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RECEIVED
8 February 2023

REVISED
11 October 2023

ACCEPTED FOR PUBLICATION
24 October 2023

PUBLISHED
14 November 2023

LETTER

The effects of dietary changes in Europe on greenhouse gas emissions and agricultural incomes in Ireland and Denmark

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Keywords: dietary changes, emissions, agricultural incomes, CGE

Supplementary material for this article is available online

Abstract

Livestock farming is one of the main sources of greenhouse gas emissions. In Europe, the agricultural sectors of Ireland and Denmark are the most livestock-intensive. Based on a scenario analysis using a computable general equilibrium model, we estimate the effects of dietary changes toward the recommendations of the EAT-Lancet Commission in Europe on the agricultural sector of Ireland and Denmark. Our results show that full adoption of the diet reduces agricultural emissions, particularly methane, with potential emission savings of 26.4% or 5.4 Mt CO_2-equivalent in Ireland and 21.7%, or 1.9 Mt CO_2-equivalent in Denmark. Global agricultural emissions decrease by 2.4% or 193.7 Mt CO_2-equivalent. However, incomes in livestock farming fall. This is offset to varying degrees by gains in horticulture and trade dynamics, leading to different outcomes across regions. Policymakers should promote plant-based diets and monitor export dynamics to achieve effective emission reductions. Additionally, methane mitigation strategies should be integrated into climate plans. This study highlights the need for further research on country-specific environmental impacts and trade-offs associated with dietary changes.

1. Introduction

By 2050, the EU27 aims to be the first region to achieve climate neutrality by reducing greenhouse gas (GHG) emissions to at least 55% below 1990 levels by 2030 (EC 2019, 2020). This requires action across all sectors and EU countries. Energy generation is the largest contributor to EU GHG emissions, accounting for 75.5%, followed by the agricultural sector at just under 12%, excluding land use, land use change and forestry (LULUCF) (EEA 2022). In Ireland and Denmark, the two countries with the most livestock-intensive agricultural sectors in the EU, the agricultural sector is responsible for 37% and 27% of national GHG emissions respectively, affecting significantly the overall emissions profile of these countries (Mielcarek-Bocheńska and Rzeźnik 2021, EEA 2022, EPA 2022, Eurostat 2022, Nielsen *et al* 2022).

In Ireland and Denmark, a large share of GHG emissions comes from methane and nitrous oxide, originating from enteric fermentation, manure management, and agricultural soils as a result of livestock production. Methane (26%) and nitrous oxide (12%) account for over a third of total Irish GHG emissions. Compared to Ireland, Denmark has a lower share of methane (17%) and a relatively higher share of nitrous oxide (14%) in total emissions due to its strong focus on pig farming (EEA 2022, see also the appendix). Although methane and nitrous oxide have higher global warming potentials than CO_2, they have shorter lifetimes, making reductions in methane emissions particularly beneficial in the short term (IPCC 2021). Specifically, for countries like Denmark and Ireland with high shares of agricultural emissions, it is crucial to early include agriculture in their strategies to reduce GHG emissions on the way to a climate neutral EU (Mielcarek-Bocheńska and Rzeźnik 2021).

In particular, the production and consumption of animal-source foods is increasingly associated with negative impacts on climate, environment and health.

Research by Poore and Nemecek (2018) reveals that the production of 1 kg of beef can cause 34.1–60.4 kg CO_2-equivalent per kg of meat, while cheese production contributes 18.6 kg CO_2-equivalent per kg. Pork and poultry meat generate lower GHG emissions, at 10.6 and 7.5 kg CO_2-equivalent per kg, respectively, but they still exceed the emission footprints of many plant-based foods such as wheat or rye bread (1.3 CO_2-eq./kg), peas (0.8 CO_2-eq./kg) or tofu (2.6 CO_2-eq./kg). Additionally, studies indicate that high consumption of animal-based foods is associated with health risks due to their energy density, saturated fatty acids, and cholesterol content, contributing to diseases like type 2 diabetes and cardiovascular disease (Friel *et al* 2009, Springmann *et al* 2018, Barnard and Leroy 2020). Currently, European citizens consume 79 kg of meat and 187 kg of dairy products per capita per year, excluding household waste, which is at least twice the global average (FAOSTAT 2022). Therefore, in theory, there is great potential for dietary change along with associated emissions reductions and health improvements in the EU.

Against this background, the EAT-Lancet commission on food, planet and health derived a diet that is consistent with public health and environmental objectives. The effects of adopting this planetary health diet may vary among countries. While middle- and low-income countries could see an increase in agricultural emissions, high-income countries could experience a decrease (Semba *et al* 2020). For European citizens, adopting this diet requires significant changes, including reducing consumption of red meat and dairy products, and increasing intake of fruits, vegetables, legumes, whole grains, and nuts. The EAT-Lancet Commission estimates that a shift toward more plant-based diets can reduce global agricultural GHG emissions by up to 80% while reducing premature mortality by 19%. Combined with improved agricultural production practices and a reduction in food waste and loss, the Commission estimates that this diet allows 10 billion people to be fed within planetary boundaries by 2050 (Springmann *et al* 2018, Willett *et al* 2019).

However, switching to a plant-based diet with less animal-based foods can be challenging for countries like Ireland and Denmark where livestock farming is an important pillar of the agricultural sector. In 2021, livestock production accounted for 74% and 56% of total agricultural output value in Ireland and Denmark, respectively (Department of Agriculture, Food and the Marine 2022, Eurostat 2022, Statistics Denmark 2022). In Ireland, dairy farming (35%) and cattle and calf farming (27%) contribute the most to agricultural production value. About 90% of produced beef and dairy products are exported, with the UK and EU27 being the main export regions (Department of Agriculture, Food and the Marine 2022). In Denmark, pig farming is the leading source of income, accounting for 28% of the agricultural production value, followed by dairy farming at 20% (Statistics Denmark 2022). Like Ireland, Denmark exports about 90% of its pig and pork production, mainly to other EU countries and China (Danish Agriculture and Food Council 2023).

Previous studies have analyzed the impact of more plant-based diets on various environmental indicators such as GHG emissions (Semba *et al* 2020, Springmann *et al* 2020), water and land use (Osei-Owusu *et al* 2022). Our study aims to contribute new knowledge by answering how a dietary shift toward the EAT-Lancet diet can influence agricultural production and incomes and contribute to savings in GHG emissions in the EU27 and the two countries, Ireland and Denmark, where emissions-intensive livestock production plays a major role. According to first modeling results, those countries' incomes could suffer the most in the EU from healthier and more sustainable diets, at least in the short-run, rendering them particular susceptible to dietary changes (Rieger *et al* 2023). In our study we take a long-term perspective, focusing on the Danish and Irish agricultural sectors.

2. Methodological approach

We use the modular applied general equilibrium tool (MAGNET) which is a computable general equilibrium (CGE) model based on microeconomic theory that describes all activities and agents in an economy, including production, consumption, trade, taxation, and savings, as well as the linkages and feedbacks among them (Woltjer and Kuiper 2014). It is based on the GTAP model but with a more detailed representation of the agricultural sector, its upstream sectors and the food industry. MAGNET covers 141 regions and countries, 113 economic sectors and 127 commodities (Kristkova 2020, Woltjer and Kuiper 2014). MAGNET is based on the GTAP 10 database, which provides a consistent representation of the global economy for the reference year 2014 (Aguiar *et al* 2019). Please refer to the appendix for a more detailed description of the MAGNET model.

