system provides crucial information for effective governance and policy design. We highlight the opportunity cost of the refusal to an improved food intake in OECD countries.

**Keywords**: climate mitigation, computable general equilibrium, behavioural changes, climate policy

## Introduction

Global food systems are struggling to deliver nutritious diets in an equitable manner[1]. Growing population, accelerating migration to cities, transitions in dietary habits to more processed and animal-source based foods, and land-use and environmental change are putting the food system under ever-increasing pressure. Transforming food systems that operate within planetary boundaries towards healthy, culturally appropriate and available diets for all is one of the greatest health and environmental challenges of the 21st century[2,3]. This transformation requires an urgent shift in mindset to recognize the importance of consumers' choices and of the agricultural sector production to meet the United Nations Sustainable Development Goals (SDGs)[4] targets for the coming decade set in the Paris Climate Agreement[5].

The concept of healthy diets gained importance in the debate, especially in relation to the trade-offs between plant- and animal-based foods[2,6,7]. A healthy diet ensures the needed macronutrients and essential micronutrients to each specific gender, age, physical activity level and physiological state, comprising diversity within and across food groups, adequacy compared with requirements, moderation and overall balance[8,9]. A growing number of countries have established national food-based dietary guidelines, with dietary recommendations that are appropriate for their unique contexts[10]. In 2019, the

EAT-Lancet Commission[1] launched what is referred to as the "EAT-Lancet reference diet", which quantitatively describes the first attempt to set universal scientific targets for the food system, based on an increase in consumption of nutritious foods (such as vegetables, fruits, whole grains, legumes and nuts), and a decrease in consumption of energy-dense foods (such as red meat, sugar and refined grains) that would provide major health benefits, while also defining sustainable food systems that minimize damage to our planet[2].

Agricultural products are essential for global food security and for the reduction of poverty and hunger, being a primary source of income for many people in developing regions. Although global production of food calories has kept pace with population growth, more than 820 million people have insufficient access to food and many more consume low-quality diets[2,11,12]. Food-system science, policy and action continue to be largely pursued as local or regional concerns, despite diet's role as a global syndemic driver[13]. Consumers can and must act as agents of change in their roles as citizens and influence the societal norms and institutional policies for the betterment of society.

To address these issues, we explore how an improved food intake in OECD countries sit alongside a climate policy in terms of greenhouse gas (GHG) emissions reduction. Improved food intake means a voluntary rebalancing in consumers' preferences between animal- and plant-based foods, in order to enhancing health and lowering social and environmental impacts. A climate-related cost of the global food system provides crucial information for effective governance and policy design. We use a computable general equilibrium (CGE) model to explore the mitigation role of behaviour changes and ambitious market-based climate policy in future climate scenarios, highlighting the opportunity cost of the refusal to an improved food intake in OECD countries.

## Climate Change, Health and the Need of Improving Food Intake

Since 1990, global GHG emissions from food systems have been roughly stable (less than 1% p.y. growth), reflecting increased agricultural productivity and intensification efforts, which helped decreasing emission intensity per unit of product[2,14]. Global food systems are currently responsible for 21-37% of total anthropogenic GHG emissions[15,16]. During the period 2007-2016, agriculture land-use change, synthetic fertilizers, enteric fermentation and manure left on pasture accounted for 75% of food systems GHG emissions[14,15,17,18], with the last two directly associated to the production of ruminants.

Livestock constitutes 40-50% of total agricultural revenues by price, and the production, processing and retailing of meat is an important economic activity in many countries[19]. The sector contributes to the livelihoods of one billion of the poorest population in the world, employs close to 1.1 billion people and provides 17% of global food-caloric consumption and 33% of global protein consumption[20]. For this reason, livestock producers have considerable political power and allocate large amounts of money to advocacy, advertising and marketing. However, meat production is the single most important direct emitter of methane ($CH_4$)[2] and is commonly associated with environmental impacts such as deforestation, which releases additional carbon dioxide ($CO_2$) into the atmosphere, and biodiversity destruction, especially in tropical regions[2,20–24]. Due to the biological inefficiencies inherent to feed conversion, animal

[1] The EAT-Lancet Commission consists of 37 world-leading scientists from 16 countries from various scientific disciplines. It seeks to reach scientific consensus on targets for healthy diets and sustainable food production.
[2] Methane is produced during digestion in ruminant livestock, such as cows and sheep (enteric fermentation).

products have been described as the electricity of food[25,26], contributing with 5-8% of the total annual anthropogenic GHG emissions globally[15,27]. In terms of temperature impact, the livestock sector accounts for around 23% of global warming[28,29] and its share on future emissions will depend most on actions to reduce emissions elsewhere, as well as by its own effort[30].

Even though the environmental burden from food systems is widely known[6], current research tends to focus on technological improvements related to agricultural productivity, while not necessarily considering human health and environmental consequences[31]. Low-quality diets cause micronutrient deficiencies and contribute to a substantial rise in the incidence of diet-related obesity and diet-related disease mortality[2,12]. Besides, the Green Revolution[3] expanded the use of land, water and chemical inputs for agricultural purposes, direct or indirectly related to food security and international trade. Food intake inextricably links human health and environmental sustainability[2,13].

