PLAN'EAT

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Recommendations and high impact areas for policy interventions

Deliverable D3.4

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Recommendations and high impact areas for policy interventions

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Nature of the deliverable		
R	Document, report (excluding the periodic and final reports)	X
DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patents filing, press & media actions, videos, etc.	
DATA	Data sets, microdata, etc.	
DMP	Data management plan	
ETHICS	Deliverables related to ethics issues.	
SECURITY	Deliverables related to security issues	
OTHER	Software, technical diagram, algorithms, models, etc.	

Dissemination level		
PU	Public	X
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CI	Classified, EU RESTRICTED, CONFIDENTIAL or SECRET under the Commission Decision No2015/444	

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Abbreviations

ESG	Environmental, Social and Governance	LCA	Life Cycle Assessment
EU	European Union	S-LCA	Social Life Cycle Assessment
FAO	Food and Agriculture Organization of the United Nations	TCA	True Cost Accounting
GHG	Greenhouse gas emissions	UPF	Ultra-processed food
GDP	Gross domestic product	VAT	Value-added tax
HSSF	High in added sugar, salt and/or fat	WTO	World Trade Organization
INRAE	Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement (eng: National Institute for Agricultural Research)		

Key concepts in this report

True Cost Accounting (TCA) is a framework designed to assess the hidden costs and benefits of agri-food systems by incorporating the full economic, environmental, social and health costs associated with food production and consumption.

High-impact foods are those that have a significantly negative effect on the environment and human health; e.g. in terms of high GHG emissions, water consumption and human toxicity, contributing to higher true costs.

High-impact areas highlight specific environmental and health impacts—such as GHG emissions, water consumption or human toxicity—that are the primary cost drivers of high-impact foods.

Foresight scenarios are strategic, forward-looking analyses that explore potential future developments in food production, consumption and sustainability.

Executive summary

Transforming food systems towards increased sustainability and improved public health is critical in order to address environmental degradation, social inequalities and health crises. The current global food system is responsible for significant hidden costs, including greenhouse gas emissions, biodiversity loss and the rise of diet-related diseases. True Cost Accounting (TCA) provides a holistic, systemic approach to uncover these hidden costs, thereby providing a powerful tool to ensure that policies and market mechanisms reflect the full environmental, health and social impacts of food production and consumption. As such, the goal of identifying and measuring true costs and benefits in food systems is to "internalize," or account for, them.

Using TCA, this report identifies high-impact foods consumed in the European Union as major contributors to environmental and health costs and social risks. The identified high-impact foods include red meat, and dairy. These findings underscore the necessity of shifting towards more plant-based diets to mitigate negative externalities. Additionally, the findings are supplemented with a literature review of foresight scenarios that reinforce these points and emphasize the importance of minimally processed diets, agroecology and food waste reduction as key aspects in the transformation towards sustainable food systems. Based on these two analyses, the report emphasizes the urgency of systemic change in agri-food systems and provides recommendations for policy interventions that facilitate this transition.

To drive this transformation, we propose adopting a systems thinking approach through the integration of TCA into the design and implementation of policies and interventions within agri-food systems. Additionally, we suggest a range of policy instruments that can be incorporated into policy packages to shift dietary patterns towards greater sustainability and health. These policy instruments fall under the categories of regulatory, fiscal, financial and information-based measures. The recommendations further outline future research priorities related to TCA.

Highlight from the report:

- **High-impact foods drive environmental, health and societal burdens.** Red and processed meat and dairy have the highest greenhouse gas emissions and health-related costs. Plant-based foods generally have lower external costs, though some (e.g. cocoa, coffee, almonds) pose environmental and social challenges. These findings on high-impact foods confirm existing knowledge on healthy and sustainable diets. The application of TCA further reinforces the evidence, providing a robust basis for guiding policy decisions for the necessary transition.
- **TCA can facilitate more effective policymaking**. TCA reveals the hidden costs of agri-food systems. Over 70% of true costs (USD 8.1 trillion globally) stem from hidden health costs linked to unhealthy diets (FAO, 2024a). TCA can provide a systems thinking approach for evaluating the full spectrum of environmental, social, economic and health impacts within the agri-food sector. This helps identify and address often overlooked interdependencies and impacts, supporting more integrated and holistic decision-making.
- **Strategies to facilitate a shift towards healthier and more sustainable diets.** It is essential to create an environment that encourages consumers to transition to more plant-based, nutrient-dense foods, while simultaneously reducing the consumption of ultra-processed foods, among which high-sugar, high-fat and/or high-salt foods. This shift is crucial for improving both planetary and public health. Key efforts should focus on increasing the availability, affordability and attractiveness of plant-based options. Recommended strategies include regulating marketing practices, adjusting food pricing, supporting innovation in plant-based food development, integrating TCA into food-based dietary guidelines and adopting TCA-based criteria in public procurement. These efforts should be complemented by comprehensive informational and educational campaigns that guide consumer choices toward healthier and more sustainable dietary patterns.

1. True cost of diets: Informing policy making with True Cost Accounting

The transformation towards healthy and sustainable food systems has become a pressing issue worldwide. An important part of this change requires a better understanding and quantification of the true costs and benefits associated with food production and consumption (FAO, 2023).

"True costs" (also often referred to as "hidden costs") relate to the negative consequences of economic activities or transactions that affect other parties, without being reflected in the price of the goods or services transacted (TEEB, 2018). Since nature and future generations cannot claim compensation, many of these costs remain hidden or are inequitably distributed. Most external costs, such as those resulting from the consequences of climate change, biodiversity loss and various forms of environmental degradation, are not adequately captured in existing economic valuation systems and ultimately burden society and future generations (Klaus et al., 2024). This also applies to hidden benefits or positive impacts associated with contributions from sustainable farming systems; e.g. ecosystem services such as soil carbon sequestration, pollination, biodiversity or nutrient cycles (Rehman et al., 2022).

True costs and benefits not only relate to the natural environment but also include important health and social dimensions. The United Nation's Food and Agricultural Organization (FAO) report, *The State of Food and Agriculture 2024*, shows that, on a global average, most of the true costs associated with foods (more than 70% or USD 8.1 trillion) are associated with hidden health costs related to unhealthy diets (FAO, 2024a). Diets high in ultra-processed foods (UPFs)[1], additives and animal products and low in plant-based foods and beneficial fatty acids increase the incidence of noncommunicable diseases such as obesity, cardiovascular disease, type 2 diabetes and different types of cancer (WHO, 2021). This diet-related deterioration of public health causes rising health care expenditure and loss of labour productivity, which is a drain on public finances, especially in low-income communities. The true cost of unhealthy diets was estimated to be approximately 9.5% of global gross domestic product (GDP) in 2020 (World Bank, 2025), highlighting the urgency of finding solutions and incentives for healthy diets.

The goal of identifying and measuring true costs and benefits in food systems is to "internalize" or account for them. This supports more informed and responsible decision-making in food production and consumption by fostering transparency across the entire food value chain, public policies and accounting rules (Hendriks et al., 2021). This transparency equips stakeholders—including policymakers, business actors along the value chain and consumers—with the information needed to better understand the environmental, health, social and economic impacts of their choices (Kennedy et al., 2023). By revealing the true costs, True Cost Accounting (TCA) provides a critical foundation for reducing negative impacts and guiding the transformation of agri-food systems toward sustainability (The Rockefeller Foundation, 2021).

In a food system context, TCA considers not only the financial resources and goods produced (produced capital) but also three other forms of capital: natural capital (the essential ecosystem services and natural resources that sustain food production); human capital (the roles of labour and expertise and the impacts on human health); and social capital (the networks, relationships and social norms that enable the production, distribution and consumption of food).

TCA systematically examines the dependencies of food systems on these forms of capital identifying potential risks and evaluates both the positive (hidden benefits) and negative (hidden costs) impacts of food systems on these capitals (Klaus et al., 2024). Applying TCA in the context of diets strengthens existing evidence on healthy and sustainable diets, guiding policy decisions for the necessary transition.

[1] Such foods, known as ultra-processed foods (UPF), include mainly carbonated soft drinks; sweet or savoury packaged snacks (e.g. chips); mass-produced packaged bread and rolls; margarine and other spreads; children's breakfast 'cereals'; powdered and packaged 'instant' soups and noodles; poultry and fish 'nuggets' and 'sticks'; reconstituted meat products; many (but not all) meat and dairy analogues; industrial ice cream, biscuits, pastries, cakes and cake mixes, confectionery, desserts, sausages, cold cuts, energy or some cereal bars.

The purpose of this report is threefold. Firstly, it provides key insights from an analysis on foods with high negative externalities ("high-impact foods") through a TCA-based analysis to determine which foods should be reduced or disincentivized in current diets. This is complemented by a literature review of foresight scenarios on food production and consumption, aimed at understanding proposed transitions and key leverage points for food systems transformation. Secondly, based on these insights, the report provides actionable policy recommendations for transitioning to sustainable food systems. Thirdly, the report highlights key insights and implications for future research on TCA. The primary target group for these recommendations includes policymakers and civil servants engaged in agri-food systems and related fields—such as health, education, trade and economic systems—at EU, national and subnational levels.

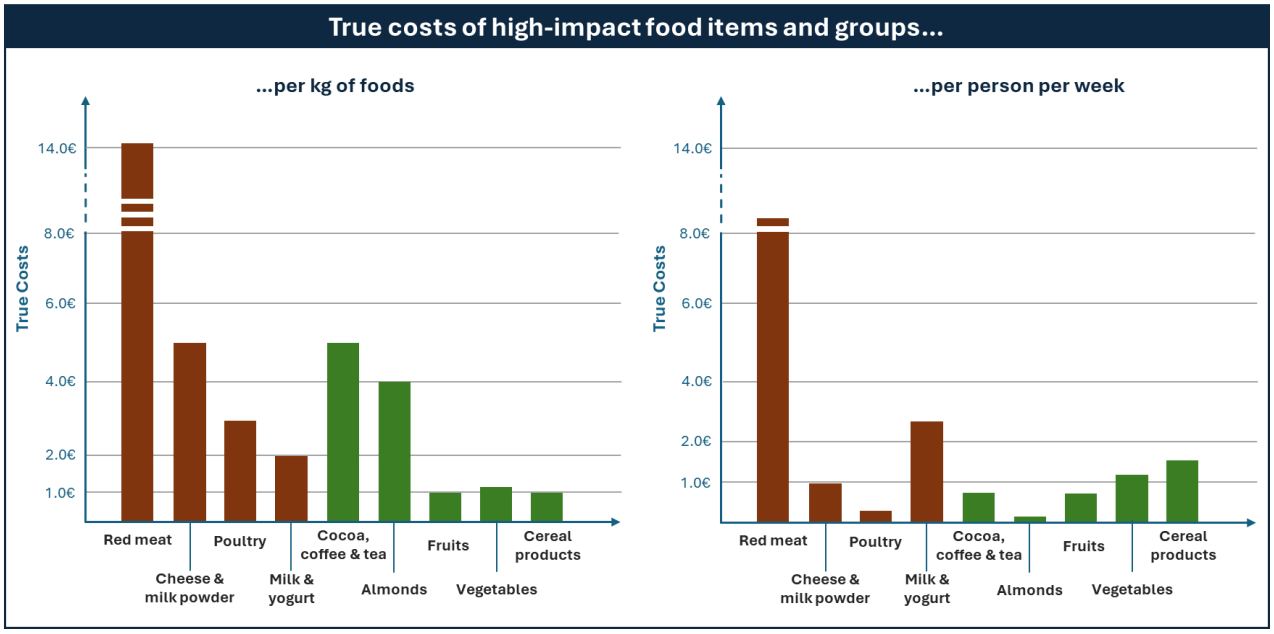
2. Levers for change: Identified high-impact foods and areas

This report is based on the analysis of three key data sources: (1) the True Costs of Food Database (PLAN'EAT T3.1); (2) TCA assessments of dietary patterns in three Living Lab countries (PLAN'EAT D3.3); and (3) a literature review of foresight scenarios for food production and consumption (PLAN'EAT T3.4). A detailed summary of the data sources can be found in the Appendix.

Building on the first two resources, we identified food items with high negative environmental, social and health impacts (referred to as "high-impact foods") and key areas of concern (referred to as "high-impact areas"), highlighting where interventions can potentially achieve the greatest positive impact. This analysis has been enriched by This analysis has been enriched with insights from foresight scenarios to identify leverage points for food system transformation at national, global and EU levels. We have utilized them to assess potential challenges and opportunities for a sustainable transition of food systems, enabling stakeholders to anticipate risks and develop strategic responses. It is important to note that although PLAN'EAT focuses mainly on the consumption side of food system transformation, this report also extends to the production side, as the scenario analyses indicate, production practices play a crucial role in shaping the sustainability outcomes of food choices and their wider impacts.