We project country and commodity-specific diets in MAGNET that are in line with baseline developments until 2050 and we tracked nutritional indicators from farm to fork based on a dedicated nutrition module developed in MAGNET (Rutten *et al* 2013). Finally, we calculate the difference between the projected diets and the EAT-Lancet recommendations for a 2500 kcal diet per capita per day in 2050 to derive three scenarios: full implementation (Lancet_full), 10% shift (Lancet_low), and 30% shift (Lancet_high) towards the EAT-Lancet diet. The required percentage changes in demand for each food group for Ireland

Table 1. Changes in food consumption to reach EAT-Lancet planetary health diet [2500 kcal/capita/day] compared to benchmark diet 2050 for Denmark and Ireland.

Diet	Benchmark diet 2050		Lancet_low		Lancet_high		Lancet_full	
Unit	kcal/capita/day		%-change		%-change		%-change	
Country	Ireland	Denmark	Ireland	Denmark	Ireland	Denmark	Ireland	Denmark
Wheat	474	439	6.9	9.2	20.7	27.7	68.8	92.2
Other grains	94	84	6.3	9.6	18.8	28.8	62.7	95.8
Rice	31	45	1.3	6.5	3.8	19.5	12.8	65.0
Horticulture[a]	300	247	16.1	17.2	48.3	51.7	161.0	172.5
Vegetable oils	369	146	−0.3	16.3	−1.0	48.9	−3.5	162.9
Sugar	305	288	−6.4	−6.2	−19.1	−18.5	−63.8	−61.8
Beef	140	85	−9.3	−9.2	−27.9	−27.7	−93.0	−92.4
Lamb	39	3	−9.4	−8.7	−28.1	−26.1	−93.5	−86.8
Pork	186	236	−9.3	−9.3	−27.9	−28.0	−92.9	−93.2
Poultry	130	70	−7.1	−4.3	−21.3	−12.9	−70.9	−43.0
Milk and dairy products	465	378	−6.8	−6.7	−20.3	−20.1	−67.5	−66.9
Eggs	36	85	−5.0	−7.7	−15.0	−23.0	−49.9	−76.6
Fish	29	43	0.1	−0.4	0.2	−1.3	0.5	−4.2
Total calories	3016	2568	−1.7	−0.3	−5.1	−0.8	−17.1	−2.7

Source: own calculations based on Springmann 2019 and the MAGNET model.

[a] Including roots, vegetables, fruits, legumes and nuts.

Note: the per capita kcal consumption of foods in the reference scenario for 2050 does not add up to the total kilocalorie consumption in Ireland and Denmark. The remaining calories come from other foods that are not intended to be consumed as part of the EAT-Lancet diet and are not the focus of this analysis.

and Denmark are shown in table 1. For comprehensive information on the benchmark and country-specific EAT-Lancet diets for other European countries, please refer to the appendix.

Across all scenarios, the largest increases in demand exist for horticultural products including fruits, vegetables, legumes and nuts. A full implementation of the EAT-Lancet diet requires an increase in demand for horticultural products of 161% in Ireland and 173% in Denmark. In contrast, the relatively largest decreases are observed for the consumption of beef and pork, where consumption needs to decrease by more than 90% in the Lancet_full scenario.

Instead of modeling policy instruments that would result in sustainable diets *('how-to')* we are more interested in the results of such dietary shifts per se *('what-if')*. Hence, we implement dietary changes as exogenous changes in consumer preferences, see appendix. In the MAGNET model, household demand is specified by an aggregated constant difference elasticity (CDE) implicit expenditure function (Hanoch 1975) and is extended by a shifter variable which allows household consumption to be altered to follow a pre-defined diet within the budget constraint. Demand patterns are changed for the EU27, the United Kingdom and the European Free Trade Association (EFTA) comprising Iceland, Liechtenstein, Norway and Switzerland. In the following, these countries are referred to as EU+. A business-as-usual (BAU) scenario based on the GDP and population development of the shared socioeconomic pathway 2 (SSP2) scenario is used as a basis for comparison for the year 2050. This SSP2-BAU scenario is adjusted for policies that are certain from today's perspective. This includes changes in direct payments and market measures from the pillar 1 budget of the EU common agricultural policy for the period 2014–2022 and includes bilateral import tariffs until 2030.

3. Results

The following section presents changes in GHG emissions, production, trade patterns and farm incomes in Ireland, Denmark and the EU27 as a result of the adoption of the EAT-Lancet diet in the EU+ countries. Changes in GHG emissions are presented for the entire primary agricultural sector, i.e., crop and other livestock production of sheep or poultry is included. Considering that the Irish agricultural sector is specialized in cattle and dairy farming and the Danish agricultural sector is mainly dominated by pig farming, the changes in production, trade patterns and farm incomes are reported for these sectors as well as for the horticulture sector.

3.1. Changes in GHG emissions

The MAGNET model calculates GHG emissions based on production output (Chepeliev 2020, Pérez-Domínguez *et al* 2021), and in this context, changes in production and therefore emissions occur as a result of changing demand patterns.

Dietary shifts in EU+ countries can significantly reduce emissions in the primary agricultural sector in Ireland and Denmark. In the Lancet_low

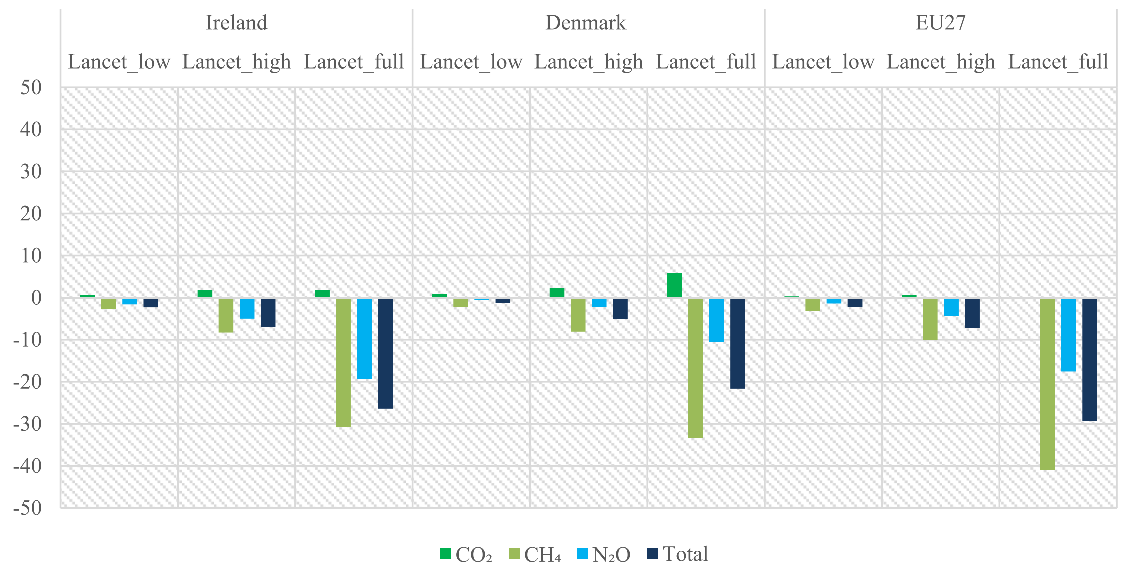

Figure 1. Changes in agricultural greenhouse gas emissions by gas [%].
Source: own simulations with the MAGNET model.

scenario, emissions decrease by 2.3% (0.5 Mt CO_2-equivalent) in Ireland and the EU27 (8.6 Mt CO_2-equivalent), and by 1.4% (0.1 Mt CO_2-equivalent) in Denmark compared to the 2050 BAU-scenario. In the Lancet_full scenario, larger reductions are achieved, with savings of 26.4% (5.4 Mt CO_2-equivalent) in Ireland and 21.7% (1.9 Mt CO_2-equivalent) in Denmark. The EU-27 as a whole can achieve emission reductions of 29.3% (111.9 Mt CO_2-equivalent).