The global average per capita meat consumption and the total amount of meat consumed are rising[32,33]. OECD regions respond by high levels of meat consumption and animal-based protein per capita (Figure 1). As a key component of the current worldwide dietary transition, meat has a special status in many societies, is one of the most popular food products, and is generally perceived as a healthy choice[34–36]. In fact, meat is an important source of energy, protein and certain essential micronutrients, including iron, B-complex vitamins, zinc and vitamin A – although it is possible to obtain a sufficient intake of these nutrients with fewer meat products by consuming a wider variety of other foods[2,32,37]. At the same time, the meat consumption in excess provides more nutrients than human needs, such as saturated fat, a major cause of heart disease and stroke[2,38–40]. Diets with high meat content have been associated with a wide range of health consequences including obesity, type 2 diabetes, cardiovascular disease, and some types of cancer[41–46]. Hence, meat provides a concentrated package of "positive" and "negative" nutrients, so that when addressing dietary patterns, the risks and benefits to health related to animal-based foods need to be balanced.



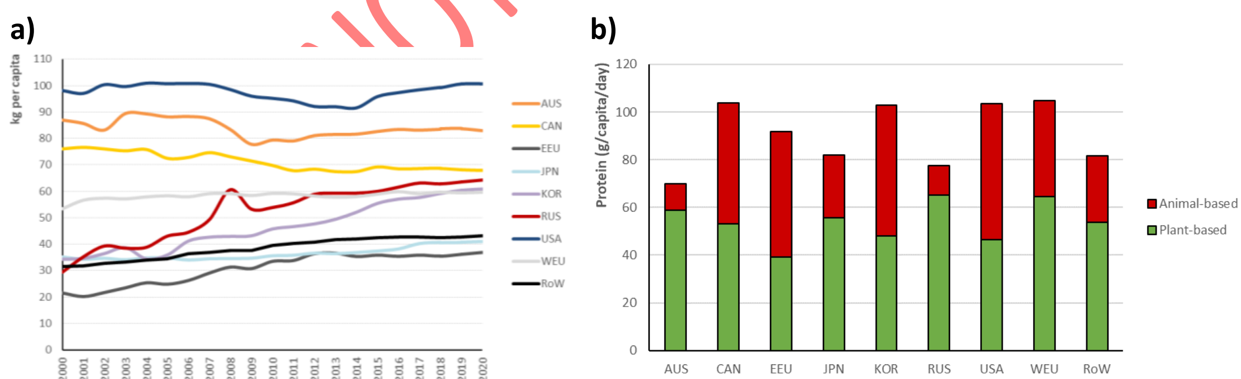


**Figure 1: a) Meat consumption (kg per capita) in OECD regions and the rest of the world (RoW)[33]; b) Plant- and animal-based food in terms of protein content (g/capita/day) in OECD regions and the rest of the world (RoW)[47]**

Studies have suggested that the rise in wealth will lead to an increase in meat consumption by around 100% between 2005 and 2050[32,48]. Valin et al. (2014)[49] suggested that growth in the demand for livestock products would increase 62-144% by the mid-century, and a major review by the FAO/UN projects an

[3] Higher agricultural productivity of staple grains, increased use of inorganic fertilizers and pesticides, improved irrigation facilities, and genetic component of traditional crops.

increase of 76% in the total quantity of meat consumed during that same period[50]. The "Livestock Revolution"[51] is nowadays found in developing countries due to dietary changes towards more animal-based foods caused by income growth, agricultural land expansion, and cultural factors[17,52]. However, high-income countries have contributed the most to historic emissions and there is an urgent need for behavior transformation in line with environmental concerns, like recent sufficiency approaches[53,54].

By doubling worldwide meat production, GHG emissions from food systems are expected to increase up by mid-century[55] and could take up to half of the total emissions budgeted to stabilize global warming to "well-below" 2°C by the end of century[39,56–58]. Recent studies concluded that while undernourished people could actually eat a little more meat and dairy, the average world citizen should substantially reduce exceeded meat consumption (approximately 50% global cut until mid-century) while shifting toward mostly plant-based dietary patterns[2,15,39,58,59]. In the context of healthy diets and sustainable foods, the worldwide EAT-Lancet reference diet recommends cuts in animal-based food consumption[2] in order to reduce GHG emissions in the global food system. The combination of potency and duration makes reduction of the rate of $CH_4$ emissions a relatively quick way of contributing to climate goals[60–62]. Key traits position a peak livestock within the next decade as an attractive option for both achieving long-term GHG reduction goals and avoiding near term global temperature rise[29,63].



## Methodology

We use a computable general equilibrium (CGE) model that represents the global food system to assess the interaction among food security, climate policies and economic impacts. CGE models track the production and distribution of goods, capturing industry-to-industry linkages, and are useful for support policies. The Total-Economy Assessment (TEA)[64] is a global-scale economic model based on general equilibrium theory. The baseline model parameters are calibrated on the basis of social accounting matrices for the base year (GTAP9 Data Base)[65], then updated every period according to GDP and population projections. Calculations are conducted at five-year intervals recursively from the base year (2011) until mid-century. The TEA model can run on a stand-alone basis or soft-linked with the COFFEE (COmputable Framework For Energy and the Environment) model[66], a partial equilibrium bottom-up model, that provides detailed energy and land-use information.

The TEA model represents eighteen regions that emphasize developing countries or economic groups with possible energy and environmental importance in the long run. In our analysis, these regions are aggregated as follows, according to their relevance:

- OECD Countries: Australia & New Zealand, Canada, European Union, Japan, Rest of Europe, Russia, South Korea and USA.
- Rest of the World: Africa (excluding South Africa), Brazil, Caspian Region, Central America, China, India, Middle East, Rest of Asia and Oceania, South Africa and South America (excluding Brazil).