High-impact foods: The findings of the TCA analysis underscore that animal products—particularly red and processed meat and dairy—cause substantial environmental, health and social harm. Meat from ruminants, such as sheep, cattle and goats, has the highest true costs, which are driven by environmental impacts, especially greenhouse gas (GHG) emissions. This also applies to dairy products, especially cheese and highly processed items like milk powders. Red and processed meat are further associated with cardiovascular health risks, resulting in additional health costs, as well as social risks including labour exploitation within production chains. There are also relatively high environmental costs and social risks associated with certain plant-based products, such as cocoa, coffee, tea and almonds. However, it is important to note that true costs are calculated on a cost-per-kilogram basis. Since a serving size of cocoa, coffee, tea or almonds is far smaller than one of meat or milk, for example, the impact per serving is much lower compared to the per kilogram impact. Figure 1 demonstrated this in a comparison of the true costs of foods and food groups on a cost-per-kilogram basis versus a cost-per-weekly-portion basis.

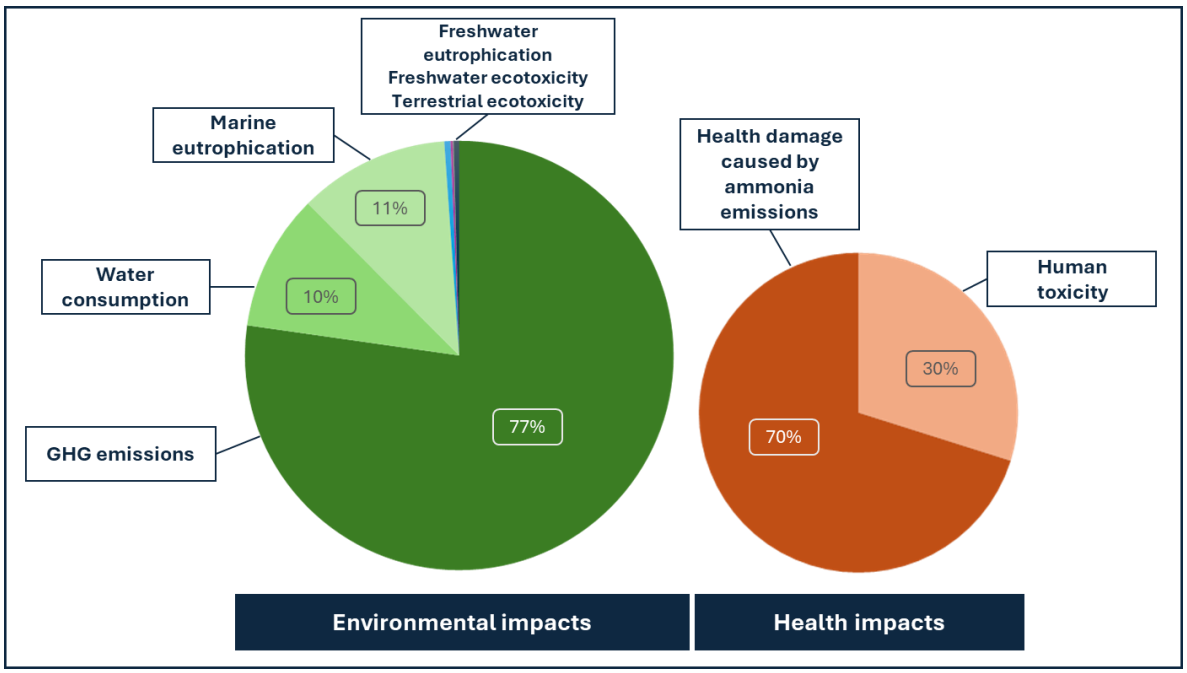
Figure 1: True costs of high-impact food items and food groups per kilogram of food/s versus per person per week



Note: Calculated costs contain environmental costs (GHG emissions, water consumption, marine and freshwater eutrophication, terrestrial and freshwater ecotoxicity) and production-related health costs (health damage caused by ammonia emissions and emissions to air, soil and/or water contributing to human toxicity). Data on portion sizes are exemplary for Germany and based on EFSA (2022) and NVSII (2008) data.

High-impact areas: Overall, environmental impacts—particularly GHG emissions—account for the largest share of production-related true costs. These costs are approximately 1.94 times higher than those related to health impacts from production (Figure 2). However, as mentioned previously, on a global average most true costs are associated with the hidden health costs of unhealthy consumption patterns (FAO, 2024a).

Figure 2: Shares of environmental and health impacts (high-impact areas) that drive the true costs of high-impact foods.



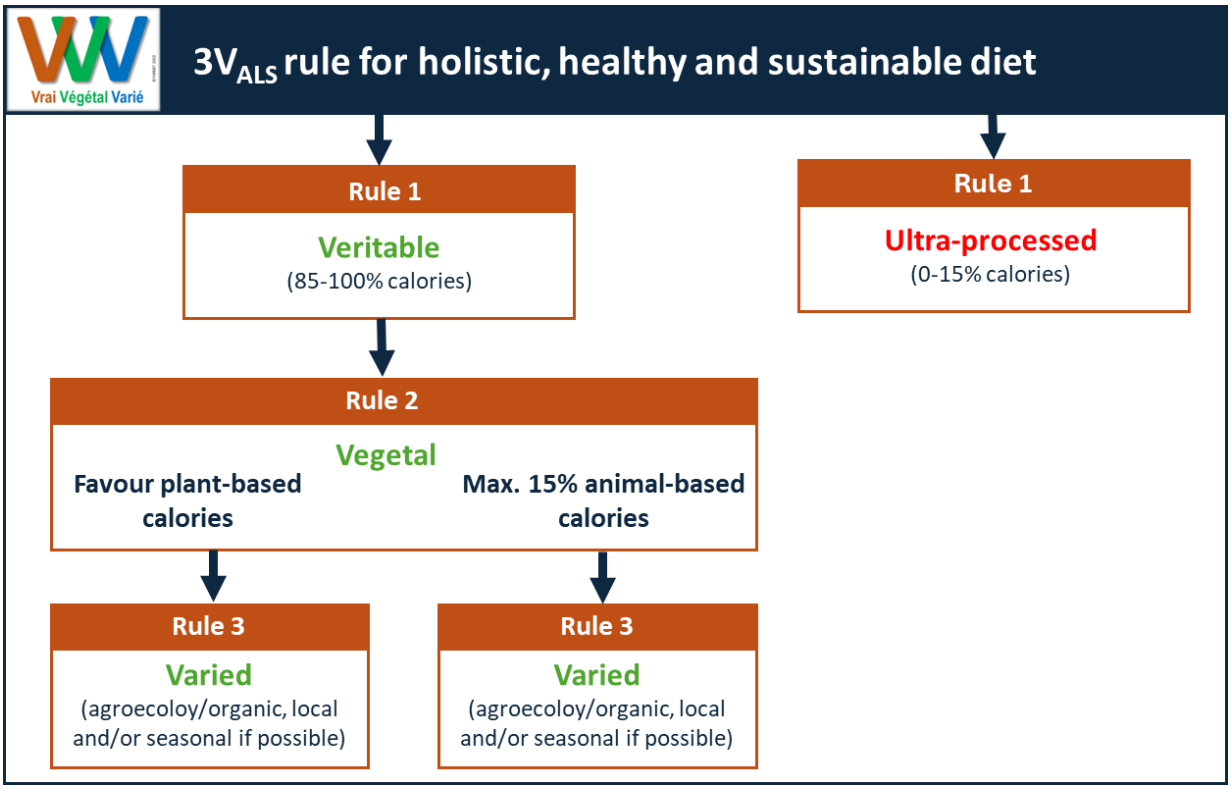
Note: The graphic is based on the True Costs of Food Database and therefore only includes production-related health impacts. The environmental impacts are 1.94 times larger than the health impacts, as visually represented by the proportional sizes of the pie charts.

Health-related costs are not only linked to consumption patterns but also to production-related health costs, such as those linked to respiratory disease from ammonia emissions released by manure and fertilizers. Here, also meat and dairy incur substantial health costs linked to harmful production practices, fuelling the development of carcinogenic and non-carcinogenic diseases.

The way forward, as outlined in foresight scenarios: The literature review of foresight scenarios aligns with these findings, underscoring the importance of transitioning to sustainable food systems by reducing animal-based food consumption and increasing plant-based diets. While certain plant-based foods—such as water-intensive crops (e.g. almonds) or greenhouse-grown vegetables (e.g. eggplants, cucumbers, peppers and tomatoes)—can have high environmental impacts, the overall external costs of plant-based foods remain substantially lower than those of animal products. The scenario analysis further reinforces the need for systemic change in food production and consumption. Key strategies may include adopting agroecological practices through organic farming (Solagro, 2014, Schiavo et al., 2021, Billen et al., 2021), relocating food production and transformation by supporting short food chains (Voglhuber-Slavinsky et al., 2021), reducing food waste (Aguilera et al., 2022, Solagro, 2014) and decreasing the consumption of highly processed, discretionary and non-core foods (known as ultra-processed foods (UPF)) (Le Mouël et al., 2016; Fardet & Rock, 2020; Schiavo et al., 2021).

The concept of the $3V_{ALS}$ rule (Fardet & Rock, 2024), developed by INRAE, could provide a beneficial framework for transitioning to healthy and sustainable diets, and is in line with the main conclusions of the European foresight scenarios reviewed. This rule encompasses three core principles: the degree of food processing (i.e. Veritable Foods: reducing the consumption of ultra-processed foods); the plant–animal ratio (i.e. Vegetal Foods: reducing the consumption of animal-based foods); and food diversity (i.e. increasing Varied Foods) and, when possible, via the development of agro-ecological, local and seasonal foods (i.e. ALS). Regarding local and seasonal foods, it is important to take a place-based approach to local conditions for food production, as local food is not by default a more sustainable choice (see section 3.1).

Figure 3: $3V_{ALS}$ rule for holistic, healthy and sustainable diets based on Fardet (2024).



Note: ALS = agro-ecological, local and seasonal foods.

3. Recommendations and leverage points to support the transition towards sustainable and healthy food systems

This report recognizes that transitioning to sustainable food systems and transforming dietary behaviour at scale requires systemic change and a multilevel approach that considers economic, social, health and environmental aspects. Policies guiding this transition should be grounded in comprehensive strategies that operate both horizontally (encompassing different policy domains) and vertically (spanning multiple levels of governance). Furthermore, this transition requires multifaceted approaches, as single policy tools are seldom sufficient to drive significant change (SAPEA, 2023). Instead, implementing multiple complementary measures—known as "policy packages"—enhances effectiveness and success rate (Fesenfeld et al., 2020).

The recommendations in this report are primarily focused on policy instruments that public authorities and policymakers can deploy to foster sustainable and healthy diets. Additionally, a few production-side recommendations are included due to their significant impact emphasized by the TCA analyses and the reviewed foresight scenarios.

The recommendations are structured as follows: overarching principles for holistic policy and intervention design are outlined, followed by targeted recommendations categorized into three types of policy instruments. These include more stringent approaches, such as regulatory measures and financial incentives, as well as softer methods such as information dissemination and education (Table 1). This categorization aligns with traditional classifications of policy tools discussed in the literature (Reisch et al., 2017; Röös et al., 2021).

Table 1: Policy recommendations to support the transition towards sustainable and healthy diets

Overarching principles for holistic policy and intervention design

- Employ TCA as a systems thinking approach
- Allow for a context-specific adaptation of policy measures

Recommendations categorized by policy instruments

Regulatory measures	Fiscal and financial measures	Information-based measures
- Incorporate TCA perspectives in public procurement - Regulate marketing of high-impact foods - Revise accounting standards for governments and businesses - Align trade policies with sustainability goals - Advocate for TCA-based global trade standards - Enforce food waste prevention as a priority	- Adjust food pricing based on different models informed by TCA - Introduce fiscal incentives for sustainable production - Leverage sustainable finance mechanisms by incorporating Environmental, Social, Governance (ESG) criteria in investments - Provide economic support to farmers transitioning to agroecology - Allocate financial support for plant-based proteins and sustainable food innovation	<u>Information efforts:</u> - Incorporate TCA into the national dietary guidelines - Promote healthy and sustainable diets: • Promote reduced meat consumption • Adjust dairy recommendations • Promote minimally processed foods and plant-based protein sources • Promote increased variety of foods • Advocate for sustainable certifications <u>Educational efforts:</u> - Integrate a holistic sustainability approach into school food and nutrition curriculum - Equip teachers with knowledge and skills to promote informed, healthy and sustainable food choices - Foster adult education (including parents) on food nutrition and sustainability in workplaces

		Increased supply chain transparency: - Explore integrating the true costs of food into food labelling

3.1 Overarching principles for holistic policy and intervention design

Based on this research, we propose key guiding elements for designing holistic, coherent, evidence-based policies to support the transition to sustainable food systems and promote better diets.

Employ TCA as a systems thinking approach: The literature review of foresight scenarios and previous research (e.g. Khan et al., 2024) highlights the urgent need for systemic change in food production and consumption.

Given the complexity of agri-food systems and the increasing pressures to meet diverse objectives under numerous constraints, it is clear that the challenges associated with this transition cannot be viewed in isolation. Adopting a systems perspective is vital for advancing sustainable food systems, as it allows for a comprehensive evaluation of impacts across various dimensions.