Methane emissions show the largest potential for reduction. While in the Lancet_low scenario methane emissions are reduced by 2%–3% in each of the three regions, in the Lancet_full scenario they can be reduced by more than 30% in Ireland and Denmark, corresponding to 4.0 Mt CO_2-equivalent and 1.5 Mt CO_2-equivalent respectively. In the EU27 methane emissions can be reduced by 41.0% or 83.6 Mt CO_2-equivalent. The majority of these savings stem from beef cattle farming, followed by reduction from reductions in dairy farming.

In the Lancet_low scenario nitrous oxide emissions decline by 1%–2% in each region. Full adoption of the EAT-Lancet diet leads to savings of nitrous oxide emissions of 19.4% or 1.4 Mt CO_2-equivalent in Ireland, 10.5% or 0.4 Mt CO_2-equivalent in Denmark and 17.6% or 28.3 Mt CO_2-equivalent in the entire EU27. Similar to methane emissions, the predominant reductions in nitrous oxide emissions come from beef production. However, part of the savings from livestock production are offset by an increased use of fertilizers in horticulture production (+0.2 Mt CO_2-equivalent in Ireland, +0.1 Mt CO_2-equivalent in Denmark, +4.9 Mt CO_2-equivalent in the EU27).

In the Lancet_full scenario, Ireland experiences a 1.8% increase and Denmark a 5.8% increase in carbon dioxide emissions due to the use of fossil energy sources in cereal and horticulture production. However, carbon dioxide emissions play a smaller role compared to methane and nitrous oxide emissions in the agricultural sector, resulting in relatively small absolute changes of 0.004 Mt CO_2-equivalent in Ireland and 0.02 Mt CO_2-equivalent in Denmark. In the EU27, both the Lancet_low and Lancet_high scenarios show a net increase in CO_2 emissions as the emissions from horticulture outweigh the reductions in livestock farming. However, in the Lancet_full scenario, the reductions in livestock farming outweigh the emissions from horticulture, leading to a decrease in CO_2 emissions by 0.2% or 0.03 Mt.

Adopting the EAT-Lancet diet reduces agricultural and total emissions in Ireland, Denmark and the EU27. In the Lancet_low scenario there is a slight decrease in total emissions, but in the Lancet_full scenario there are more significant reductions. Ireland experiences a decrease of 9.0%, Denmark a decrease of 4.8% and the EU27 a decrease of 3.7% in total emissions. Methane emissions show the largest reductions, with decreases of 21.3% in Ireland, 17.8% in Denmark and 12.8% in the EU27. Partial implementation has a limited global impact, but full implementation in EU+ countries can reduce global agricultural emissions by 2.4% or 193.7 Mt CO_2-equivalent including reductions in methane emissions by 3.0% and nitrous oxide emissions by 1.6% (supplementary data).

3.2. Production changes

Table 2 displays the percentage changes in production resulting from a dietary shift towards the EAT-Lancet diet in the EU+ countries. These production changes are influenced by the simulated demand changes and trade effects.

Table 2. Effects of dietary changes on production, incomes and trade in Ireland, Denmark and the EU27 [%].

	Ireland			Denmark			EU27		
%-change	Lancet_low	Lancet_high	Lancet_full	Lancet_low	Lancet_high	Lancet_full	Lancet_low	Lancet_high	Lancet_full
Production volume									
Dairy cattle farming	0.0	0.0	−3.3	0.0	−4.1	−29.8	0.0	−1.7	−30.0
Beef cattle farming	−3.8	−11.5	−41.5	−5.7	−17.1	−58.1	−6.1	−18.2	−62.4
Sheep and goat farming	−2.9	−8.7	−30.8	−2.9	−8.5	−31.4	−2.1	−6.3	−20.7
Pig farming	−1.4	− 4.1	−14.0	−1.5	−4.4	−14.8	−2.7	−8.2	−26.7
Horticulture	10.0	28.8	80.2	4.3	12.3	32.7	5.5	15.8	47.1
Total Primary Agriculture	−1.0	−3.1	−13.7	−0.3	−1.8	−10.1	−0.1	−0.6	− 6.1
Agricultural Incomes									
Dairy cattle farming	−0.2	−0.7	−6.2	0.1	−5.6	−39.1	0.3	−1.6	−33.3
Beef cattle farming	−3.3	−9.9	−32.6	−6.0	−18.9	−61.1	−5.8	−17.4	−54.2
Sheep and goat farming	−2.5	−7.6	−25.2	−3.0	−9.8	−37.1	−1.5	−4.7	−16.9
Pig farming	−0.3	−0.8	−1.9	−1.6	−5.8	−22.1	−1.9	−6.2	−22.9
Horticulture	14.2	48.1	209.2	13.5	43.5	166.1	10.7	34.1	131.3
Total primary Agriculture	−0.2	−0.1	1.1	0.8	0.2	−7.2	1.8	5.3	17.4
Exports									
Dairy products	1.2	4.4	18.8	2.2	−1.4	−19.2	12.5	35.6	60.2
Beef meat	−6.7	−20.6	−75.0	−7.2	−21.7	−73.2	−6.1	−18.3	−63.3
Sheep and goat meat	−0.8	−2.2	−2.3	0.3	1.6	13.9	0.8	2.7	12.3
Pig meat	−1.3	−3.9	−13.7	−1.5	−4.6	−15.8	0.6	1.9	11.2
Horticulture	8.2	22.9	55.9	0.4	1.4	2.3	−0.5	−0.3	6.1
Imports									
Dairy products	−4.1	−11.3	−33.6	−7.0	−18.9	−56.5	−17.4	−42.7	−74.1
Beef meat	−6.6	−20.0	−66.7	−7.4	−22.3	−76.6	−8.3	−25.0	−78.7
Sheep and goat meat	−6.7	−20.2	−67.8	−8.2	−24.7	−84.2	−8.1	−24.2	−81.7
Pig meat	−8.4	−25.2	−84.6	−7.4	−22.4	−75.6	−8.1	−24.6	−85.1
Horticulture	6.4	19.7	71.5	14.9	45.3	160.9	17.3	56.0	221.4

Source: own simulations with the MAGNET model.

Dietary shifts towards the EAT-Lancet diet in Ireland, Denmark, and the EU27 result in similar production changes. Cattle production significantly declines across all regions, with decreases of 3.8% in Ireland, 5.7% in Denmark, and 6.1% in the EU27 in the Lancet_low scenario. In the Lancet_full scenario, the declines are much greater, at 41.5% in Ireland, 58.1% in Denmark, and 62.4% in the EU27.