The economic activity is characterized in each region by twenty sectors, including a detailed representation of energy supply and demand, as well as flexibility in the possibilities of substitution between energy sources, mainly in the power sector. In addition, TEA explicitly represents the food production and land use system, which includes the agricultural and livestock sectors, as well as plant- and animal-based food industries. Production in each sector is represented with multi-level nested production functions, which use intermediate goods, labor, capital, land and energy as input. Consumer's preferences (household sector) are expressed by a utility function. Firms maximize their profits and the household sector maximizes its welfare (utility) under budget constraints. International trade, taxes and capital formation/depreciation are also considered in the model.

The scenarios are designed to assess the mitigating role of behavioral changes and the effects of ambitious climate policy. Two kinds of policies are tested: (i) improved food intake condition (quantity) and (ii) carbon pricing (relative prices). To quantify these effects in climate mitigation, we develop a set of four scenarios: one improved food intake condition for OECD countries (OECD_Diet), two carbon budgets scenarios to keep global temperature well-below 2°C, and a baseline scenario (BASE) that assumes current trends. Table 1 presents a summary of the scenarios.

**Table 1: Summary of the scenarios**

| | **Scenario description** |
|---|---|
| **BASE** | Socio-economic drivers from SSP2 storyline. Without carbon budget restriction. |
| **OECD_Diet** | Socio-economic drivers from SSP2 storyline. Without carbon budget restriction. More healthy and sustainable food consumption patterns in OECD countries according to the reference diet targeted in 2050 by the EAT-Lancet Commission. |
| **WB2C_1000** | Stabilization of global average temperature in well-below 2°C by 2100. 1000 $GtCO_2$ of global carbon budget restriction. Market-related climate policy: global cap-and-trade for energy-related $CO_2$ emissions; agricultural non-$CO_2$ emissions pricing mechanism. |
| **WB2C_600** | Stabilization of global average temperature in well-below 2°C by 2100. 600 $GtCO_2$ of global carbon budget restriction. Market-related climate policy: global cap-and-trade for energy-related $CO_2$ emissions; agricultural non-$CO_2$ emissions pricing mechanism. |

The macroeconomic drivers used in BASE scenario follow the Shared Socioeconomic Pathway 2 (SSP2) storyline that describes the 'middle of the road' pathway to address the uncertainty of socio-economic conditions[67]. In SSP2, the global population reaches 9.3 billion by 2050[68], an increase of 35% relative to 2010, and global GDP triples[69]. The food demand is based on projected regional growth factors for available food.

Voluntary changes in the preference structure of individuals, leading to a global plant-rich diet and more healthy and sustainable consumption patterns, constitutes one type of sufficiency[53,70]. Changes in the demand-side of the food equation may occur due to cultural changes or social tipping points[71] about what constitutes well-being, based on moral considerations and a sense of responsibility. To address these issues, we increase plant-based food preferences in OECD countries. The improved food intake condition is a variant of the BASE scenario, therefore, without restrictions on emissions, but including a voluntary rebalancing in OECD consumers' preferences between animal- and plant-based foods. All improving food intake consider a nutritionally sound protein equivalent plant-based food replacement of animal source foods, according to the EAT-Lancet reference diet[2]. Figure 2 shows the protein consumption gap in OECD countries in the base year compared with the reference diet.

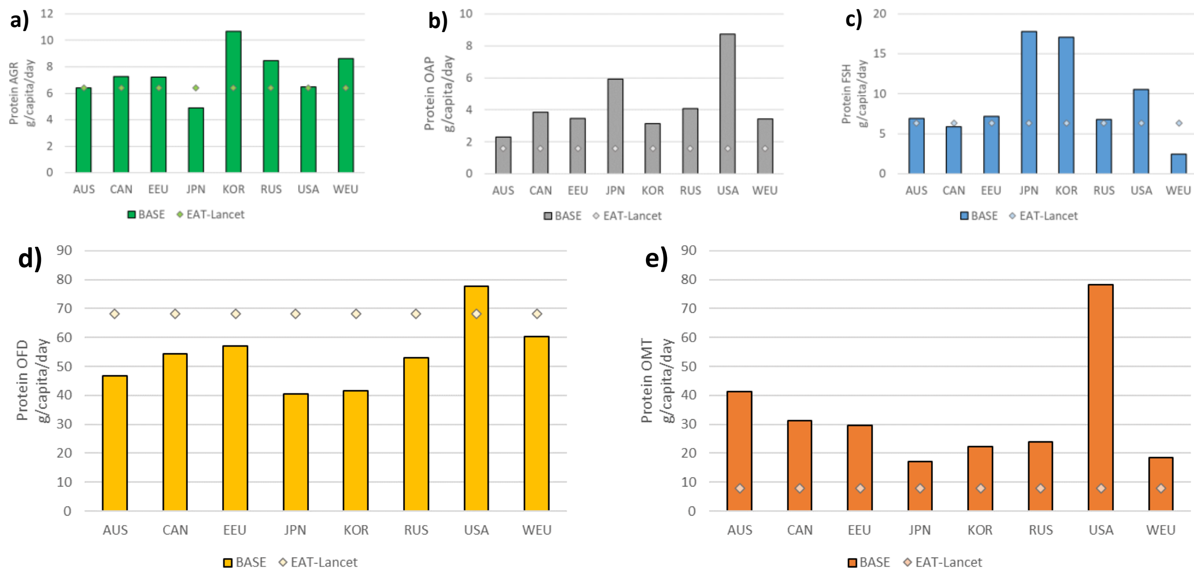


**Figure 2: Protein consumption gap for a) agricultural products, fruits & vegetables (AGR), b) eggs & milk (OAP), c) fish products (FSH), d) plant-based food products (OFD) and e) animal-based food products (OMT) in OECD countries**

The regional and gradual changes in food preferences were defined according to the difference between the OECD average protein consumption from animal- and plant-based food (in the BASE scenario) and the protein consumption targeted by the EAT-Lancet reference diet for the year 2050. The idea behind this scenario is to analyze what is the mitigating role of voluntary modification of individual preferences motivated by environmental concerns, not induced by market prices, and the economic effects of increased adoption of plant-rich diets in OECD countries from 2020-2050.