TCA can be an effective tool to evaluate the full spectrum of environmental, social, economic and health impacts and dependencies within agri-food systems, including those often overlooked (Baker et al., 2020). By exposing the impacts and interdependencies across environmental, social and human dimensions (FAO, 2024a), TCA can help bridge various aspects of sustainability and policy domains, thereby fostering more holistic and integrated decision-making.

Allow for a context-specific adaptation of policy measures: When implementing policies locally, it is important to ensure adaptability to diverse contexts by considering the unique social, cultural, economic and environmental conditions specific to each territorial context. This approach recognizes that sustainability practices can vary widely; what is sustainable in one region may not be suitable in another. Consequently, policies must be flexible and closely aligned with local conditions to ensure they are equitable, appropriate and culturally relevant.

3.2 Regulatory measures

Regulatory policy instruments are critical to advancing more sustainable food systems and healthier diets, encompassing measures such as limitations and bans, marketing regulations, and procurement criteria for food served in public institutions. By incorporating insights from analyzing high-impact foods and applying a TCA approach, these regulatory measures can effectively steer consumption towards healthier and more sustainable options (FAO, 2024a).

Incorporate TCA perspectives in public procurement: Public institutions can play an important role in piloting and encouraging food-related behavioural changes. By integrating TCA principles into procurement criteria, public institutions at national, regional and local level can prioritize low-impact products and incorporate social, environmental and health considerations into their purchasing decisions. TCA-guided procurement can help minimize the use of high-impact products, inform menu planning and serve as a framework to guide those involved in logistics and food preparation. This also includes adhering to high environmental and social standards, such as sourcing from companies that are socially certified and uphold stringent labour and human rights standards.

Regulate marketing of high-impact foods: Government agencies responsible for overseeing advertising practices should strengthen advertizing restrictions in public spaces and digital platforms to limit the promotion of high-impact foods, particularly among vulnerable groups like children. Implementing marketing limitations on products high in fat, added sugars and/or salt (HFSS) and highly processed products (UPFs) can reduce their appeal. For example, stricter in-store promotion guidelines can help prevent unhealthy options from being prioritized. In Portugal, for instance, the Advertizing Code from 2019 prohibits the advertizing of HFSS and high-calorie foods to children across various media platforms and within 100m of environments such as schools and playgrounds (Khan et al., 2024).

Additionally, reevaluating how marketing campaigns are financially supported is crucial: redirecting EU promotional funds away from predominantly animal-based products toward plant-based and minimally processed alternatives can encourage healthier dietary choices and advance sustainability objectives.

Revise accounting standards for governments and businesses: Adapting current accounting frameworks to include natural, social and human capital is crucial for a truly holistic economic assessment. Present systems predominantly focus on financial metrics, often overlooking the external costs of environmental damage, social inequalities and human well-being. Incorporating these factors encourages more responsible corporate and governmental behaviour, while fostering decisions that favour long-term sustainability. Models like the United Nations (UN) System of Environmental-Economic Accounting (SEEA) can serve as a blueprint for including ecosystem services and biodiversity in national evaluations; while concept such as SEBIT can promote the integration of sustainability information into cooperate financial reporting (Henkel et al., 2024). Additionally, the UN Sustainable Development Solutions Network's 2019 report, *Fixing the Business of Food*, underscores the importance of updating accounting standards to align with the UN Sustainable Development Goals (SDGs), promoting an integrated approach that measures financial, social and environmental impacts. Aligning these standards can ultimately strengthen policy development by connecting economic activities more closely to sustainability objectives.

Align trade policies with sustainability goals: Apply TCA principles to import regulations to ensure that the hidden costs of food production—such as deforestation, GHG emissions and labour conditions—are reflected in policy decisions at a national or regional level. This approach can support regulations that prioritize low-impact commodities while discouraging imports linked to unsustainable practices. Additionally, trade rules can be adapted to favour producers adhering to high labour and environmental standards, such as those following regenerative agriculture or agro-ecological principles, thereby reinforcing a more sustainable global food system.

Advocate for TCA-based global trade standards: Global trade standards should integrate sustainability and equity considerations to effectively address social risks. Incorporate TCA metrics into World Trade Organisation (WTO) discussions and trade agreements to ensure that environmental and social costs are reflected in international pricing, tariffs and sustainability benchmarks. Advocating for the development of frameworks for global trade policies similar to the "Codex Planetarius" would support long-term sustainability goals and strengthen the alignment of trade policies with environmental and social objectives (WWF, 2016).

Enforce food waste prevention as a priority: To effectively reduce food waste—a priority highlighted in the reviewed foresight scenarios—regulations should prioritize prevention of food waste over the redistribution of surplus food, thereby ensuring that food is not wasted in the first place (SAPEA, 2023). Governments should consider implementing binding legal measures that require businesses, retailers and food service providers to adopt waste prevention strategies. Additionally, setting clearer requirements for data sharing, and assessing and reporting on food waste, as well as tackling food waste at household level are necessary, see more in Wikström et al. (2024).

3.3 Fiscal and financial measures

Fiscal policies play a crucial role in incentivizing dietary shifts to healthier and more sustainable diets (Springmann et al., 2025). By employing incentivizing (such as subsidies) and disincentivizing (such as taxes) fiscal measures, these instruments can be tailored to reflect the full impacts of food systems and encourage a shift towards sustainable production and consumption. On the other hand, financial measures encompass a broader range of actions including accounting, budgeting and investment strategies. These are primarily concerned with the management and allocation of resources.

Adjust food pricing based on different models informed by TCA: Adjusting prices—increasing them on high-impact foods and reducing them on low-impact alternatives—aligns with economic principles and addresses market failures stemming from societal and environmental costs not reflected in food prices. In designing such measures, it is important to ensure that price shifts do not disproportionately impact vulnerable groups.

A thorough examination is needed to determine if accompanying social measures are necessary to mitigate any potential adverse effects on low-income groups, ensuring that the reforms are equitable and do not disproportionately impact economically disadvantaged members of society. The "Food Tax Shift" model proposes to introduce a tax on high-impact foods, such as red meat, while reducing tax on low-impact alternatives like fruits, vegetables, whole grains and legumes (Larsson et al., 2024). This model suggests a combination of excise taxes on foods that are both environmentally- and health-damaging (e.g. red meat and sugar-sweetened beverages), coupled with the removal of value-added tax (VAT) for plant-based options and products carrying an official health label. These tax modifications are designed to yield substantial benefits for public health and the environment without negative economic effects for either consumers or the state. This model also enjoys relatively high public acceptance (ibid.).

Reforming VAT rates offers an alternative approach. A recent study (Springmann et al., 2025) showed that reforming VAT rates—raising them on meat and dairy while lowering them on fruits and vegetables—can improve diets and yield health, environmental and economic benefits across most European countries, aligning with TCA principles. Additionally, it is essential to explore the potential application of these models to processed meat, given their high impact as identified in this report.

Leverage sustainable finance mechanisms: Financial markets should incorporate environmental, social and governance (ESG) criteria to drive sustainability. Policies such as the EU taxonomy help standardize what qualifies as a sustainable investment, increasing transparency and ensuring financial flows align with climate and environmental goals. Embedding ESG criteria in financial regulations—for example with the Sustainable Performance Accounting approach (Henkel & Lay-Kumar, 2022)—can direct private capital toward sustainable projects focused on, for example, reducing GHG emissions, enhancing biodiversity and improving social equity. Sustainable finance policies can also foster innovation by making green bonds and sustainability-linked loans more accessible, incentivizing businesses to adopt lower-impact models.

Provide economic support for farmers transitioning to agroecology: Financial incentives could be structured to encourage the adoption of practices that minimize environmental, social and health impacts. Agroecology, in particular, is recognized in foresight scenarios as crucial for developing sustainable food systems. One effective approach to support sustainable farming is through guaranteed offtake agreements, as exemplified by the Conservation Finance Network. These agreements secure committed buyers for products grown using agroecological methods, thereby reducing financial risks for farmers and incentivizing long-term investments in sustainable practices through the assurance of a stable market and predictable income.

Allocate financial support for plant-based proteins and sustainable food innovation: Similar to Denmark's Plant-Based Food Grant, European governments should consider creating a dedicated fund to accelerate the production, processing and distribution of plant-based foods, including minimally processed plant-based proteins. This fund would provide support through research grants, financial incentives and market development initiatives to enable plant-based options to compete effectively with animal-based options. By investing in plant-based startups, improving infrastructure for domestic production and implementing educational measures, policymakers can encourage a shift toward more sustainable and efficient food systems.

3.4 Information-based measures

Information-based instruments, such as educational campaigns and disclosure initiatives, play a vital role in expanding the public's knowledge, shifting attitudes, facilitating the transformation of social norms, and increasing transparency. These measures are also important in fostering broader public acceptance of more intrusive policies, such as taxes and regulations, by helping people understand the reasons behind them (Jungsberg et al., 2024).

3.4.1 INFORMATION EFFORTS

Integrate TCA into national dietary guidelines: To catalyse a transformation towards sustainable food systems and extend their influence beyond consumer education, it is crucial that national dietary guidelines encompass health and nutrition alongside the environmental and social impacts of food choices. Integrating TCA into guidelines may facilitate a more accurate representation of the true costs associated with different foods. This approach supports the FAO's Food Systems-Based Dietary Guidelines methodology, which adopts a holistic food systems perspective to promote healthy diets while considering socio-cultural, economic and environmental sustainability (FAO, 2024b).

Promote healthy and sustainable diets: Promote a diverse and plant-based diet to ensure nutritional adequacy while supporting sustainability objectives. As conceptualized under the $3V_{ALS}$ rule (Fardet & Rock, 2020), key aspects include:

- **Promote reduced meat consumption:** Dietary guidelines should promote less resource-intensive protein and fat sources, and instead more whole grain cereals, legumes, nuts, oilseeds and moderate amounts of poultry and sustainably sourced or farmed fish.
- **Adjust dairy recommendations:** Current guidelines for daily dairy consumption should be adjusted to reflect the high environmental costs, especially of high-impact dairy products like cheese and processed milk products. By encouraging moderate dairy intake, it is possible to meet nutritional needs while minimizing environmental and health impacts.
- **Promote minimally processed foods and plant-based protein sources:** Dietary recommendations should emphasize the benefits of legumes, such as fava beans, lentils and chickpeas, which provide protein with lower environmental impact than meat. Foods that are minimally processed and low in added fat, sugar and/or salt should be prioritized as healthier, lower-impact options compared to highly processed products.
- **Promote increased variety:** Promoting a wider array of fruits, vegetables, legumes, nuts and wholegrain cereal products not only benefits health, but also reduces reliance on high-impact foods and contributes to the development of resilient food systems (Fardet & Rock, 2020).
- **Advocate for sustainable certifications**: Given the social risks associated with imported foods like coffee, cocoa and rice, consumption should be reduced and awareness of certifications that support fair labour conditions should be encouraged. Sourcing foods certified by organizations/labels like Fairtrade and The Rainforest Alliance supports food choices toward fair labour standards and environmental stewardship.

3.4.2 EDUCATIONAL EFFORTS

Targeted education on nutrition and sustainability, including true costs of food, can empower individuals to make informed food choices from an early age. Schools play a crucial role in fostering lifelong healthy eating habits by integrating hands-on lessons in balanced diets, sustainable food practices and waste reduction. Similarly, workplace and community programs can enhance adults' understanding of sustainable nutrition, linking dietary choices to both personal health and environmental impact.

Integrate a holistic sustainability approach into school food and nutrition curriculum: According to the FAO (n.d.), integrating food and nutrition education as a fundamental component of national curricula and school health policies is increasingly common. For school-based food and nutrition education (SFNE) to be truly impactful, a broader, more hands-on approach is required (FAO, n.d.). This should transcend the confines of traditional classroom settings to include project-based activities and extracurricular engagements that involve the entire school community, including canteens, parents and the local food system. The FAO's Nutrition Education in Primary Schools Guide emphasizes that nutrition education must foster long-lasting attitudes and behaviours through active participation and experiential learning, going beyond mere knowledge transfer to truly embed these lessons for life (FAO, 2005).

Equip teachers with knowledge and skills to enable students to make informed, healthy and sustainable dietary choices: Research by Nanayakkara et al. (2024) suggests that boosting secondary school teachers' confidence in teaching food and nutrition could be achieved through enhanced professional development. This includes providing additional resources, sufficient preparation time, updates on current food trends and elevating the status of food and nutrition subjects within the educational curriculum.

Foster adult education (including for parents) on food nutrition and sustainability in workplaces: Introduce adult educational programs that include workshops on meal preparation, seasonal ingredient use, food waste reduction and crafting balanced meals, with an emphasis on plant-based proteins and minimally processed foods. Promote the concept of "sustainable nutrition", linking diet choices to environmental and health outcomes. Companies can enhance employee wellness by integrating food education into workplace programs, organizing seminars and improving cafeteria menus.

Additionally, user-friendly mobile apps featuring recipes, sustainability tips and meal-planning tools can deliver personalized guidance for various demographics, such as parents, seniors or individuals with specific nutritional requirements. Research shows that parental involvement can significantly enhance the impact of school-based interventions, especially when parents actively participate in homework or other school activities related to food education (Kristjansdottir, 2010).