In all three regions, trade effects mitigate declines in milk and pig production. In Ireland and Denmark, pig production falls by approx. 1% to 15%, larger reductions appear in the EU27 (2.7%–26.7%). Milk production remains stable in the Lancet_low scenarios, but in the Lancet_full it experiences a larger decline of around 30% in Denmark and the EU27. The decline in production in Ireland is smaller, at 3.3%, due to higher exports of dairy products. Horticultural production increases due to increased demand for fruits, vegetables, legumes, and nuts, with the largest relative increases observed in Ireland (up to 80.2% in the Lancet_full scenario) and significant increases in Denmark and the EU27 of 32.7% and 47.1%, respectively.

3.3. Trade effects

Beef and pork meat exports from Ireland and Denmark predominantly decline to EU+ countries and cannot be offset by non-EU+ exports (table 2). Beef exports in particular are not competitive on the world market and are in sharp decline in the Lancet_full scenario, both in Ireland (−75.0%) and Denmark (−73.2%) and in the EU27 (−63.3%). While pig meat exports from Ireland and Denmark fall overall mainly due to lower demand in the EU+, at the EU27 level pig meat exports can increase by up to 11.2%, mainly going to Asia including China. Sheep- and goat meat exports increase in Denmark and the EU27, but the absolute increases are relatively small (supplementary data). In contrast, dairy exports show a different trend. Ireland and the EU27 can expand dairy exports to Asia, North America and the Middle East and North African (MENA) countries, compensating for declines in EU+ exports and leading to total export growth of up to 18.8% in Ireland and 60.2% in the EU27 in the Lancet_full scenario. Denmark can also increase dairy exports, primarily to MENA countries, but the increase is modest compared to the loss of exports to other EU+ countries, particularly in the Lancet_full scenario where dairy exports decrease by 19.2%. Horticultural exports can be increased in Ireland (+55%) and Denmark (+2.3%), especially to other EU+ countries, but absolute levels remain relatively low.

On the import side, all three regions reduce imports of animal products by up to 80%. Beef imports decline mainly from EU+ countries and South America, while pork imports decrease mainly from Asia. Imports of dairy products primarily decrease from Australia/New Zealand, MENA, and North America. However, there is a contrasting trend for horticultural products, with Ireland, Denmark, and the EU27 increasing imports from South America and Africa, particularly in the Lancet_full scenario where EU27 imports increase by 221.3%.

3.4. Changes in agricultural incomes

In MAGNET, sectoral income is measured as value added evaluated at producer prices. The overall income effects in the primary agricultural sector are decisively influenced by the income potential of horticulture and by trade effects (table 2).

In the Lancet_low and Lancet_high scenarios, income gains in horticulture in Ireland are insufficient to compensate for income losses in livestock farming, resulting in a slight decrease of up to 0.2%. In the Lancet_full scenario, the Irish agricultural sector achieves a 1.1% income gain due to positive developments in horticulture and relatively small losses in dairy cattle farming, driven by increases in dairy exports. Conversely, in Denmark, income gains in horticulture can offset losses in livestock farming in the Lancet_low and Lancet_high scenarios. However, in the Lancet_full scenario, relatively low dairy exports lead to a 39.1% loss in dairy income, contributing to a 7.2% reduction in total primary agricultural income.

In the EU27, dairy farming experiences the highest absolute losses, followed by cattle farming. Income losses in pig farming are smaller in comparison, partly due to the greater export potential of pork to Asia. In addition, the substantial income gains in horticulture, driven by rising demand and production, lead to an overall increase in primary agricultural sector income of 17.4% in the Lancet_full scenario.

4. Discussion and conclusion

This study examines the effect of adopting the EAT-Lancet commission's recommended planetary health diet on GHG emissions and agricultural incomes in the EU27, Ireland and Denmark, using the CGE model MAGNET. The dietary change involves a reduction in the consumption of animal-based foods, which can significantly affect agricultural sectors with intensive livestock production. The overall effect on agricultural incomes is mainly influenced by changes in horticultural and animal-based production. In the EU27, increased income from horticultural production offset losses from livestock, leading to positive income effects in all scenarios. A full dietary transition leads to an EU-wide increase in income of 17.4%. In Ireland, a moderate dietary shift leads to income losses, but a full transition results in an income gain of 1.1%, driven by strong growth in horticulture, while losses in dairy could be muted with higher exports. On the other hand, Denmark experiences income gains of up to 0.8% for partial dietary shifts, but income losses of 7.2% for full adoption of the EAT-Lancet diet due to the lack of export potential for livestock products.

With respect to agricultural GHG emissions, in Ireland, where beef and dairy production dominate the agricultural sector, reductions of up to 26.4% or 5.4 Mt CO_2-equivalent compared to the 2050 baseline are possible if the EAT-Lancet diet is fully implemented. In Denmark, where pig farming plays an important role, agricultural GHG emissions can be reduced by up to 21.7%, or 1.9 Mt CO_2-equivalent. In the EU27 full adoption of the EAT-Lancet diet could reduce GHG emissions by 29.3% or 111.9 Mt CO_2-equivalent. Particularly large reductions are possible for methane emissions from cattle farming, which could fall by more than 30% in Ireland and Denmark and by more than 40% in the EU-27 with full adoption of the EAT-Lancet diet. Adopting this diet also has a wider impact, reducing total emissions by 9.0% in Ireland, 4.8% in Denmark and 3.7% in the EU27, with the largest reductions of 13% to 21% for methane. Global agricultural emissions could be reduced by 2.4% or 193.7 Mt CO_2-equivalent.

Our findings diverge from previous studies conducted by Semba *et al* (2020) and Springmann *et al* (2020). These studies estimated more substantial reductions in agricultural emissions for Ireland and Denmark, ranging from 66% to 79%, by fully implementing the EAT-Lancet diet. The main factor contributing to these differences is that their studies assessed the impact of a global dietary change, whereas our study only evaluates the consequences of a change in the EU+ diet, leaving the diets of other countries unchanged. However, other recent studies by Clora *et al* (2021), Osei-Owusu *et al* (2022) and Rieger *et al* (2023) analyze the effects of changing diets in European countries and yield results relatively similar to our findings. Rieger *et al* (2023), using the MAGNET model, simulate a potential 22% reduction in agricultural emissions in the EU27 through the full implementation of the EAT-Lancet diet in 2050. Osei-Owusu *et al* (2022) employing an environmentally extended multi-regional input–output model, estimate substantial reductions in food-related GHG emissions, reaching −34% for a meat-free diet and a 50% reduction in dairy consumption. A scenario more similar to our simulations, involving a 50% reduction in meat and dairy consumption with plant-based food substitution, leads to a reduction potential of 26% compared to the BAU scenario in 2011. Unlike the scenario analysis conducted in this paper for the year 2050, Clora *et al* (2021) incorporate sustainable and healthier dietary changes directly into their baseline projections. Their estimates suggest a potential reduction in agricultural GHG emissions of 22% between 2014 and 2050. When coupled with advanced agricultural practices, emissions could be reduced by 31% compared to 2014 levels. In line with our study, Rieger *et al* (2023) and Osei-Owusu *et al* (2022) emphasize the particular reduction potential of reduced beef consumption, while the results of Clora *et al* (2021) highlight the significant impact of dietary changes in general compared to supply-side measures and underline the central role of dietary changes in achieving emission reductions.