Shaping human behavior is one of the most challenging aspects of policy design. Economic theory suggests that comprehensive carbon pricing is the most efficient instrument to reach ambitious climate targets[72,73]. Market prices should reflect their actual societal costs (internalization of environmental externalities, such as pollution), as only then do markets lead to a socially optimal allocation of goods and services[74,75] If we assume that a large-scale sufficiency will not happen voluntarily without incentives, especially related to dietary change[56,61], a global carbon price associated with livestock's GHG emissions could increase the cost of methane emissions and provide economic benefits for environmentally friendly consumption. In fact, carbon pricing incentivizes consumers and producers to reassess their behavior, the use of technology and to look for best-practices in order to minimize the costs for polluting the environment[6].

For climate scenarios, we set a market-related climate policy represented by a global cap-and-trade system from 2020 onwards, considering two carbon budget restrictions that amount for 1000 $GtCO_2$ and 600 $GtCO_2$, in line with the stabilization of global average temperature well-below 2°C by 2100. This market runs under a perfect competition assumption and incorporates energy-related $CO_2$ emission credits (or allowances) for industrials and household sectors, allowing international and intersectoral trade, in order to establish an equilibrium global carbon price ($p^{CO2}$).

Pricing carbon emissions at source, as is usually envisaged for climate policies covering the energy sector, incentivizes emissions reductions across the life cycle[52,61]. Under such carbon market, there are limited incentives to reduce agricultural GHG emissions because non-$CO_2$ gases allowances are not accounted/traded. Therefore, food with greater emissions intensity tends to be produced in place of another equivalent in nutritional terms, simply because it has lower costs of production. In order to include the right incentives for agricultural non-$CO_2$ emissions, we derive carbon taxes from the global carbon price and add them to the capital productive factor of the agricultural sector[76,77]. The capital employed in the production of agricultural activities is closely related to emissions of the pollutant (cattle in livestock sector, for example). The implementation of a non-$CO_2$ price at the animal-based food system may cause changes in the competitiveness of regional food system sectors by affecting emissions intensity within the global market. The pricing of non-$CO_2$ gases from agricultural sectors is implemented through differentiated taxes ($p_K^i$) on capital of each agricultural activity, as follows.

$$p_K^i = p^{CO2} \cdot GWP_{100}^i \qquad i = CH_4; N_2O$$

The climate impacts of non-$CO_2$ emissions are converted to their so-called $CO_2$-equivalent ($CO_2$eq)[78]. GHG prices are derived from climate-related effects from agricultural methane and nitrous oxide emissions, as a result of multiplying the global uniform carbon price by the century-scale global warming potential of $CH_4$ and $N_2O$ relative to that of $CO_2$ ($GWP_{100}$). GHG prices ensure cost-effective achievement of emissions reduction, inducing a shift to a low-carbon economy, thus affecting regional and sectoral competitiveness and the penetration of advanced technologies over time. This is achieved within the TEA model by endogenous variations in market prices, which leads to an increase in the cost of production and decreased wages and household incomes. Consumers respond to relative price increase and income loss by decreasing consumption and by shifting to less expensive and less emission-intensive goods.

We assume an identity between carbon prices and the social cost of carbon, translating that into an estimation of the cost of the impact that emissions have on health, well-being, and quality of life in monetary values. The opportunity cost of the refusal to an improved food intake is an economic valuation of the environmental effects of dietary change, estimated by the present value of the difference between food system GHG emissions in BASE and OECD_Diet scenarios multiplied by the global carbon price of climate scenarios. The social cost of carbon ($SCC$) expresses the impact of additional units of agricultural non-$CO_2$ emissions ($E^i$) in monetary values:

$$SCC^i = \sum_{t=2020}^{2050} \frac{p^i \cdot E^i}{(1+r)^t} \qquad \begin{array}{l} i = CH_4; N_2O \\ r = \textit{discount rate} \end{array}$$

Exploring the climate-related cost of global animal source food system is interesting, even if population and the value of money change in the future. As an analogue for what could be achieved over the next decades via dietary pattern enhancements, we estimate the opportunity cost of the refusal to an improving food intake in OECD countries. Finally, we also perform a sensitivity analysis on annual discount rates (2.5%, 3% and 5%) to represent concerns of the society about future generations.

## Results and discussion

This section presents the results of the simulations and discusses their implications. First, the macroeconomic impacts of the improved food intake in OECD countries and the market-related climate policy are presented, followed by the results of global and regional GHG emissions by scenarios, as well as analyses involving global climate-related costs of animal-based diets in OECD countries.

## Macroeconomic Impacts

Results suggest a marginal decrease in global GDP in climate scenarios from 2020 onwards compared with the BASE scenario. Figure 3 shows that the implementation of a global cap-and-trade for energy-related $CO_2$ emissions, as well as an agricultural non-$CO_2$ emissions pricing mechanism, represent a growing global GHG price in 2020-2050 period of nearly 1.5 to 24 USD/t$CO_2$ in the WB2C_1000 and 10 to 55 USD/t$CO_2$ in the WB2C_600 scenario. In 2050, moderate global GDP losses are expected in climate scenarios: -0.34% (WB2C_1000) and -0.91% (WB2C_600). This represents an average annual GDP growth at 2.29% in WB2C_1000 and 2.28% in WB2C_600. The BASE and OECD_Diet scenarios are based on SSP2 assumptions, which represent an annual global GDP growth at 2.30% p.y.