3.4.3 INCREASED SUPPLY CHAIN TRANSPARENCY

Access to information about the true cost of food may increase supply-chain transparency, as well as encourage more responsible practices among producers, retailers and consumers.

Explore integrating the true costs of food into labelling: Implementing true cost principles in the food environment requires providing clear, accessible information on the true impacts of food to facilitate informed choices. A TCA-based label could enhance transparency by not only displaying the nutritional content but also the environmental, health and social costs associated with the production and consumption of food items.

4. Future research on TCA

Expand primary data collection: A key challenge for advancing TCA is the availability of high-quality primary data. While environmental impacts are often quantified, social and health impacts remain difficult to measure and monetize. More comprehensive data collection methods are needed to capture these dimensions. In addition, sector-specific data gaps need to be addressed, as various industries—especially agriculture—require detailed insights into soil health, water use and biodiversity. The development of a TCA database for the EU-food system, similar to AGRIBALYSE, would improve data accessibility and comparability across the EU.

Develop the TCA methodology: Further development of Life Cycle Assessment (LCA) methodology is essential for standardization and accuracy. Current LCA methodologies need refinement, particularly in the area of impact assessment and the inclusion of environmental indicators such as biodiversity loss. Harmonization of LCA methodologies across sectors is needed to ensure consistency. Social LCA (s-LCA) is still in its infancy, with monetization methodologies still underdeveloped. In addition, the functional unit for food and diet analysis needs to be improved, as measuring the impact of food by weight alone does not fully capture its nutritional and energetic value.

Practical application and policy integration: For TCA to have a meaningful impact, its integration into business and policy frameworks needs to be strengthened. The development of software tools could reduce the resource intensity of conducting TCA, making the methodology more accessible and improving its cost-effectiveness.

Improve consumer transparency: TCA can also contribute to greater consumer awareness through improved transparency in labelling and information materials. Approaches such as secondary pricing could enable consumers to better understand the true cost of products. However, this needs to be better understood.

Further research is also needed to improve the comparability of plant-based and animal-based foods, conventional and organic products, as well as minimally processed and ultra-processed foods, in order to support more informed purchasing decisions.

5. Conclusions

The transition towards healthier, more sustainable dietary patterns and an equitable food system requires a systemic change, with the TCA approach serving as a valuable tool to facilitate this transformation.

By integrating TCA principles into policymaking, governments and institutions can address the hidden environmental, health and social costs of food, ensuring that these externalities are accounted for in decision-making.

If the true cost of food continues to be overlooked, it will escalate, further exacerbating climate change, increasing the prevalence of diet-related diseases, and deepening existing inequities (The Rockefeller Foundation, 2021).

The findings from this report highlight the urgent need to reduce the consumption of high-impact foods—particularly red and highly processed meat products—while promoting minimally-processed plant-based foods and sustainable farming practices. Additionally, leveraging regulatory frameworks, financial incentives and educational and information measures can have a positive effect on consumer behaviour and industry practices, fostering a resilient and equitable food system.

Moving forward, achieving a sustainable dietary transition will require the active participation of policymakers, industry leaders and consumers. Coordinated efforts across multiple governance levels, from EU-wide trade policies to national dietary guidelines, will be essential in driving meaningful change. Transparency, accountability and accessibility of information will play a key role in enabling informed decision-making for all stakeholders. By embracing an integrated approach that combines regulation, financial support, education and consumer empowerment, we can work towards a food system that prioritizes public health, environmental sustainability and social well-being.

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Recommendations and high impact areas for policy interventions

Appendix

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Abbreviations

COI	Cost of Illness	LCI	Life Cycle Inventory
DALY	Disability-adjusted life years	LL	Living Lab
DGE	Deutsche Gesellschaft für Ernährung (German Nutrition Society)	LLD	Living Lab Diet
EU	European Union	NRD	National Reference Diets
FAO	Food and Agriculture Organization of the United Nations	PHD	Planetary Health Diet
GHG	Greenhouse gas emissions	s-LCA	Social Life Cycle Assessment
HFSS	High in added fat, salt and/or sugar	SHDB	Social Hotspot Database
INRAE	Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement (National Institute for Agricultural Research)	TCA	True Cost Accounting
LCA	Life Cycle Assessment		

A1. Background material—methods and data

A1.1 Analysis of the True Costs of Food Database

A1.1.1 RESEARCH DESIGN

The True Costs of Food Database (V1), created by TMG in collaboration with social enterprise True Price,[2] is an open-access resource that quantifies food products' hidden environmental and health costs using True Cost Accounting (TCA). The database aims to estimate and compare true costs across food supply chains to support sustainable diet assessments in the European Union (EU) and aid decision-making for environmental and health-conscious policies. The aim of the following analysis is to identify and analyse foods with high total true costs ("high impact foods") as well as impact areas with significant environmental and health burdens resulting in relatively high true costs ("high impact areas").

A1.1.2 ENVIRONMENTAL AND HEALTH COST ASSESSMENT

The **environmental cost assessment** is based on the following indicators: greenhouse gas (GHG) emissions, water consumption, marine and freshwater eutrophication[3] and ecosystem toxicity[4] (terrestrial, freshwater and marine). For the **health cost assessment**, human toxicity[5] and health damage caused by ammonia emissions (NH_3) are considered. Social costs are not assessed in this analysis, due to the lack of primary data. Conducting a comprehensive TCA assessment using secondary Social Life Cycle Assessment (s-LCA) databases is not feasible due to significant data gaps. These databases only indicate risk levels—that is, the likelihood of an impact occurring—rather than actual occurrences. Consequently, social impacts cannot be accurately estimated or monetized. The True Costs of Food Database developed in the PLAN'EAT project encompasses data on 208 products from 81 countries, resulting in over 2,000 product–country combinations. These products include raw items (e.g. wheat) and minimally processed goods (e.g. flour). The database focuses on products consumed in the EU but produced and sourced globally. The impacts and true costs are estimated along the supply chain from the cradle to the farm gate for raw products and to the factory or processing gate for processed products.

The database, developed using the Life Cycle Inventory database AGRIBALYSE V3.0 and the Sustainable Agriculture and Food Systems Database (SAFAD) V1.99 dataset, is divided into two distinct sub-databases:

- An AGRIBALYSE-based sub-database that covers raw and minimally processed foods.
- A SAFAD-based sub-database that covers exclusively raw foods.

These sub-databases differ in their underlying data, scope and impact modelling methods. Therefore, they should not be combined or directly compared. For example, the AGRIBALYSE sub-database includes impacts from production and waste, while the SAFAD sub-database focuses on farm-level impacts, such as GHG emissions from agricultural production.

Several frameworks exist for monetary valuation of human and environmental impacts. However, TCA is a relatively young field and no consensus exists on which factors to use for which application, while estimates in monetary terms always bring some uncertainty. Because of this, the True Costs of Food Database calculates costs using two distinct monetization frameworks: the rights-based and damage cost approaches.

[2] True Price is a non-profit organization based in Amsterdam, the Netherlands, focused on methods and tools to measure and monetize true costs.

[3] Refers to the process by which excessive nutrients, primarily nitrogen (in marine systems) and phosphorus (in freshwater systems), accumulate in water bodies. This nutrient overload often stems from agricultural runoff, wastewater discharge and industrial activities.

[4] Refers to the potential of chemical substances to cause harm to ecosystems, including plants, animals, microorganisms, soil and water organisms. It measures the toxic effects of pollutants, such as pesticides, heavy metals and industrial chemicals, on land- and water-based ecosystems.

[5] Related to production: emissions to air, soil and/or water contributing to human toxicity (carcinogenic and non-carcinogenic).

The rights-based approach of True Price assesses the true cost of products by identifying and quantifying social and environmental externalities based on fundamental human rights (True Price, 2023). It assesses risks or violations along the value chain, such as inadequate wages, unsafe working conditions and unequal access to resources, using internationally recognized frameworks such as the Universal Declaration of Human Rights. These violations are translated into monetary values using standardized methodologies, such as calculating the gap between actual wages and living wages, or the cost of health impacts caused by poor working conditions.

The damage-cost approach quantifies the true cost of products by measuring the actual damage caused to people and the environment throughout the value chain (de Bruyn et al., 2023). It assigns monetary values to the negative impacts of activities, such as pollution, GHG emissions or health problems caused by poor working conditions. These costs are based on the expenditure required to address or compensate for the damage, such as healthcare costs, ecosystem restoration or lost productivity. By focusing on the consequences of specific impacts, the damage cost approach provides a tangible measure of the externalities associated with a product.

A1.1.3 DATA ANALYSIS

The database analysis using Excel and IBM SPSS Statistics focuses on data from the AGRIBALYSE V3.0-based TCA sub-database, capturing raw and minimally processed products.

The analysis used a descriptive approach to identify “high impact foods” and “high impact areas.” For the identification and analysis of high-impact foods, the foods were first grouped into food categories to provide a better overview of the items. The following categories were used: protein products, vegetables, fruits and nuts, grains, dairy products, fats and oils, beverages, and sweets. The items with the highest actual total costs within the categories were then determined. The results were visualized in a scatter plot by SPSS.

The analysis of high-impact areas identifies the specific environmental and health impacts that contribute to the true costs of these high-impact foods. This step assesses which indicators—such as GHG emissions, water consumption or human toxicity—are the primary cost drivers for each food item. By highlighting these key contributors, the analysis provides insights into the factors influencing true costs and their composition.

The high-impact foods and areas summarize the most important leverage points and derive recommendations for a transition to healthier and more sustainable dietary patterns.

A1.2 Case study: true costs and benefits of 3 EU dietary patterns (D3.3)

A1.2.1 RESEARCH DESIGN

This study (PLAN’EAT D3.3) presents a comprehensive evaluation of the environmental and health costs and social risks associated with different dietary patterns across three European countries using a TCA approach. Within each living lab (LL)—in Germany, Ireland and France—the analysis compares the true costs of three diets: the Living Lab Diet (LLD), National Reference Diet (NRD), and the regionalized Planetary Health Diet (PHD). By identifying the key foods or food groups that contributed to external costs and social risks within each diet, this study highlights the most impactful levers for driving sustainable dietary transitions in each country.

For the here presented part of the study, we placed particular emphasis on depicting the foods with the highest true costs, thereby targeting the third research question of the D3.3 study: *Where are the most expensive environmental and health costs and highest social risk contributions (i.e. hotspots) within each dietary pattern?*

The complete D3.3 study including research design, methodological approach and results can be found in: Michalke, A., Köhler, A., Ghukasyan, S., Riemer, O., Çınar, G., Ohlau, M. (2024): D3.3 – True costs and benefits of 3 EU dietary patterns. PLAN’EAT—Food systems transformation towards healthy and sustainable dietary behaviour. Currently under review.

A1.2.2 DIET MAPPING

From the mapped dietary patterns, the average dietary intakes of the three analyzed LLs (Germany, Ireland, France) were derived. These current dietary patterns were compared with the NRDs and PHDs constructed on the basis of national dietary intakes. The comparison of the PHD with the LLD and NRD allows practical conclusions to be drawn regarding the potential and pathways towards more environmentally and socially sustainable dietary patterns and (national) dietary recommendations. The diets assessed in this study are defined below, along with their underlying data sources:

Living Lab Diet (LLD): The LLDs reflect the average daily consumption in terms of both quantity and type of food consumed by the age group of the respective LL of the PLAN'EAT project. The consumption amount of the representative food products was modelled according to actual consumption based on the EFSA Comprehensive European Food Consumption Database (EFSA, 2022).

National Reference Diet (NRD): The NRDs are based on national dietary recommendations which serve as guidelines developed by public health authorities to promote optimal nutrition and overall well-being for specific populations. They are modelled following the general dietary guidelines from Germany's German Nutrition Society (DGE, 2024), France's Public Health Authorities (Santé Publique France) under the Programme National Nutrition Santé (PNNS4, 2019–2023) and Ireland's Department of Health of the Irish Government Department (Gov.ie, 2019).

Planetary Health Diet (PHD): The PHD released in 2019, as proposed by the EAT-Lancet Commission, is a health-based dietary recommendation that also considers environmental sustainability impacts (Willet et al., 2019). The study developed a regionalized PHD for each LL country (Germany, Ireland, France). These customized PHDs were designed to reflect the geographical differences and actual consumption patterns of the LLs. To achieve this, The PHD consumption patterns were modelled according to the consumption patterns of LLD, adjusting the appropriate amounts of food for the modelled age groups of the LL populations.

A1.2.3 ENVIRONMENTAL AND HEALTH COST ASSESSMENT

The **environmental impacts** of each diet are assessed using the Life Cycle Assessment (LCA) approach and using the Life Cycle Inventory (LCI) database AGRIBALYSE (v.3.1). This was done by modelling the representative products consumed within each diet in LCA software using LCI data to reflect the impacts of the diets as accurately as possible. The system boundaries of the assessment are defined as cradle to processing gate; this includes all processes of resource extraction (like feedstock production, nitrogen fertilizer production, etc.), manufacturing and the transportation in between.