Dietary changes have the potential to significantly reduce agricultural GHG emissions in the EU, and policymakers should actively promote these changes. Livestock-intensive countries like Ireland and Denmark, where substantial reductions in methane emissions are possible, offer a high potential for immediate emission savings through the promotion of plant-based diets. However, challenges exist in the agri-food chain due to significant income losses in livestock farming and the need for extensive restructuring towards plant-based food production. Policymakers should also implement measures to mitigate income losses in livestock farming, such as facilitating conversion or diversification into horticulture. The results of the study also show that livestock production in the regions analyzed is export-oriented, which allows partial offsetting of emission reductions through increased exports, especially for competitive animal products such as dairy. To achieve effective emission reductions, policymakers need to monitor export dynamics to prevent increasing exports to non-EU countries offsetting emission reductions achieved through dietary changes. Additionally, dietary changes primarily reduce methane emissions, highlighting the need to integrate methane mitigation strategies into climate plans, as methane reductions have more immediate climate benefits compared to CO_2 emissions. By addressing these implications and taking targeted action, policymakers can effectively promote sustainable dietary changes and achieve significant reductions in agricultural GHG emissions.

The present study focuses primarily on examining the economic implications and GHG emissions associated with dietary changes. One limitation of our analysis is that carbon stock changes associated with land use change, which together with CO_2 emissions from forestry account for 11% of global emissions, are not modeled (IPCC 2014, Chepeliev 2020). This is an important dimension that should be modeled in future work. It should also be noted that achieving substantial reductions in GHG emissions may require shifts in consumption patterns beyond dietary changes (Costa *et al* 2021). Additionally, adopting the EAT-Lancet diet can have various environmental impacts beyond GHG emissions such as on water or land use (Springmann *et al* 2020) and other spillover effects on other non-agricultural sectors or social dimensions that are not considered in this analysis. Furthermore, our analysis primarily focuses on dietary changes and their consequences within Europe. While the savings in GHG emissions could be significantly greater if diets also change in other countries

(Semba *et al* 2020, Springmann *et al* 2020), the specific impact on agricultural incomes is uncertain, as dietary adjustments can vary among low-, middle-, and high-income countries (Semba *et al* 2020). While the export opportunities for animal products from the EU to other high-income countries may decline, there could be a rise in opportunities for exporting animal products to low- and middle-income countries. Future research should explore the broader impacts and potential trade-offs associated with dietary changes in countries with different production focusses to provide a more comprehensive understanding of their effects on environment, economy and societal well-being.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Acknowledgment

This work was conducted as part of the MACSUR SciPol III (Modelling European Agriculture with Climate Change for Food Security Science-Policy Knowledge Forum) project under the framework of the European FACCE-JPI. We acknowledge funding from the Federal Ministry of Food and Agriculture (BMEL), through the project FKZ 2821ERA04J. We thank the participants from the MACSUR SciPol and the anonymous reviewers for their useful comments and suggestions.

Appendix

I. Greenhouse gas emissions in Ireland and Denmark

80% of EU-wide emissions excl. LULUCF are caused by CO_2. In the agricultural sector, however, emissions follow a different pattern, with methane as the largest contributor and nitrous oxide as the second largest (figure A1). In Ireland, methane emissions mainly from enteric fermentation and manure management represented 54% of total agricultural emissions in CO_2-equivalent in 2020. Nitrous oxide emissions mainly from manure management and agricultural soils, accounted for 46% of total agricultural emissions. CO_2 accounted for only 2% of total emissions.

The relatively large importance of the agricultural sector results in a different emissions profile in Ireland than the EU average with relatively larger shares of methane and nitrous oxide emissions. Carbon dioxide accounts for the majority of total Irish emissions at 61%, but more than a quarter is caused by methane (26%) and 12% by nitrous oxide (figure A1).

Compared to 1990, annual GHG emissions in Ireland have increased by 6%, from approximately 54.4–57.7 million tons (Mt) CO_2-equivalent in 2020 (figure A2). The strongest emission increases are observed in the agricultural sector, which rose by 12% or about 2.2 Mt CO_2 compared to 1990. These increases in the agricultural sector are primarily attributable to higher methane emissions resulting from increased production due to increased livestock numbers and higher milk yields per cow (EPA 2022; EEA 2022).

The influence of the agricultural sector on the structure of total emissions is also evident in Denmark. Overall, 68% of total emissions in CO_2-equivalent are caused by carbon dioxide, 17% by methane and 14% by nitrous oxide. In the agricultural sector, most emissions are caused by methane (52%) and nitrous oxide (45%) (figure A1).

In contrast to Ireland, Denmark succeeded in reducing both, total emissions from 71.1 to 41.7 Mt CO_2-equivalent (−41%) and agricultural emissions from 13.3 to 11.3 Mt CO_2-equivalent (−16%). The savings in agricultural emissions are primarily due to reductions in nitrous oxide emissions from agricultural soils. This decrease is due to a national environmental policy aimed at preventing nitrogen losses from agricultural soils to the aquatic environment, which has led to a large decrease in the use of inorganic fertilizers (Nielsen *et al* 2022). Nevertheless, savings in the agricultural sector have been lower compared to savings in the energy, waste, and industry sectors, so that the relative share of agricultural emissions in total emissions has increased from 19% in 1990 −27% in 2020 (figure A3).

II. The MAGNET model

MAGNET, www.magnet-model.eu is a CGE model based on microeconomic theory that describes all activities and agents in an economy, including production, consumption, trade, taxation and saving, and the linkages and feedbacks between them.

It is based on the GTAP model but with a more detailed representation of the agricultural sector, its upstream sectors and the food industry. One key feature of MAGNET is its utilization of a more comprehensive multilevel sector-specific nested constant elasticity of substitution production function. This allows for substitution not only between primary production factors like land, labor, capital, and natural resources but also between different intermediate input components. For example, MAGNET considers various types of land with imperfect substitutability and permits substitution between different animal-feed components in the agricultural sector. In terms of factors markets, MAGNET introduces segmentation and imperfect mobility between agriculture and non-agriculture labor and capital (Keeney and Hertel 2005, Woltjer and Kuiper 2014).

Land data from GTAP (in values) is matched with land data from the IMAGE model (in km^2) in the MAGNET model. Land supply is treated as

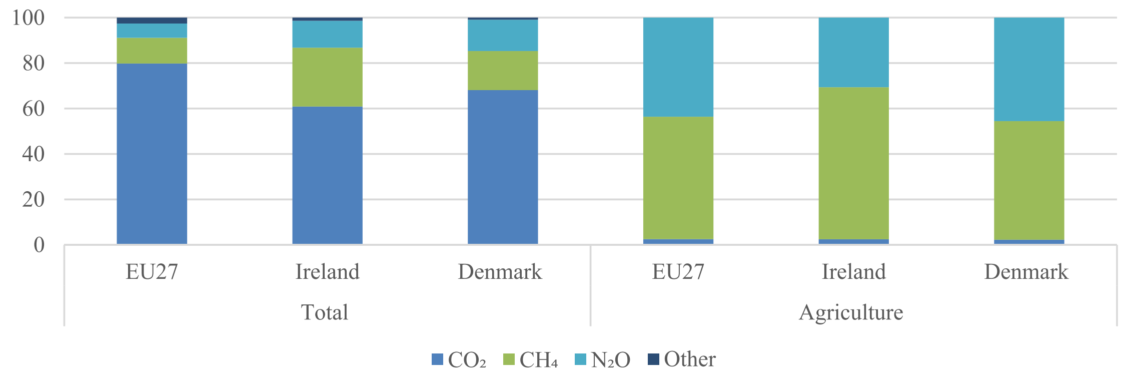

Figure A1. Share of gases in total and agricultural emissions in the EU27, Ireland and Denmark [%]. Source: EEA (2022).