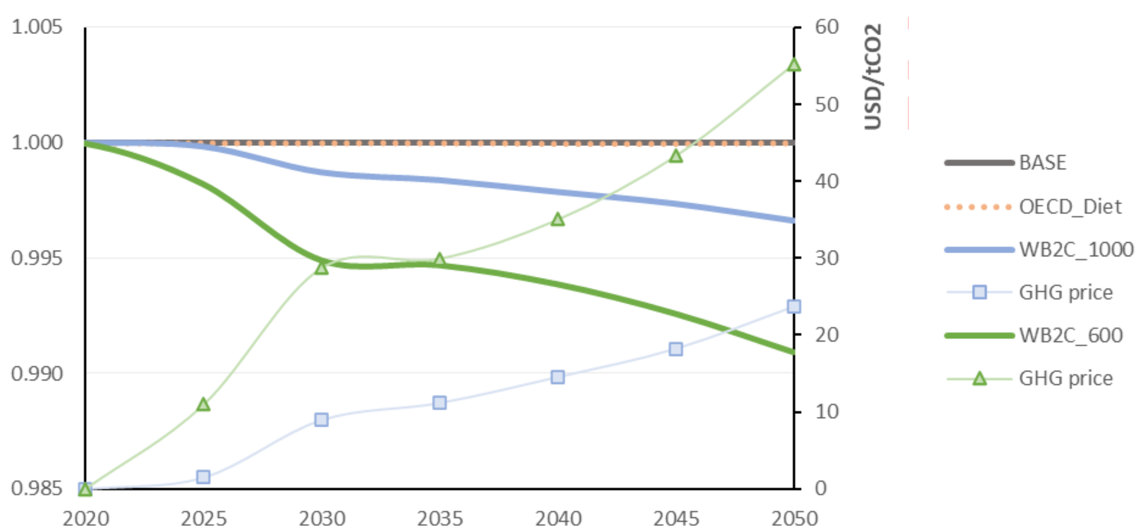


**Figure 3: Impacts on global GDP (index GDP BASE = 1.000) and GHG prices trajectories by scenario**

Table 2 shows the annual growth of global food demand in contrast with OECD regions until mid-century by scenario. The BASE scenario suggests an increase of about 1.78% p.y. worldwide, while the OECD_Diet scenario indicates 1.68% p.y. Global household food demand for agricultural products, vegetables, and fruits (AGR) increase nearly 8% in the OECD_Diet scenario compared with the BASE scenario. Plant-based food products (OFD) respond by the higher demand growth in the OECD_Diet scenario, achieving 2.13% p.y. (16% more than in the BASE scenario). On the other hand, results indicate a reduction of 50% on global household demand for animal-based food products (OMT) in the OECD_Diet scenario, which exposes the level of transformation needed in OECD countries, according to the EAT-Lancet reference diet[2].

In the OECD_Diet scenario, Australia & New Zealand (AUS) and European Union (EEU) stand out, with high growth rates for plant-based food products (OFD). Although there is greater growth in global demand for fish products (FSH), Japan (JPN) and South Korea (KOR) show reductions, which signals excessive consumption nowadays in these regions. Also noteworthy are the USA with growth in demand for plant-based foods (AGR and OFD) and the lowest demand for animal-based foods, especially OMT. All of these results are related to the dietary change proposed in the OECD_Diet scenario, which also might drive marginal changes in food prices in the future: plant-based food prices tend to increase, while animal-based food decrease. In OECD regions, we can observe more relevant price variations (compared with price trajectories in the BASE scenario) related to plant-based food – nearly +2% in JPN and KOR – and animal-based food – around -1% in the USA – in 2050. Even lower OMT prices in the USA do not result in demand increases due to the simulated new food preferences. Variations in the food consumption from non-OECD regions show up irrelevant in the OECD_Diet scenario, indicating any influence for reducing animal-based food consumption in other regions outside OECD.

Table 2: Annual growth (%) of food demand by households between 2011-2050 for each scenario