The environmental true costs in this study are calculated using marginal damage costs, encompassing both restoration and compensation costs. Restoration costs cover efforts to return ecosystems to their original or targeted states, such as reforestation after land-use changes. Compensation costs represent societal burdens due to environmental impacts, including damage to infrastructure, ecosystems and human health (Amadei et al., 2021). These costs were monetized using data from the *Environmental Prices Handbook* (CE Delft, 2018), based on the ReCiPe 2016 framework and adjusted for 2022 inflation rates in the three LL countries.

Health impacts are quantified using the Cost of Illness (COI) method to describe the true costs of (mal)nutrition, or potential cost savings due to healthier diets (e.g. Springmann et al., 2021). The most common diseases caused by malnutrition were identified as cardiovascular diseases (including stroke), type 2 diabetes mellitus and neoplasms (cf. Seidel et al., 2023). For each of the three LL countries, Disability Adjusted Life Years (DALYs) for each of the three diseases were calculated to measure the overall disease burden expressed as the number of years lost due to ill health, disability or early death. With the COI, both direct (healthcare-related) and indirect (productivity loss) costs associated with the diseases most frequently caused by unhealthy diets were estimated and adjusted for each reference country based on inflation and population changes.

The study assessed **social risks** associated with dietary patterns using the s-LCA methodology. S-LCA is a relatively new approach and monetization techniques are still emerging. The s-LCA therefore assesses the severity and likelihood of social risks along the food value chain.

These risks are expressed in medium risk hour equivalents per kilogram (mrheq/kg), which combine the likelihood of risks occurring (e.g. due to long working hours) with the potential impact (severity) of these risks. Rather than monetizing these risks, the results are interpreted qualitatively; i.e. they are used to identify and compare social risk hotspots across products, product categories or supply chain stages. For example, the assessment may highlight specific products (such as beef or vegetables) or supply chain stages (such as a country of origin with high-risk practices) that contribute significantly to the social risks associated with a diet.

The s-LCA relied on data from the Social Hotspot Database (SHDB), which identifies social risks within global supply chains, such as labour conditions, human rights issues and community impacts. SHDB data encompasses various sectors—including agriculture, manufacturing, and mining—where social risks are prominent. SHDB sources its data from reputable organizations like the International Labour Organization, non-governmental organizations, government reports and academic research.

A1.3 European foresight scenarios

A1.3.1 RESEARCH DESIGN

INRAE led a consultation with LL leaders to gather and analyze existing foresight food scenarios at national LL country, European and world levels, and to use them to synergistically enrich the TCA analysis and subsequent recommendations.

The most impactful foresight scenarios on health, socio-economic and environmental levels were selected, and their leverage points identified for the transition towards healthier and more sustainable diets and food systems.

A1.3.2 METHODOLOGICAL APPROACH

The methodological approach has been carried out in three steps:

Step 1: Consultations were conducted with LL leaders to gather and analyze existing foresight food scenarios at national LL country, European and global levels. LL leaders were responsible for collecting foresight scenarios specific to their respective countries, while INRAE handled the collection of scenarios pertaining to France, Europe and the global context. Foresight food scenarios have been selected from original peer-reviewed papers and grey literature; e.g. reports of public agencies (e.g. FAO), associations, expert groups, think tanks, etc. The search by keywords was initially led in ISI Web of Science Core Collection, and including several databases, notably those in relation with agricultural and food sciences (Clarivate©): (scenario* OR foresight*) AND (diet* OR food* OR food system* OR health*). If no scenario was found for a specific country with these keywords, a new specific literature search was carried out by each LL leader.

Step 2: Initial results and findings were compiled by LL leaders within an online Excel file hosted on SharePoint. The most impactful scenarios—for both human health and food system sustainability (as proposed in authors' analyses)—at the country level were identified, along with their main characteristics and conclusions. This process included:

- Synthesizing the most relevant levers to activate in the coming years
- Identifying key barriers to overcome in the coming years
- Selecting the most impactful dimensions that characterize the diet–global health relationship (e.g. the animal/plant ratio at production and consumption levels) to achieve the highest impact at European and national LL country levels; these dimensions are those most common to all selected food scenarios

Step 3: INRAE derived and drafted recommendations, synthesizing the key leverage points to prioritize at the European level for a transition towards healthier and more sustainable food systems. This included:

- Identifying actionable strategies based on the most impactful scenarios
- Highlighting opportunities for alignment with European policies and frameworks

- Proposing guidelines to enhance cooperation among LLs and stakeholders
- Formulating recommendations to support the implementation of levers and overcome barriers identified in previous steps

A2. Key Results

A2.1 High-impact foods and impact areas per food category identified using the True Costs of Food Database

In the **protein products** category (Figure A1), red meat from ruminants is linked to the highest true costs. Sheep meat incurs the highest total costs, reaching €13.60 per kg (rights-based approach) and €11.12 per kg (damage costs). Beef also ranks high, with true costs varying from €4.50 to €12.60 per kg, depending on the specific type of animal, livestock practices and production location. The high true costs of beef and sheep meat are particularly linked to high GHG emissions, especially from ruminants. Additionally, both goat and sheep meats incur notable production-related health costs due to ammonia emissions from livestock rearing, which can vary depending on factors such as production systems, manure management, feed composition and animal physiology. The higher costs observed may be related to the predominance of "indoor" production systems, but the dataset alone does not allow us to determine which specific factor is driving these differences.

Pork displays a wide range of total costs due to different livestock systems. Organic pig production has slightly higher true costs than the conventional system. GHG emissions are the main cost driver, but there is an additional impact from increased human toxicity.

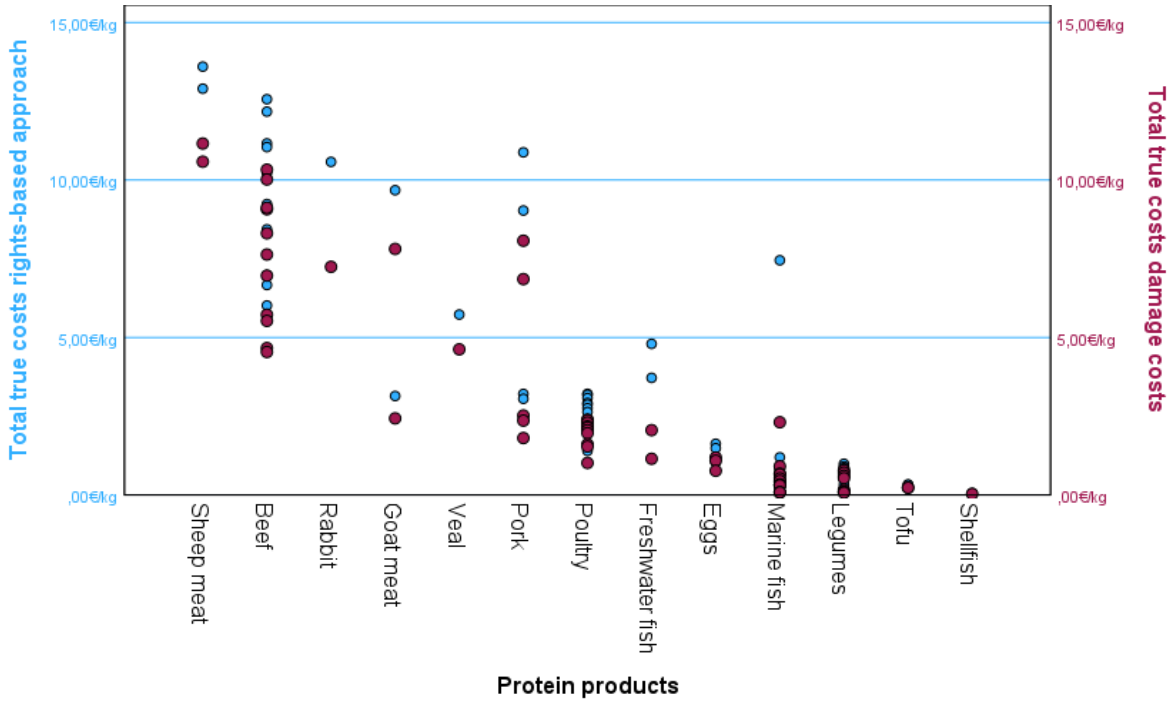
Rabbit meat from farming also incurs relatively higher costs of €10.58 per kg (rights-based approach) and €7.24 per kg (damage costs), primarily due to terrestrial ecotoxicity.

Among fish, freshwater fish—in this case trout—show higher true costs compared to other protein sources, up to €2.14 per kg (rights-based approach) and €1.54 per kg (damage costs), primarily due to GHG emissions and freshwater eutrophication. Salmon is notable among marine fish, with true costs of €7.45 per kg (rights-based approach), where freshwater eutrophication is the main cost driver. Other marine fish, as well as poultry and eggs, show lower total costs among animal protein options, making them relatively lower-impact choices.

In comparison, plant-based protein products such as legumes have the lowest true costs within this category, underscoring their potential as a more sustainable protein source.

However, when comparing protein products, it should be noted that the analysis of the actual cost per kilogram of food is different from that of per kilogram of protein. The protein content, as well as the protein quality, in the different food groups varies greatly, which affects their efficiency as a source of protein. For example, studies have shown that while plant-based proteins generally have a lower cost per kilogram of food, their cost per kilogram of protein can be higher than that of some animal-based proteins (e.g. Azarkamand et al., 2024). Therefore, the assessment of the true cost per kilogram of protein is recommended for a more accurate comparison of the sustainability and economic efficiency of different protein sources.

Figure A4: The results of the true costs according to the rights-based and damage costs approaches for protein products in descending statistical order

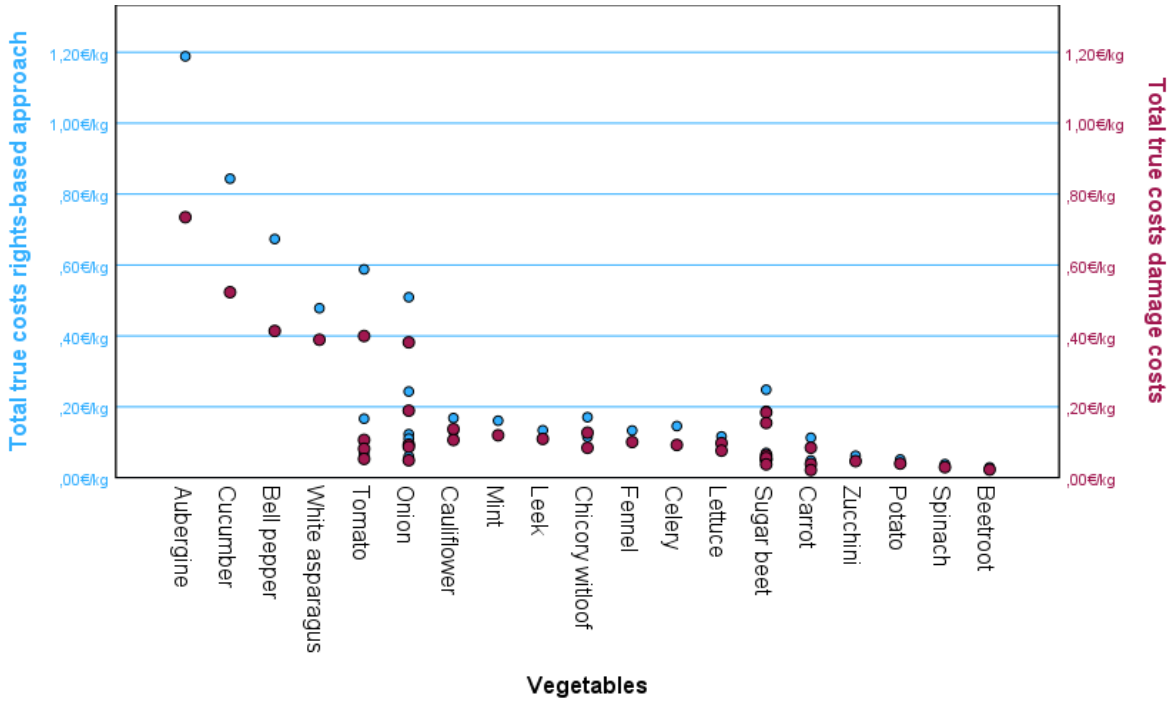


Note: Blue dots in the graph indicate the rights-based approach, while red dots indicate the damage costs approach. Multiple dots for a food indicate that several products for this food are represented in the database.

In the **vegetable** category (Figure A2), aubergine has the highest total costs, reaching €1.19 per kg (rights-based approach) and €0.75 per kg (damage costs). These high costs are mainly attributed to elevated GHG emissions and significant terrestrial ecotoxicity, likely due to greenhouse production practices. Other vegetables such as cucumbers, bell peppers, white asparagus and tomatoes also exhibit higher costs within this category, with GHG emissions as a primary factor—again, likely influenced by greenhouse cultivation.

In contrast, root vegetables (e.g. beetroot), leafy vegetables (e.g. lettuce) and collard vegetables (e.g. cauliflower) demonstrate significantly lower true costs, making them more sustainable options within the vegetable category.