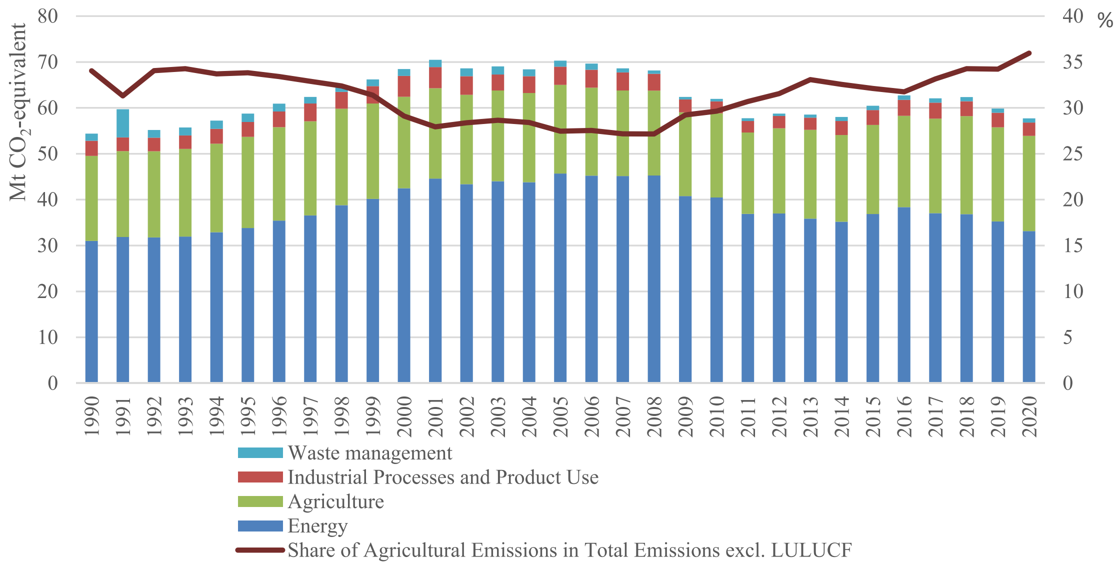

Figure A2. Total emissions in Ireland [Mt CO_2-eq.] and share of agricultural emissions in total emissions [%]. Source: EEA (2022).

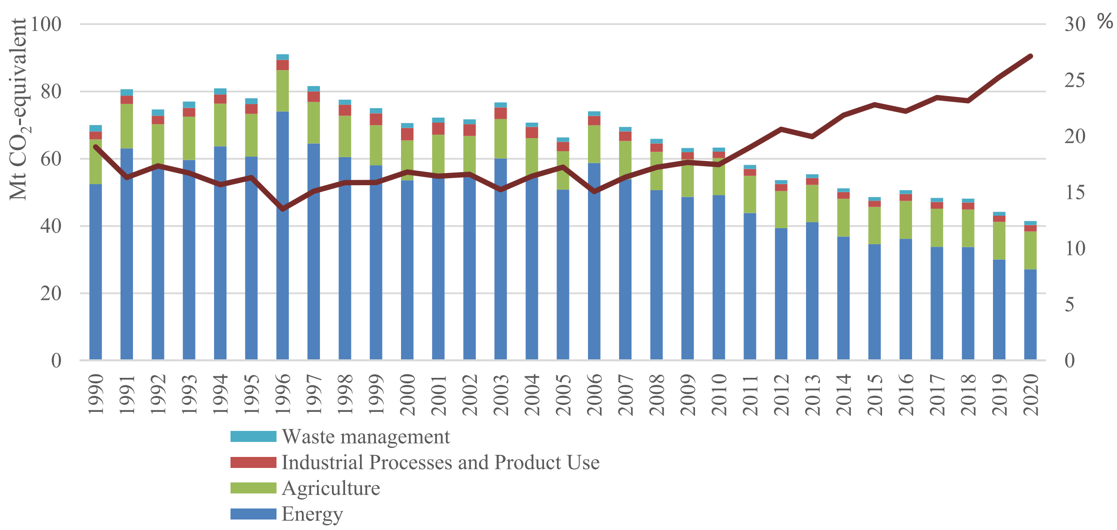

Figure A3. Total emissions in Denmark [Mt CO_2-eq.] and share of agricultural emissions in total emissions [%]. Source: EEA (2022).

endogenous, allowing for additional agricultural land in response to increases in land rents. To limit the land that can be transformed for agriculture a so-called land asymptote is introduced to the model that implements an upper bound of land that can be used for agricultural purposes. The asymptote is calibrated such that it describes 'the total available land excluding non-productive land (mainly ice and desert in regions like Canada and the Middle East), urban areas and protected reserves to take into account nature conservation' (Eickhout *et al* p. 215) and was updated with data from the IMAGE model to reflect more recent developments (Doelman *et al* 2018). The model also features a CET function which takes different substitutability of different land types into account. This implies that, e.g. the substitution elasticity of land that is transformed from pasture to horticulture is different from the elasticity that governs the substitution of land from grain to oilseeds (Woltjer and Kuiper 2014).

On the consumption side, MAGNET and GTAP implement an aggregated CDE implicit expenditure function, which was first proposed by Hanoch (1975). The non-homothetic CDE function allows goods and services to have different income elasticities. The demand system in MAGNET also adjusts income elasticities over time in line with GDP growth. This is particularly important for food, whose share in the household budget declines as income rises. In addition, the demand system is extended by an exogenous taste shifter which allows to increase or decrease the preference for a particular commodity while respecting the budget constraint (Woltjer and Kuiper 2014).

The regions in the MAGNET model are connected by trade flows, which are subject to border policies, transport costs, and the Armington assumption. The Armington assumption allows for the distinction of goods based on their origin and enables the trading of similar products between countries (Armington 1969).

The current version of MAGNET uses the GTAP 10 database, which provides a consistent representation of the global economy for the reference year 2014 (Aguiar *et al* 2019). MAGNET covers 141 regions and countries, 113 economic sectors and 127 commodities (Woltjer and Kuiper 2014, Kristkova 2020). The sectoral and regional aggregation used for this model-based analysis can be found in tables A1 and A2.

We chose a CGE instead of PE model, although PE models usually have a higher resolution in terms of agricultural products and sectors. CGE models, however, cover several parts of the value chain from primary agriculture to processed food and final consumption. They also capture the interdependence with agriculture and the rest of the economy. In addition, due to larger supply side elasticities, we believe that CGEs are better suited to model long-run scenarios like ours, see Rieger *et al* (2023). Ideally, this study would be complemented by PE models for the Irish and Danish agricultural sector in future research.

III. Scenario description

The BAU scenario is based on the GDP and population development of the SSP2 scenario. Emission intensities, which measure emissions per unit of output, are also influenced by specific factors inherent to our model in our BAU scenario. Within the SSP2 baseline, emission intensities change due to assumptions about technological progress, including changes in yields due to technological improvements or changes in feed efficiency in livestock production (Pérez-Domínguez *et al* 2021). The development of agricultural emissions from 2014 to 2050 in Ireland, Denmark and the EU27 can be seen in table A3.

We utilized the MAGNET model to project diets specific to countries and commodities, aligning them with baseline developments until 2050. We calculate the difference between the projected diets and the EAT-Lancet recommendations for a 2500 kcal diet per capita per day in 2050 to derive three scenarios, including full implementation (Lancet_full), 10% shift (Lancet_low), and 30% shift (Lancet_high) towards the EAT-Lancet diet. The benchmark diets for 2014 are shown in table A4 and for 2050 are shown in table A5. The required percentage changes in demand for each food group for all EU+ regions are shown in table A6.