| | | AUS | CAN | EEU | JPN | KOR | RUS | USA | WEU | Global |
|---|---|---|---|---|---|---|---|---|---|---|
| **BASE** | **AGR** | 1.05 | 1.07 | 1.11 | 0.13 | 0.65 | 0.51 | 0.71 | -0.01 | 1.75 |
| | **OAP** | 1.04 | 0.63 | 0.54 | -0.19 | -0.24 | 1.32 | 0.49 | 0.29 | 1.64 |
| | **FSH** | 1.08 | 0.96 | 1.19 | 0.26 | 0.88 | 0.15 | 0.61 | -0.38 | 1.94 |
| | **OFD** | 1.70 | 1.43 | 1.64 | 0.48 | 0.77 | 1.16 | 1.23 | 0.87 | 1.83 |
| | **OMT** | 1.62 | 1.44 | 1.66 | 0.38 | 0.72 | 1.57 | 1.19 | 0.75 | 1.74 |
| **OECD_Diet** | **AGR** | 1.95 | 1.44 | 1.71 | 1.01 | 0.25 | 1.14 | 1.40 | 0.98 | 1.88 |
| | **OAP** | 1.37 | 0.14 | 0.57 | -1.65 | -0.03 | 0.08 | -1.43 | 0.20 | 1.56 |
| | **FSH** | 1.60 | 1.63 | 1.51 | -1.26 | -0.58 | 1.38 | 0.45 | 2.94 | 1.97 |
| | **OFD** | 2.73 | 2.12 | 2.30 | 1.49 | 2.04 | 2.20 | 1.33 | 1.85 | 2.13 |
| | **OMT** | -0.74 | -0.58 | -0.27 | -0.68 | -0.54 | -0.11 | -2.31 | 0.18 | 0.88 |
| **WB2C_1000** | **AGR** | 0.99 | 1.06 | 1.11 | 0.12 | 0.65 | 0.47 | 0.70 | -0.02 | 1.74 |
| | **OAP** | 0.99 | 0.61 | 0.52 | -0.19 | -0.25 | 1.26 | 0.46 | 0.26 | 1.63 |
| | **FSH** | 1.05 | 0.96 | 1.19 | 0.26 | 0.88 | 0.11 | 0.61 | -0.39 | 1.94 |
| | **OFD** | 1.67 | 1.42 | 1.64 | 0.48 | 0.78 | 1.13 | 1.22 | 0.86 | 1.83 |
| | **OMT** | 1.56 | 1.42 | 1.66 | 0.37 | 0.72 | 1.53 | 1.17 | 0.73 | 1.72 |
| **WB2C_600** | **AGR** | 0.94 | 1.05 | 1.10 | 0.12 | 0.64 | 0.41 | 0.68 | -0.06 | 1.72 |
| | **OAP** | 0.95 | 0.59 | 0.50 | -0.20 | -0.27 | 1.18 | 0.42 | 0.20 | 1.61 |
| | **FSH** | 1.02 | 0.96 | 1.18 | 0.26 | 0.88 | 0.06 | 0.60 | -0.41 | 1.94 |
| | **OFD** | 1.65 | 1.42 | 1.63 | 0.47 | 0.77 | 1.09 | 1.21 | 0.83 | 1.82 |
| | **OMT** | 1.51 | 1.41 | 1.64 | 0.36 | 0.70 | 1.47 | 1.14 | 0.69 | 1.69 |



In the climate scenarios, it is possible to observe the influence of the agricultural non-$CO_2$ emissions pricing mechanism on the global food system. All sectors that produce plant- or animal-based foods are slightly penalized due to their $CH_4$ and $N_2O$ emissions, resulting in higher consumer prices and lower food demand by households. The modification of relative prices that mirror their societal costs leads to sustainable consumption patterns towards non-market, non-polluting and healthy goods, influencing human lifestyle changes[75]. Noteworthy is the OMT demand, which presents the greatest reductions due to global price increases of nearly 2% in the WB2C_1000 and 4% in the WB2C_600 scenario, compared to the BASE scenario. The USA and AUS stand out for 6% and 9% increased OMT prices, while non-OECD regions as South America (SAM) and Brazil (BRA) might rise 7% to 13% in 2050.

The economic sectors behind the global food demand are marginally impacted by the market-related climate policy implemented in WB2C_1000 and WB2C_600 scenarios, while the improved food intake in OECD countries results in significant transformations in the global food system. Figure 4 indicates the changes in food systems between 2020-2050 in the OECD_Diet scenario. With the improved food intake guided by a reference diet in OECD countries, the global production of plant-based food may increase about 8% more than in the BASE scenario and economic activities related to the production of animal-based foods might decrease up to 11% in 2050. In terms of plant-based food production, JPN, KOR and RUS stand out, followed by Europe (EEU and WEU) and AUS. The game changers are the USA and Russia (RUS) with impressive up to 40% reductions in livestock production in 2050.

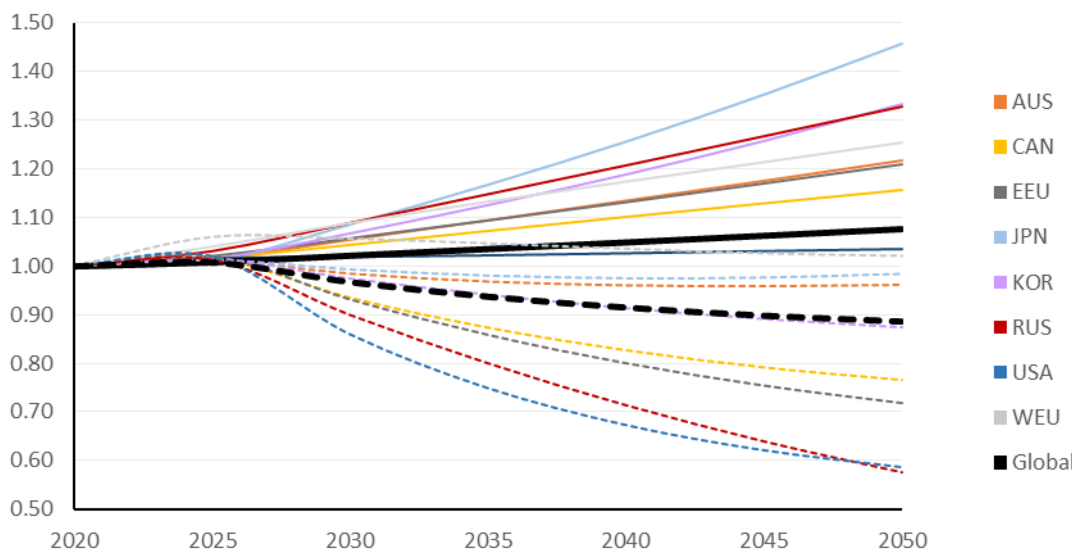


**Figure 4: Plant- (solid line) and animal-based (dashed line) food production trajectories (index BASE = 1.00) between 2020-2050 in OECD_Diet scenario**

The international food trade is impacted by both the improved food intake in OECD countries and the market-related climate policy. In the OECD_Diet scenario, exports and imports of plant-based food tend to rise nearly 10%, while animal-based food trade might decline 18% globally, even in non-OECD regions, compared to the BASE scenario. In climate scenarios, international food trade might suffer marginal decreases (< 1%) for plant-based food and relevant drops of 2% to 5% for animal-based food in the WB2C_1000 and WB2C_600 scenarios, respectively.