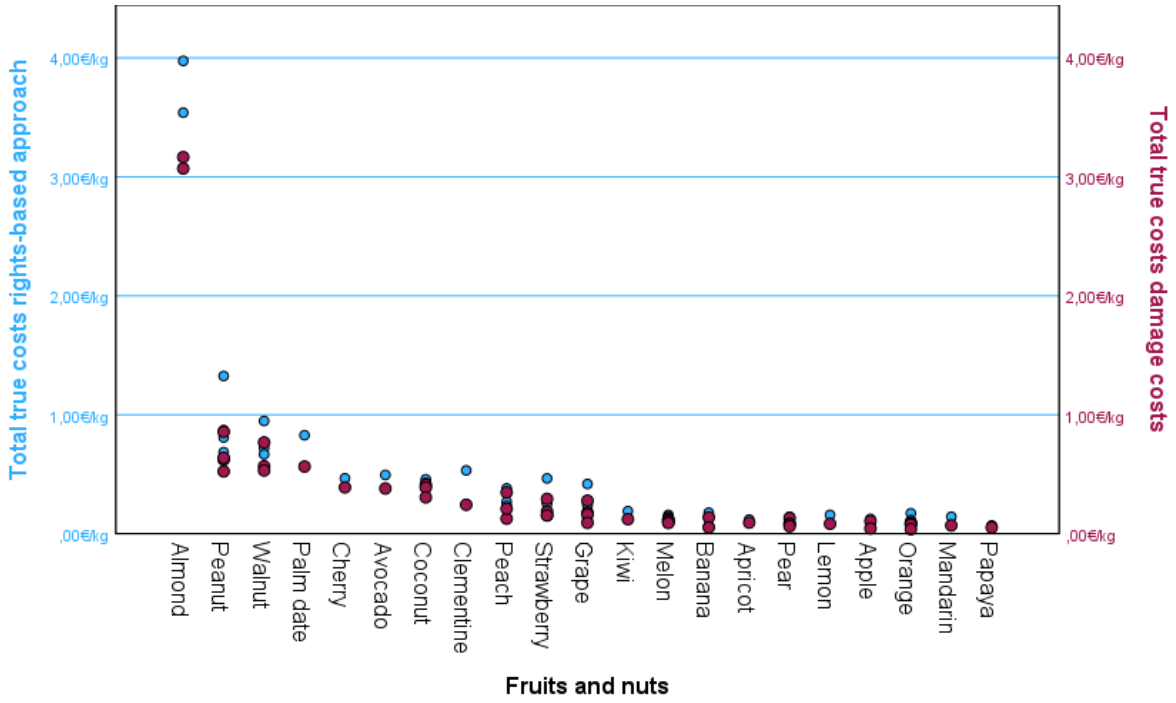
Figure A5: The results of the true costs according to the rights-based and damage costs approaches for vegetables in descending statistical order



Note: Blue dots in the graph indicate the rights-based approach, while red dots indicate the damage costs approach. Multiple dots for a food indicate that several products for this food are represented in the database.

Among **fruits and nuts** (Figure A3), almonds have particularly high true costs, ranging from €3.97 to €3.17 per kg (rights-based approach) and €3.54 to €3.07 per kg (damage costs), due primarily to high water consumption required for cultivation, but also to human toxicity. Peanuts, walnuts and palm dates follow as food items with higher impact within this category, although their true costs are notably lower than almonds. Fruits have lower true costs overall, except for palm dates, all of which have a total true cost of less than €0.50 per kg.

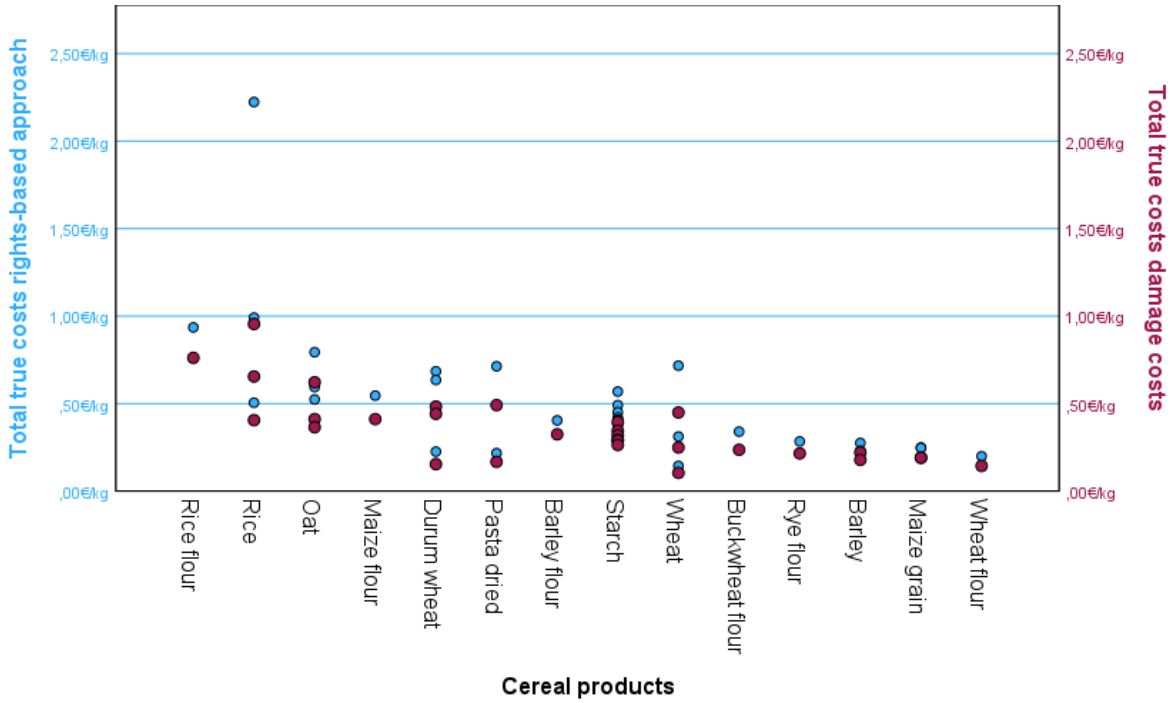
Figure A6: The results of the true costs according to the rights-based and damage costs approaches for fruits and nuts in descending statistical order



Note: Blue dots in the graph indicate the rights-based approach, while red dots indicate the damage costs approach. Multiple dots for a food indicate that several products for this food are represented in the database.

In the category of **cereal products** (Figure A4), the total true costs of products are less than €1.00 per kg. An exception is a rice product, which shows a notably higher true cost of €2.22 per kg (rights-based approach). These costs are largely caused by environmental impacts; however, it should be treated as an outlier.

Figure A7: The results of the true costs according to the rights-based and damage costs approaches for cereal products in descending statistical order



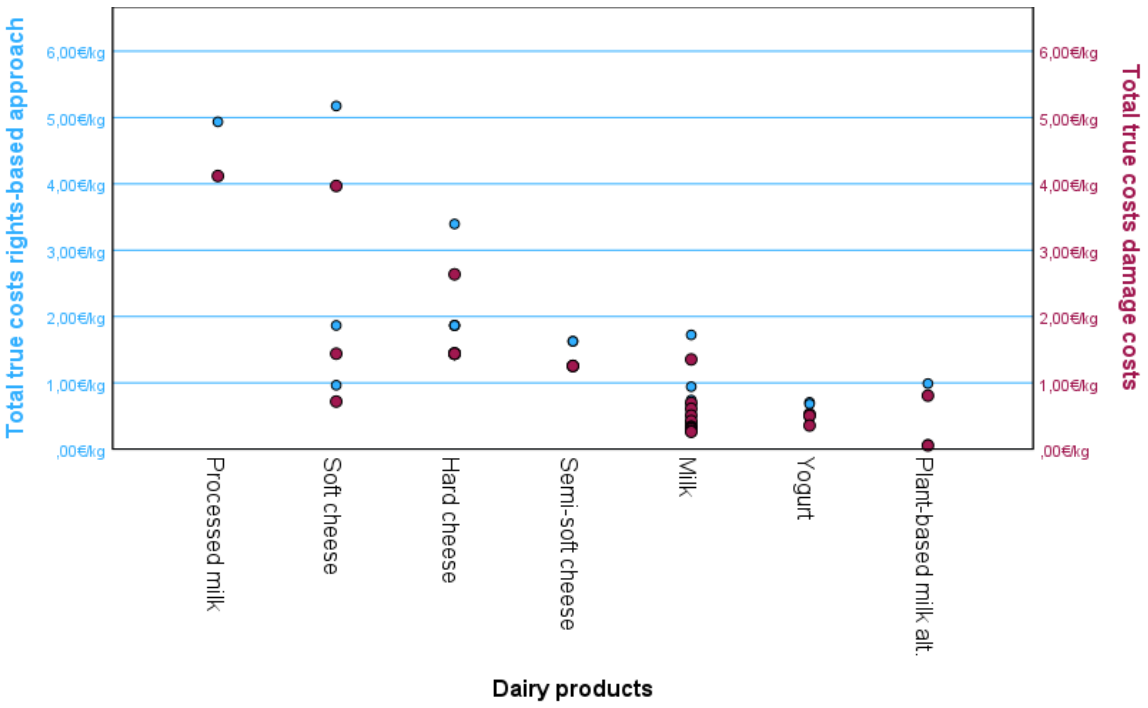
Note: Blue dots in the graph indicate the rights-based approach, while red dots indicate the damage costs approach. Multiple dots for a food indicate that several products for this food are represented in the database.

In the **dairy products** category (Figure A5), hard and soft cheeses—especially soft goat cheese with true costs of €5.17 per kg (rights-based approach) and €3.97 per kg (damage costs) and hard goat cheese with €3.40 per kg (rights-based approach) and €2.64 per kg (damage costs)—have the highest true costs. Processed milk products (in this case milk powder) also had high true costs, with €4.94 per kg (rights-based approach) and €4.12 per kg (damage costs). These costs are primarily driven by GHG emissions from livestock production and additional processing steps required to produce cheese and milk powder. For goat cheese, there are also increased true costs related to human toxicity.

In contrast, milk and yoghurt remain in the lower cost range, with true costs generally below €1.00. This is mainly because they consist mainly of water, which results in lower resource consumption per kg. It takes 6–15 kg of milk to produce 1 kg of cheese.

For plant-based milk alternatives, true costs are also generally lower. However, coconut milk stands out with relatively higher costs (€0.99 per kg for the rights-based approach and €0.81 per kg for damage costs); the impact driver here is water consumption. In comparison, almond milk has significantly lower true costs, at €0.07 and €0.06 per kg for the rights-based and damage costs, respectively.

Figure A8: The results of the true costs according to the rights-based and damage costs approaches for dairy products in descending statistical order

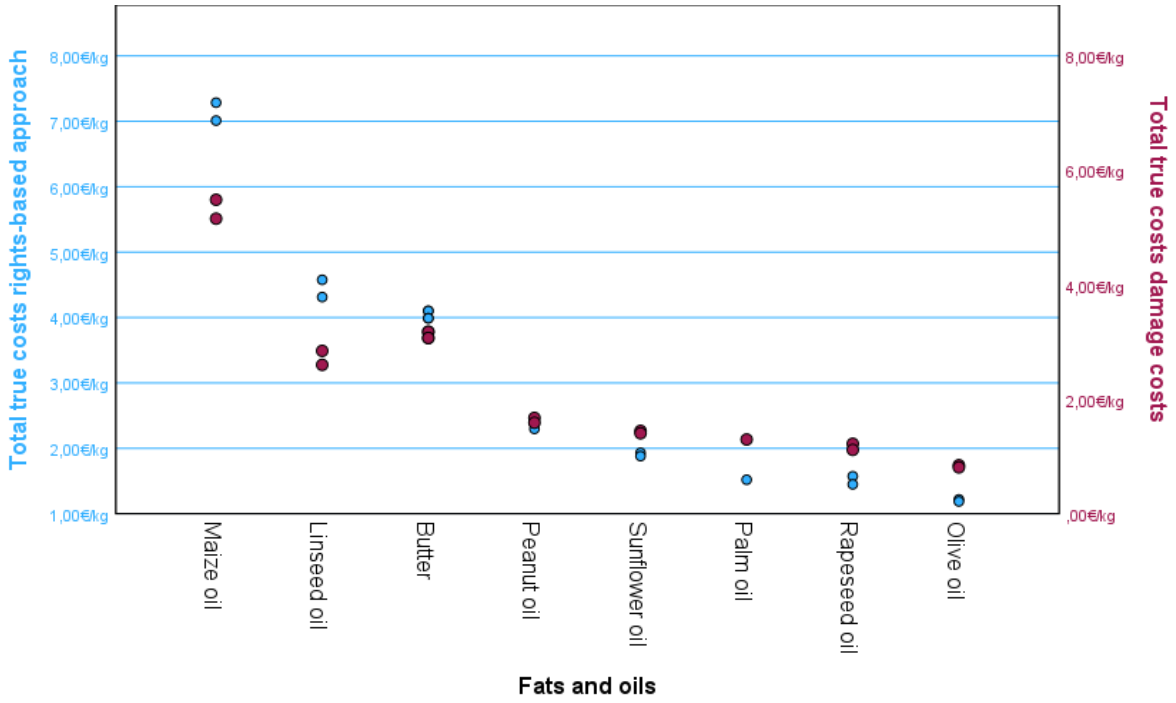


Note: Blue dots in the graph indicate the rights-based approach, while red dots indicate the damage costs approach. Multiple dots for a food indicate that several products for this food are represented in the database.