The dietary changes are implemented as exogenous changes in consumer preferences by a shifter variable in the private demand system. In the provided code below, the variable ap(i,r) represents the exogenous preference for a commodity i in region r, which can be adjusted to increase or decrease the preference for particular commodities. If the preference for a particular commodity is increased by a positive shock to ap(i,r) in all regions, it would lead to an increase in the demand for this good. However, all else equal, this would violate the budget constraint. To address this, the ap_ave(r) variable is introduced, which affects the demand for all commodities equally. It ensures that the private household's budget remains unchanged by shifting the demand for all goods simultaneously. The adjustment required to maintain the budget is determined by the equation AF_AVE1.

An increase in demand for a particular good implemented by the taste shifter ap(i,r) reduces demand for other commodities through the ap_ave(r) term in the demand equation. The variable ap(i,r) acts as a shifter that affects the share of total private household consumption devoted to commodity i in region r. As a result, it also impacts

Table A1. Regional aggregation used in the scenario analysis.

Aggregate	Included regions and countries
AUS	Austria
EU8	Belgium, Finland, Greece, Italy, Luxembourg, Portugal, Spain, Sweden
CEEC13	Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia
DEN	Denmark
FRA	France
DEU	Germany
IRE	Ireland
NLD	Netherlands
GBR	United Kingdom
EFTA	Switzerland, Norway, Rest of EFTA
RUS	Russian Federation
UKR	Ukraine
ASIA	Hong Kong, Korea, Taiwan, Rest of East Asia, Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Philippines, Singapore, Thailand, Vietnam, Nepal, Pakistan, Sri Lanka, Bangladesh, Rest of Southeast Asia
CHN	China
JPN	Japan
IND	India
CAN	Canada
USA	United States of America, Rest of North America,
ANZ	Australia, New Zealand
MEX	Mexico
ARG	Argentina
BRA	Brazil
CSAM	Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Puerto Rico, Trinidad and Tobago, Jamaica, Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Rest of Central America, Dominican Republic
TUR	Turkey
MENA	Bahrain, Israel, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates
MED	Egypt, Morocco, Tunisia, Rest of North Africa
AFRICA	Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Guinea, Nigeria, Senegal, Togo, Rest of Western Africa, Central Africa, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Tanzania, Uganda, Zambia, Zimbabwe, Rest of Eastern Africa, Kenya, South Africa, Rest of South African Customs, South Central Africa, Ethiopia, Botswana, Namibia
ROW_NWTO	Belarus, Rest of Oceania, Rest of South America, Rest of Eastern Europe, Rest of Europe, Kazakhstan, Azerbaijan, Iran Islamic Republic of, Rest of Western Asia, Rest of the World
ROW_WTO	Mongolia, Caribbean, Albania, Kyrgyzstan, Tajikistan, Armenia, Georgia, Rest of Former Soviet Union

Source: own representation of the regional aggregation in the MAGNET model.

the income elasticity of demand and price elasticity of demand, which are determined by the consumption shares. The taste shifter is also linked to production via a technology change variable. In this way, we were able to shift not only household demand, but also out-of-home consumption of animal and plant-based foods through the service sector and the use of these foods through processed foods according to the EAT-Lancet diet (Woltjer and Kuiper 2014).

Table A2. Aggregation of agricultural sectors used in the scenario analysis.

Aggregate	Included sector and commodities
pdr	Rice: seed, paddy (not husked)
wht	Wheat: seed, other
grain	Other Grains: maize (corn), sorghum, barley, rye, oats, millets, other cereals
hort	Veg & Fruit: vegetables, fruit and nuts, edible roots and tubers, pulses
oils	Oil Seeds: oil seeds and oleaginous fruit
sug	Cane & Beet: sugar crops
oagr	Fibres crops
crops	Other crops
cattle	Cattle (live animals)
othctl	Other ruminants, sheep and goats, horses and other equines (live animals)
pltry	Poultry (live animals)
pigpls	Swine (live animals)
milk	Raw milk
bfmt	Cattle Meat: fresh or chilled; meat of buffalo, fresh or chilled;
othcmt	Meat of sheep, fresh or chilled; meat of goat, fresh or chilled; meat of camels and camelids, fresh or chilled; meat of horses and other equines
pulmt	Poultry meat, fresh or chilled
othmt	Other Meat: meat of pigs, fresh or chilled
wol	Wool: wool, silk, and other raw animal materials used in textile
frs	Forestry: forestry, logging and related service activities
dairy	Milk: dairy products
pcr	Processed Rice: semi- or wholly milled, or husked
sugar	Sugar and molasses
vol	Vegetable Oils
cvol	Vegetable raw oils
ofd	Other Food: processed food incl. Beverages and Tobacco products
feed	Processed animal feed
ddgs	DDGS
oilcake	Oilcake
fishm	Fish meal
wfish	Wild fish
aqcltr	Aquaculture
fishp	Processed fish
res	Residuals of crop production
plan	Plantings
pel	Pellets
fert	Fertilizer
biog	Bioethanol (1. Generation)
eht	Bioethanol (2. Generation)
biod	Biodiesel

Source: own representation of the aggregated sectors in the MAGNET model.

Table A3. Emissions from primary agriculture in Ireland, Denmark and the EU27 in Mt CO_2-equivalent.

	EU27	Ireland	Denmark
2014	436.22	18.92	11.11
2050	382.01	20.50	8.89

Source: own simulations with the MAGNET model.

Table A4. Benchmark diets 2014 by food group in kcal/capita/day.

MAGNET sector	Austria	EU8	France	Germany	Netherlands	Ireland	Denmark	CEEC13	UK	EFTA
Wheat	401	439	435	367	314	439	415	462	429	384
Rice	22	56	37	35	22	20	38	28	38	33
Other grains	121	62	58	123	25	87	87	149	39	47
Horticulture[a]	282	292	230	238	294	280	238	254	329	206
Vegetable oils	469	449	421	415	410	338	148	322	401	313
Sugar	349	268	297	318	362	248	323	262	272	356
Beef meat	58	75	85	41	85	113	87	34	69	65
Lamb meat	6	19	18	5	5	28	5	8	33	57
Pork meat	297	190	215	231	150	166	231	166	210	222
Poultry meat	57	59	80	47	62	88	60	73	95	46
Dairy products	286	355	363	326	453	383	331	274	326	412
Eggs	45	38	49	42	62	25	73	40	35	33
Fish	19	33	38	19	33	26	43	15	26	35
Total calories	2833	2390	2786	2655	2697	2698	2515	2101	2726	2336

Source: own calculations based on Springmann 2019 and the MAGNET model.

[a] including roots, vegetables, fruits, legumes and nuts.

Table A5. Benchmark diets 2050 by food group in kcal/capita/day.