## Global and Regional GHG Emissions

Figure 5 shows the global GHG emissions as well as agricultural non-$CO_2$ emissions from OECD regions by source and scenario. The global cap-and-trade system induces significant curbs in $CO_2$ emissions from the global energy sector in midcentury, nearly 35% in the WB2C_1000 and up to 50% in the WB2C_600 scenario, compared to the BASE scenario. The biggest emissions cuts occur in fossil fuel, mainly in the coal sector, which accounts for relevant $CH_4$ and $N_2O$ emissions as well. $CO_2$ emissions from industrial processes are marginally reduced in climate scenarios, while land-use change emissions show a similar trajectory to the BASE scenario.

Pricing non-$CO_2$ emissions from agricultural sectors affects the market competitiveness in the food system, but also contributes to reducing regional and global GHG emissions in order to stabilize the global average temperature in well-below 2°C. Lower food production and demand by households might ensure 2% to 3.5% reductions in agricultural $CH_4$ emissions and 2% to 5% in agricultural $N_2O$ emissions globally in 2050, compared to the BASE scenario. However, stringent global climate change mitigation policies can raise the risk of food insecurity in low-income regions[79]. With a shift away from emissions-intensive foods to less emissions-intensive foods due to rising consumer prices, changes in dietary patterns may end up being the result and not the cause behind emissions reduction.

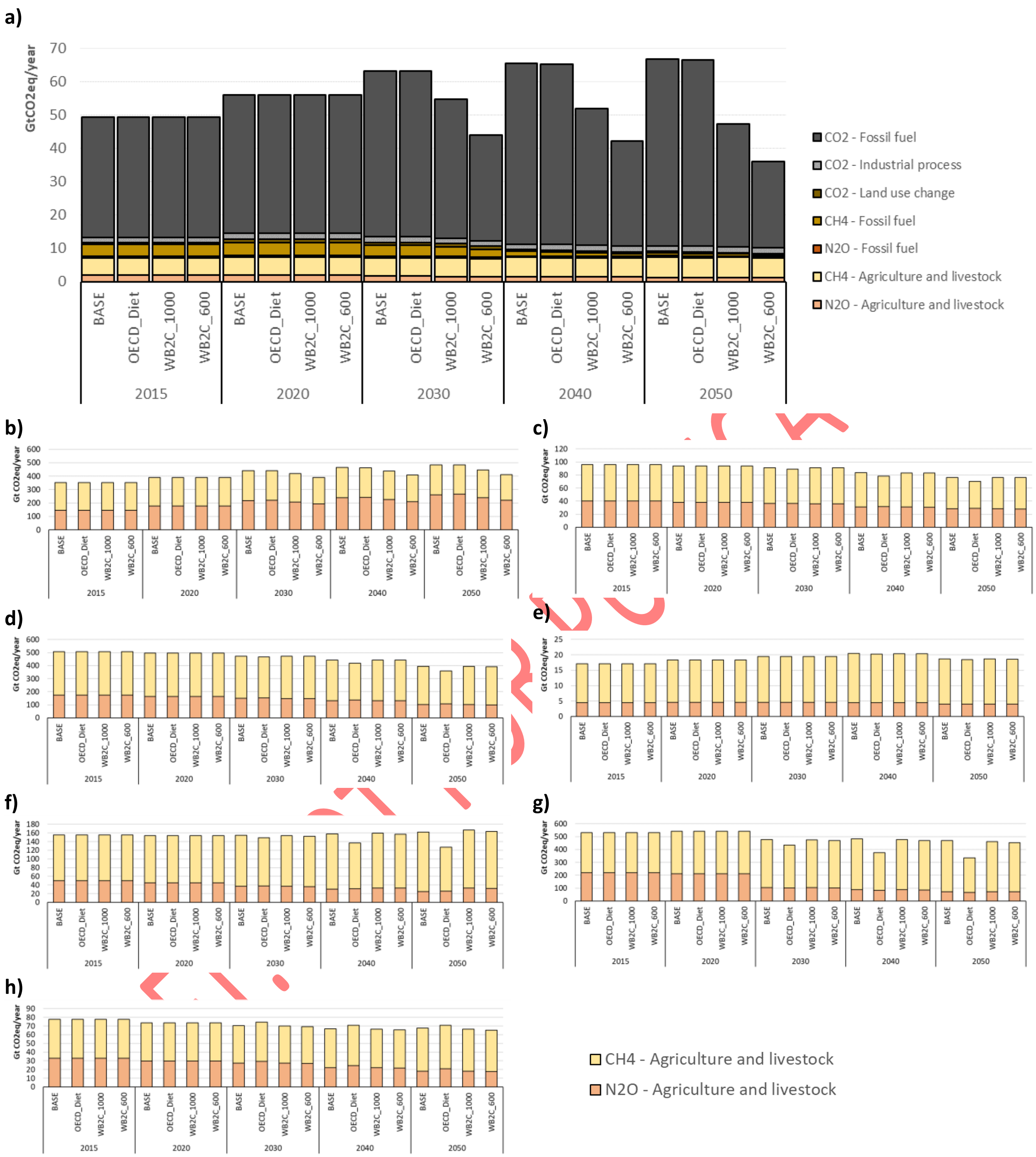


**Figure 5: a) Global GHG emissions and agricultural non-$CO_2$ emissions from b) Australia & New Zealand, c) Canada, d) European Union, e) South Korea, f) Russia, g) USA and h) rest of Europe by scenario**