Among **fats and oils** (Figure A6), maize oil stands out with the highest true costs among vegetable oils, exceeding €7.01 per kg (rights-based approach) and €5.16 per kg (damage costs). These high costs are primarily driven by GHG emissions and water consumption, with additional human health impacts due to ammonia emissions. Linseed oil follows with true costs of €4.31 per kg (rights-based approach) and €2.60 per kg (damage costs), also showing elevated human health impacts related to ammonia usage.

For animal fats, butter incurs true costs of around €4.00 (rights-based approach) and €3.10 (damage costs) per kg, demonstrating that animal fats do not necessarily have the highest environmental impacts when compared to certain vegetable oils. In the case of butter, the primary impact driver is GHG emissions from livestock production.

Figure A9: The results of the true costs according to the rights-based and damage costs approaches for fats and oils in descending statistical order



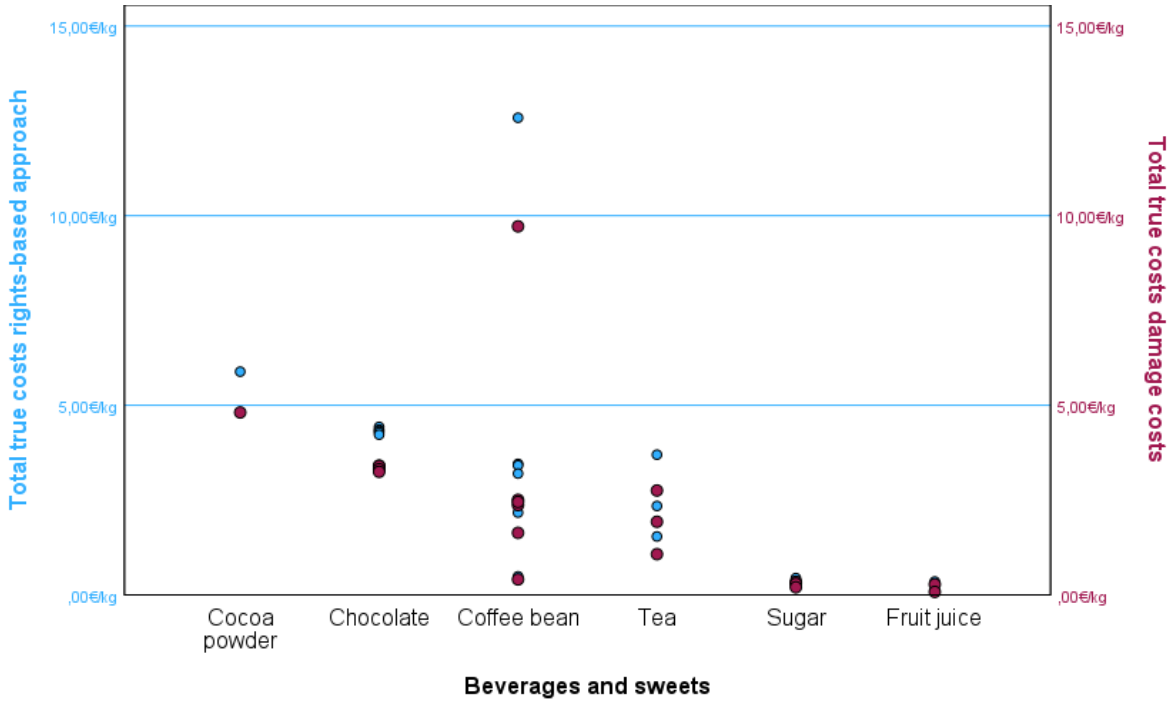
Note: Blue dots in the graph indicate the rights-based approach, while red dots indicate the damage costs approach. Multiple dots for a food indicate that several products for this food are represented in the database.

In the **beverages** category (Figure A7), hot drinks—especially cocoa, coffee and tea—show higher true costs, generally ranging from €2 to €5 per kg. While the costs of coffee and cocoa are largely driven by GHG emissions, tea incurs additional costs related to water consumption.

An Indian coffee bean stands out with especially high true costs, reaching €12.58 per kg (rights-based approach) and €9.72 per kg (damage costs). This elevated cost stems not only from high GHG emissions but also from substantial human health impacts linked to ammonia use in cultivation practices. While these figures underscore coffee's environmental impact, it is important to note that this coffee supply chain may represent an outlier and does not imply that all coffee beans from India have similarly high costs.

Chocolate, as a **sweet product**, has high true costs reaching €4.43 per kg (rights-based approach) and €3.41 per kg (damage costs), primarily due to the environmental impact of its main ingredient, cocoa. Refined sugar itself has relatively lower true costs at €0.27 (rights-based approach) and €0.21 (damage costs) per kg respectively).

Figure A10: The results of the true costs according to the rights-based and damage costs approaches for beverages and sweets in descending statistical order



Note: Blue dots in the graph indicate the rights-based approach, while red dots indicate the damage costs approach. Multiple dots for a food indicate that several products for this food are represented in the database.

A2.2 High-impact food items identified from the case studies

Generally, high-impact foods consistently include meat (especially beef, pork and processed meats), dairy and certain imported plant-based products like nuts, tea and coffee on a cost per kilogram basis. These foods drive substantial environmental, health and social costs across French, German and Irish diets. Beef and pork, especially, are major environmental burdens due to their high GHG emissions, land use and fine particulate matter formation, with additional health risks linked to cardiovascular disease and cancer. Dairy products, particularly high-fat varieties, such as full-fat milk and cream and those with high milk content, such as cheese, also contribute significantly to environmental costs and are associated with cardiovascular health risks, alongside social challenges such as labour exploitation in production chains. To achieve greater change, targeting the environmental and health impacts of meat and dairy production and consumption should be prioritized. Plant-based foods such as beans, rice and nuts offer health benefits but are often sourced from regions with high social and environmental risks. It is important to note that legumes (e.g. soybeans) fed to livestock carry these same risks and contribute to even greater social and environmental impacts. Meanwhile, beverages like tea and coffee add further social risks due to labour concerns in global supply chains.

A2.2.1 HIGH-IMPACT DIETARY PATTERNS IN THE ASSESSED DIETS PER COUNTRY

Ireland

The Irish LLD has the highest environmental, social and health costs among the three diets studied, largely due to high consumption of meat (especially beef) and dairy (Figure A8). **Beef** emerges as the primary environmental impact, driven by global warming impacts and land use requirements. Additionally, red and processed meats contribute heavily to health costs, due to their associations with cardiovascular disease and cancer risks. Meat products, particularly beef and poultry, also present significant social risks, often related to poor labour conditions in the supply chain.

Dairy products are another key impact foods, contributing substantially to environmental costs, especially in the LLD and NRD. High-fat dairy options are recommended to be consumed in moderation due to increase cardiovascular health risks, contributing to health costs. The dairy industry also shares social risks similar to the meat sector.

Tea, coffee and sugary beverages further contribute to the environmental, health and social impacts of diets in Ireland. Sugary beverages are associated with health risks, while tea and coffee have notable social risks, especially given the labour issues in global supply chains. The Irish PHD shows the lowest environmental costs due to reduced meat and dairy intake, but items like vegetable oils, beans, and nuts still carry social risks due to current import practices.

In summary, **meat (especially beef), dairy and certain beverages** consistently stand out as high-impact foods across all Irish diets (LLD, NRD and PHD), significantly impacting environmental sustainability, public health and social equity.

Figure A11: Contribution to environmental costs of LLD, NRD and PHD from product categories in Ireland per person per day.

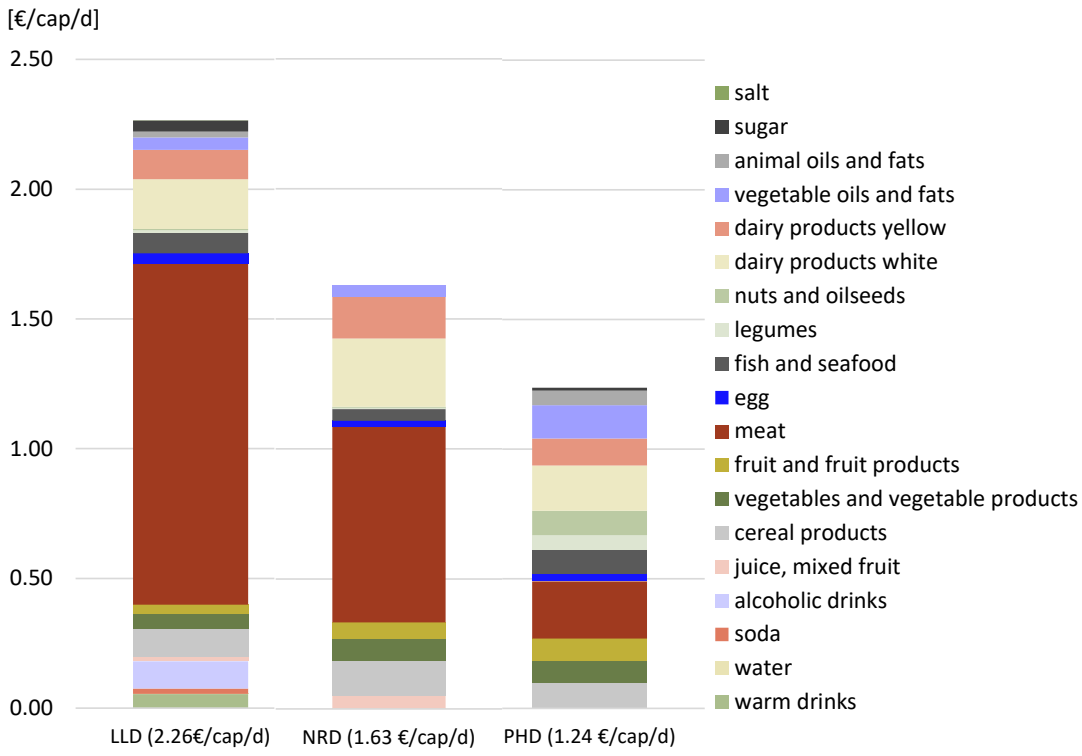
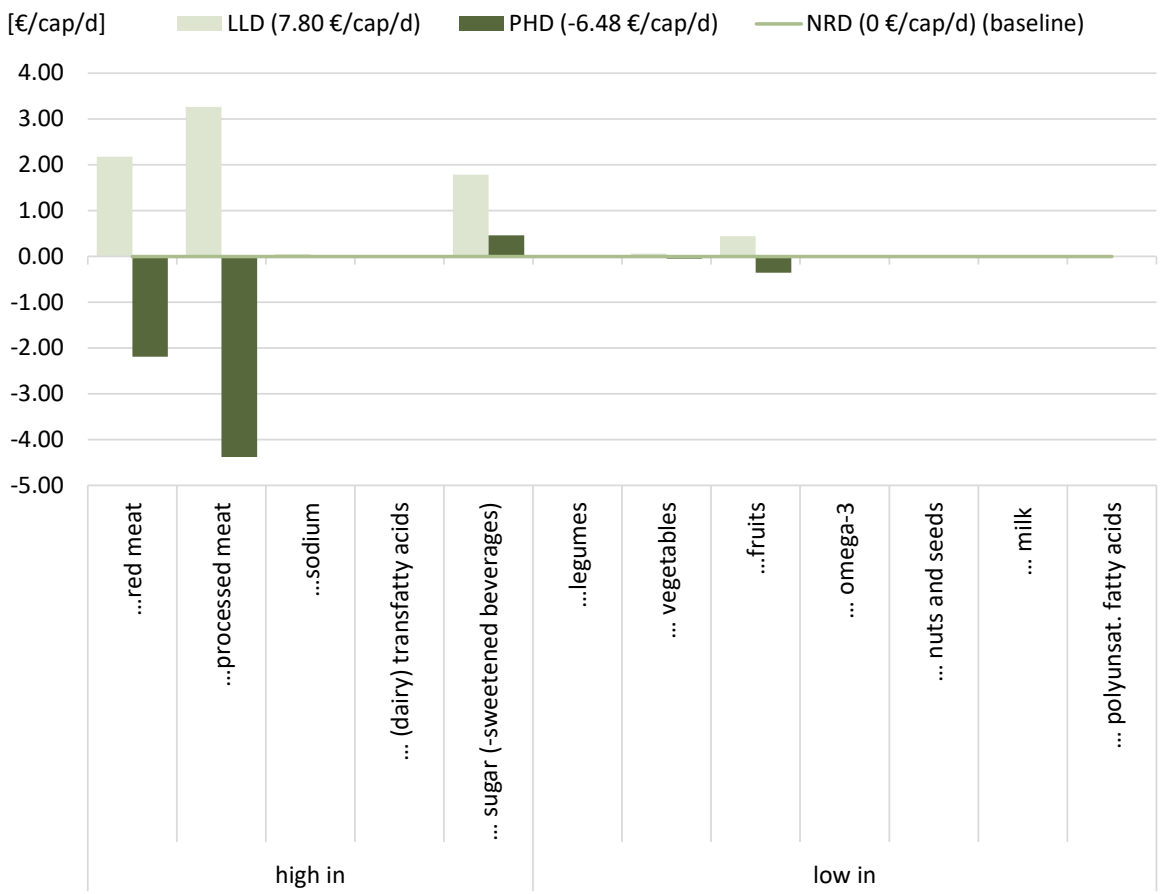


Figure A12: Health costs for LLD and PHD across all dietary risk factors in Ireland per person per day. NRD is the healthful benchmark diet and therefore depicted as the zero line over all dietary risk factors.