MAGNET sector	Austria	EU8	France	Germany	Netherlands	Ireland	Denmark	CEEC13	UK	EFTA
Wheat	382	436	438	364	338	474	439	450	433	405
Rice	30	56	46	41	21	31	45	32	38	34
Other grains	121	61	57	131	24	94	84	143	38	46
Horticulture[a]	288	307	244	255	303	300	247	251	332	204
Vegetable oils	462	427	431	477	404	369	146	308	401	314
Sugar	354	271	325	326	371	305	288	267	267	331
Beef meat	62	81	86	42	84	140	85	42	65	67
Lamb meat	5	11	14	2	1	39	3	8	22	30
Pork meat	248	213	302	234	69	186	236	126	210	269
Poultry meat	69	67	111	76	57	130	70	78	114	52
Dairy products	308	348	378	352	450	465	378	277	317	434
Eggs	55	43	69	67	57	36	85	43	42	37
Fish	22	32	38	19	31	29	43	14	28	35
Total calories	2824	2401	2957	2803	2628	3016	2568	2033	2724	2394

Source: own calculations based on Springmann 2019 and the MAGNET model..

[a] including roots, vegetables, fruits, legumes and nuts.

Table A6. Changes in food consumption to reach EAT-Lancet planetary health diet [2500 kcal/capita/day] compared to benchmark diet 2050.

	Austria	EU8	France	Germany	Netherlands	Ireland	Denmark	CEEC13	UK	EFTA
					Lancet_low					
Wheat	8.4	8.7	9.7	9.5	13.5	6.9	9.2	8.1	8.0	11.5
Other grains	5.2	8.4	10.9	7.6	14.7	6.3	9.6	5.9	7.5	9.6
Rice	1.8	8.4	6.7	6.2	15.8	1.3	6.5	7.1	7.9	11.5
Horticulture	15.9	12.0	17.2	18.7	17.2	16.1	17.2	18.6	14.4	23.6
Vegetable oils	0.4	0.7	−0.5	−1.3	0.3	−0.3	16.3	2.8	0.4	2.5
Sugar	−6.8	−5.9	−6.6	−6.6	−7.0	−6.4	−6.2	−5.9	−5.9	−6.6
Beef meat	−9.3	−9.1	−9.0	−9.1	−8.8	−9.3	−9.2	−9.0	−8.8	−8.9
Pork meat	−9.2	−9.2	−9.4	−9.2	−7.7	−9.3	−9.3	−8.4	−9.0	−9.1
Poultry meat	−4.5	−4.5	−6.0	−4.9	−3.4	−7.1	−4.3	−5.1	−6.6	−3.0
Dairy products	−5.9	−6.2	−6.4	−6.4	−7.2	−6.8	−6.7	−4.9	−5.8	−6.5
Lamb meat	−9.2	−8.3	−8.8	−7.5	−4.1	−9.4	−8.7	−8.7	−8.2	7.8
Eggs	−6.7	−5.8	−7.3	−7.3	−6.8	−5.0	−7.7	−5.8	−5.7	−5.1
Fish	5.2	1.0	−2.4	6.3	1.3	0.1	−0.4	14.6	0.5	1.0
Total Calories	−1.1	0.4	−1.5	−1.1	−0.5	−1.7	−0.3	2.3	−0.8	0.4
					Lancet_high					
Wheat	25.2	26.2	29.2	28.6	40.4	20.7	27.6	24.3	24.0	34.5
Other grains	15.5	25.3	32.6	22.8	44.2	18.8	28.8	17.7	22.4	28.9
Rice	5.5	25.1	20.1	18.6	47.3	3.8	19.5	21.2	23.6	28.9
Horticulture	47.8	36.0	51.7	56.1	51.6	48.3	51.7	55.8	43.1	70.7
Vegetable oils	1.2	2.2	−1.6	−4.0	0.9	−1.0	48.9	8.3	1.2	7.4
Sugar	−20.5	−17.7	−19.8	−19.8	−21.1	−19.1	−18.5	−17.7	−17.6	−19.8
Beef meat	−28.0	−27.2	−27.1	−27.3	−26.5	−27.9	−27.7	−27.0	−26.4	−26.7
Pork meat	−27.7	−27.5	−28.1	−27.5	−23.0	−27.9	−28.0	−25.3	−26.9	−27.4
Poultry meat	−13.6	−13.5	−17.9	−14.7	−10.1	−21.3	−12.9	−15.2	−19.9	−9.1
Lamb meat	−27.6	−24.9	−26.3	−22.5	−12.2	−28.1	−26.1	−26.2	−24.7	−9.1
Dairy products	−17.8	−18.7	−19.3	−19.3	−21.7	−20.3	−20.1	−14.7	−17.5	−19.4
Eggs	−20.1	−17.3	−22.0	−21.8	−20.3	−15.0	−23.0	−17.3	−17.1	−15.2
Fish	15.6	2.9	−7.3	18.8	3.8	0.2	−1.3	43.7	1.5	3.1
Total Calories	−3.4	1.2	−4.6	−3.2	−1.5	−5.1	−0.8	6.9	−2.5	1.3

(Continued.)

Table A6. (Continued.)

	Lancet_full									
Wheat	84.2	87.2	97.2	95.3	134.6	68.8	92.2	81.1	79.9	115.0
Other grains	51.5	84.3	108.5	76.0	147.3	62.7	95.8	59.0	74.6	96.4
Rice	18.5	83.5	67.0	61.9	157.8	12.8	65.0	70.6	78.8	107.0
Horticulture	159.2	119.9	172.4	187.0	172.1	161.0	172.5	185.9	143.8	235.8
Vegetable oils	3.8	7.4	−5.4	−13.5	2.9	−3.5	162.9	27.8	3.9	24.7
Sugar	−68.4	−59.0	−65.9	−66.1	−70.2	−63.8	−61.8	−58.8	−58.7	−65.9
Beef meat	−93.4	−90.7	−90.5	−91.1	−88.2	−93.0	−92.4	−89.9	−88.0	−88.9
Pork meat	−92.3	−91.7	−93.6	−91.6	−76.7	−92.9	−93.2	−84.4	−89.6	−91.3
Poultry meat	−45.4	−45.1	−59.7	−49.2	−33.8	−70.9	−43.0	−50.6	−66.5	−30.4
Lamb meat	−91.8	−82.9	−87.6	−74.9	−40.6	−93.5	−86.8	−87.5	−82.4	−78.8
Dairy products	−59.3	−62.3	−64.3	−64.4	−72.2	−67.5	−66.9	−49.1	−58.5	−64.6
Eggs	−66.9	−57.6	−73.3	−72.5	−67.6	−49.9	−76.6	−57.6	−56.8	−50.7
Fish	52.0	9.6	−24.5	62.7	12.5	0.5	−4.2	145.5	5.1	10.3
Total calories	−11.5	4.1	−15.5	−10.8	−4.9	−17.1	−2.7	23.0	−8.2	4.4

Source: own calculations based on Springmann 2019 and the MAGNET model.

[a] including roots, vegetables, fruits, legumes and nuts.

Model code:

Variables

qp(i, r): *private household demand for commodity i in region r*

pp(i, r): *private consumption price for commodity i in region r*

pop(r): *regional population in region r*

yp(r): *regional private consumption expenditure in region r*

ap(i, r): *taste change in favor of commodity i in region r #*;

ap_ave(r): *average taste change in region r*;

Coefficient

VPA(i, r): *private household expenditure on commodity iin region r*

Private household demand system

Equation QP1_GCON_M: *Private household demand system*(**all**, i)(**all**, r)

qp(i, r)-pop(r)=**sum**(k, EP(i, k, r)*pp(k, r))
+EY(i, r)*[yp(r)-pop(r)]+ ap(i, r)- ap_ave(r);

Equation AP_AVE1: *Average taste change in region r* (**all**,r)

sum{i, VPA(i, r)}*ap_ave(r)=**sum**[i,VPA(i, r)*ap(i, r)];

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