Comparing agricultural $CH_4$ and $N_2O$ emissions from the climate scenarios and the OECD_Diet, it is possible to observe analogous emissions trajectories. In the Diet_OECD scenario, $CH_4$ emissions from the agricultural sector fall on average 3.5% in the world in 2050 compared to the BASE scenario, quite similar to the WB2C_600 scenario. In OECD countries, the USA and Russia stand out with up to 30% cuts in $CH_4$

emissions, followed by European Union and Canada with nearly 13%. The improved food intake in OECD countries affects also agricultural $CH_4$ emissions from other important regions such as Brazil (-1.9%), Central America (-5.6%), and South America (-1.2%). Unlike climate scenarios, agricultural $N_2O$ emissions rise 0.7% globally in 2050 in the OECD_Diet scenario. The growing demand for plant-based food might induce a marginal increase in $N_2O$ emissions. In OECD countries, rest of Europe (WEU) stands out as the region that pulls global $N_2O$ emissions upwards in the OECD-Diet scenario, with almost 15% growth in 2050 compared to the BASE scenario.

## Global Climate-Related Costs of Animal-Rich Diets in OECD Countries

As an analog for what could be achieved over the next decades via global dietary pattern enhancements, we estimate the opportunity cost of the refusal to an improving food intake in OECD countries. Figure 6 shows how the agricultural $CH_4$ emissions trajectories by scenario are comparable, highlighting the OECD_Diet trajectory in contrast with the climate scenarios. There is a correspondence between agricultural $CH_4$ emissions from the OECD_Diet scenario and the WB2C_1000 during the next 15 years, while the same might occurs in the 2040-2050 period with the WB2C_600 scenario. The USA responds by 60% reduction of the global $CH_4$ emissions from the agricultural sector, followed by the European Union (18%) and Russia (16%).

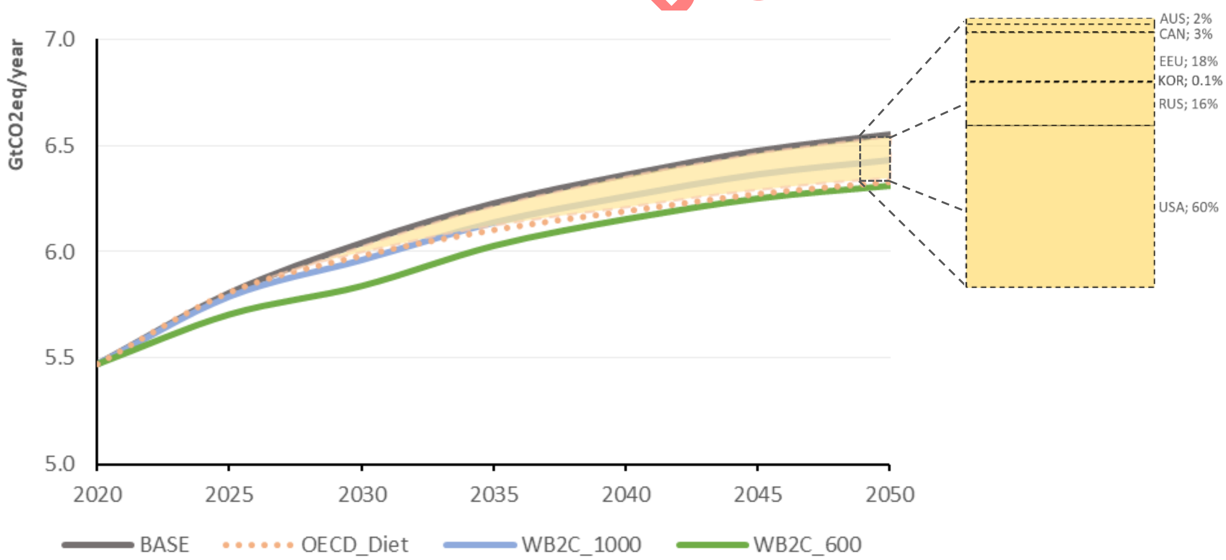


**Figure 6: Agricultural $CH_4$ emissions trajectories by scenario and the participation of regions in cut emissions of the OECD_Diet scenario compared to the BASE scenario**

Including all non-$CO_2$ emissions from the agricultural sector, it is possible to estimate global climate-related costs around USD 50 bi during the 2020-2050 period, considering a discount rate of 3% p.y., that could be avoided if the OECD consumers adopted the EAT-Lancet reference diet. The sensitivity analysis considers discount rates at 2.5% and 5% p.y., which represent USD 32 bi and USD 57 bi, respectively.

# Final Remarks

A voluntary improved food intake in OECD countries could reduce the consumption of animal-based food and, at the same time, raise plant-based food demand, affecting the global food system and reducing global GHG emissions. There is an opportunity cost in maintaining the current diet pattern in OECD countries. However, many factors influence decisions to consume animal-based food. Behavioral scientists have questioned the presumption of control that consumers have over their consumption[80], owing to consumer lock-ins created by the interaction between external factors – such as social conventions, infrastructure, and technology – and biological factors (with a variety of psychological determinants) in order to shape diets[81–84]. Such lock-ins reinforce existing social and cultural structures and may hinder a transition towards more sustainable food systems. However, concerns about the ethics, human health, and environmental consequences of an animal-based diet have been led to an expansion of meat substitutes and to sufficiency approaches.

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