Germany

In the German LLD, high-impact foods include meat products, especially **red meat and processed meat**, which drive significant environmental and health costs (Figures A10 and A11). Here, pork in particular is associated with higher GHG emissions and resource use, while its processed forms contribute to health risks, notably cardiovascular disease and cancer. Social risks linked to pork also emerge due to labour issues in its supply chain.

Dairy products, particularly hard cheese, also stand out as high-impact foods in all diets due to their high GHG emissions and land use demands. Hard cheese contributes to health risks related to saturated fats and cardiovascular health, and its production is associated with social risks, including labour exploitation.

Tea and coffee present additional social risk hotspots, with high labour and social concerns tied to their global supply chains. Although the environmental impacts of these beverages are notable, health effects were not assessed in this study.

In the NRD, the recommendations for reduced levels of pork and meat intake lower environmental costs, although dairy, especially cheese, remains a notable cost driver. Social risks in the NRD are lower than in other diets but persist for foods like beans, rice and cheese.

The German PHD, focused on environmental sustainability, sees increased environmental costs due to higher recommended poultry, nut and vegetable oil intake. However, it offers the most health benefits by reducing red and processed meat consumption and simultaneously increasing legumes. Yet, the PHD has the highest social risks due to higher levels of beans, rice and nuts, which could offset some benefits gained from reduced meat intake.

In summary, **red meat (especially pork), processed meats, cheese and beverages (tea and coffee)** consistently emerge as high-impact foods across environmental, health and social impacts, making them key targets for interventions aimed at improving sustainability and health in German diets.

Figure A13: Contribution of the different food categories to the daily per capita environmental costs of LLD, NRD and PHD in Germany

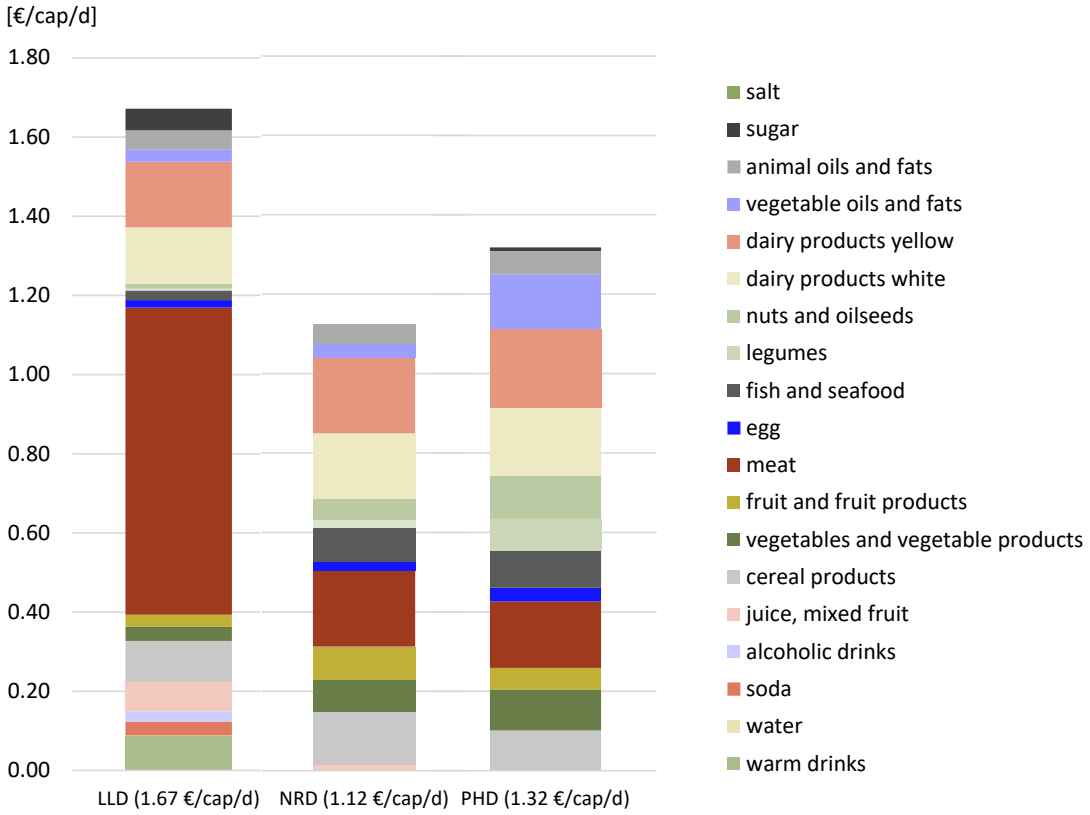
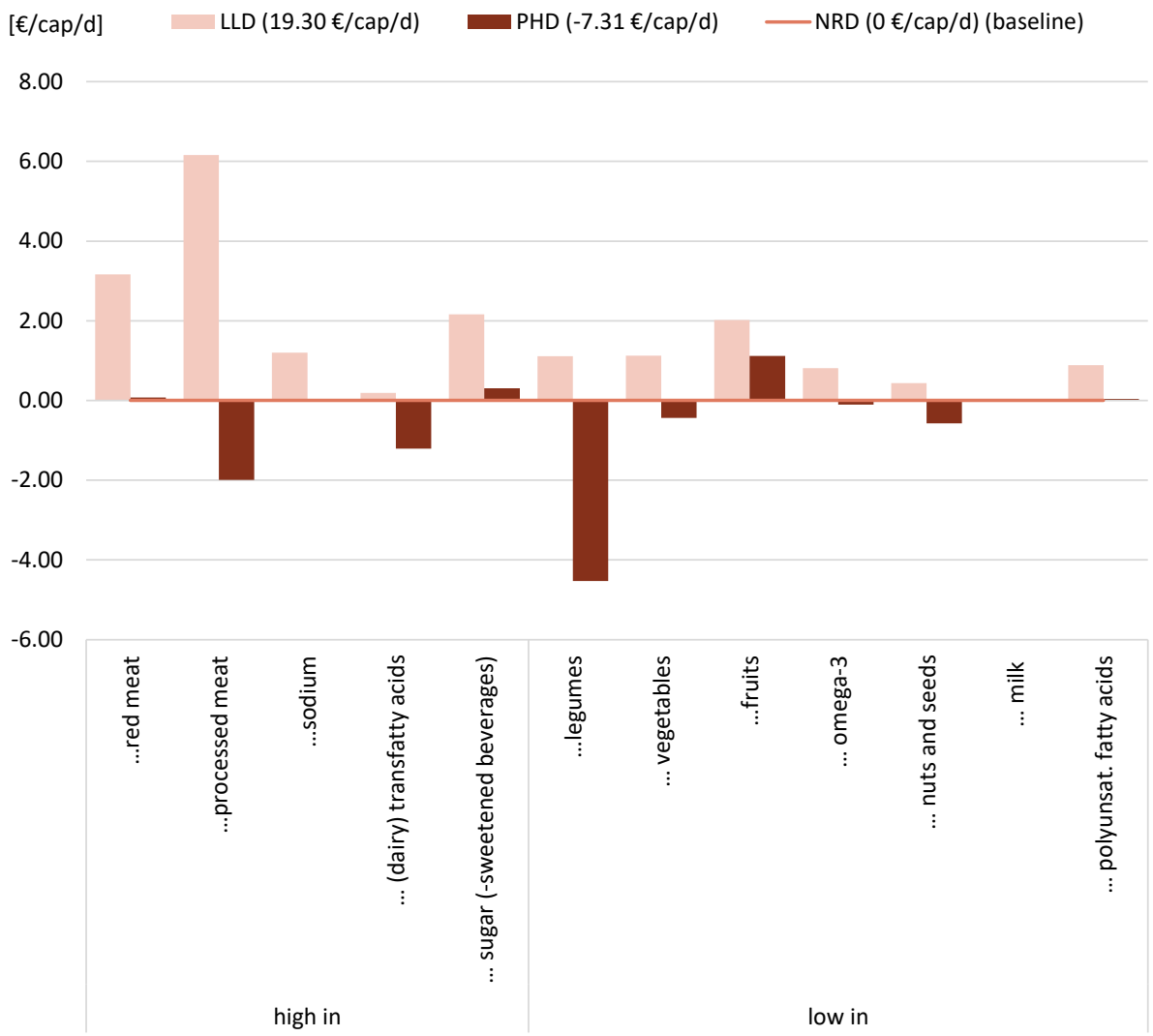


Figure A14: Health costs per person per day for LLD and PHD across all dietary risk factors in Germany. NRD is the healthy benchmark diet and therefore depicted as the zero line over all dietary risk factors.



France

In the French LLD, NRD and PHD, several foods contribute significantly to environmental, health and social costs, with notable overlap across all impact areas. **Red meat**, especially beef, and **processed meat** emerge as major environmental cost drivers (Figure A12), contributing to high GHG emissions, land use and fine particulate matter formation. It is also a key driver of health costs (Figure A13) and social risks due to labour exploitation within its supply chains.

While plant-based foods like **legumes and whole-grain rice** offer health benefits, their sourcing can result in environmental and social issues. In the NRD, beans and whole-grain rice from high-risk countries contribute to social risks, while in the PHD, legumes such as chickpeas or beans have environmental costs due to water consumption and low yields in their countries of origin.

In these diets, **dairy products** have a lower impact on health and social risks, but they do contribute to environmental costs through GHG emissions and land use, with cheese having the highest impact.

Nuts and vegetable oils, particularly in the PHD, also contribute to environmental costs due to resource-intensive production practices, with almonds and vegetable oils having the highest impacts.

Figure A15: Contribution to environmental costs of LLD, NRD and PHD from product categories in France.

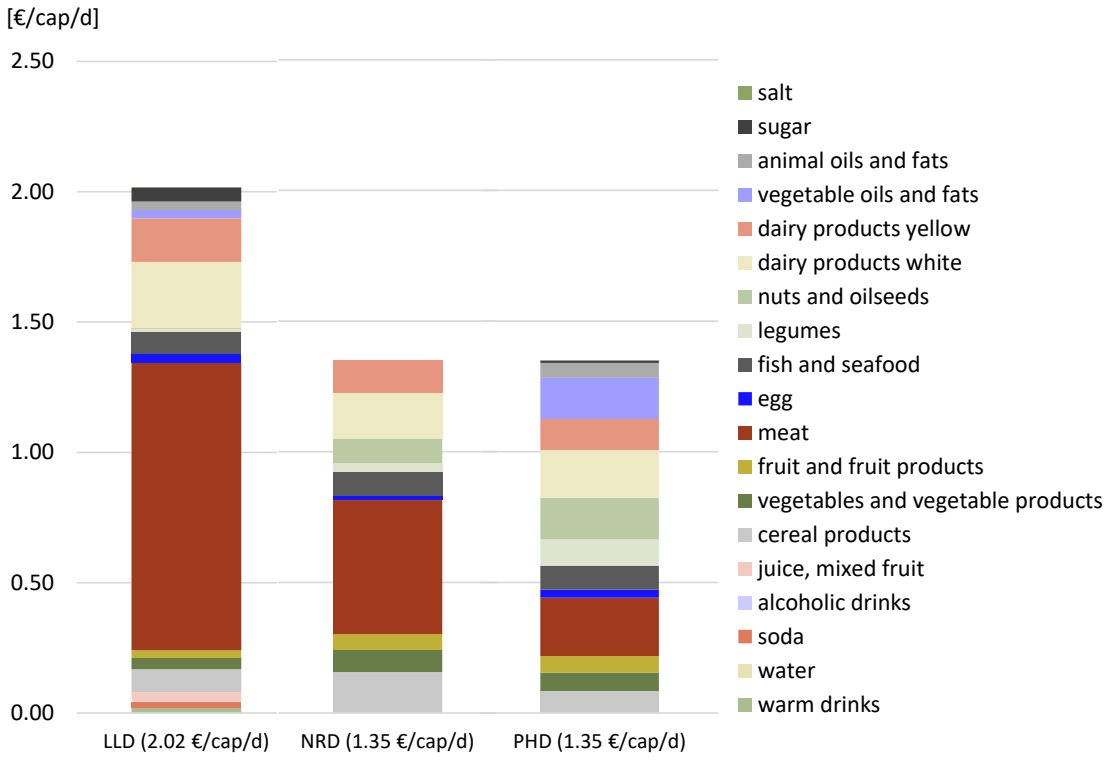
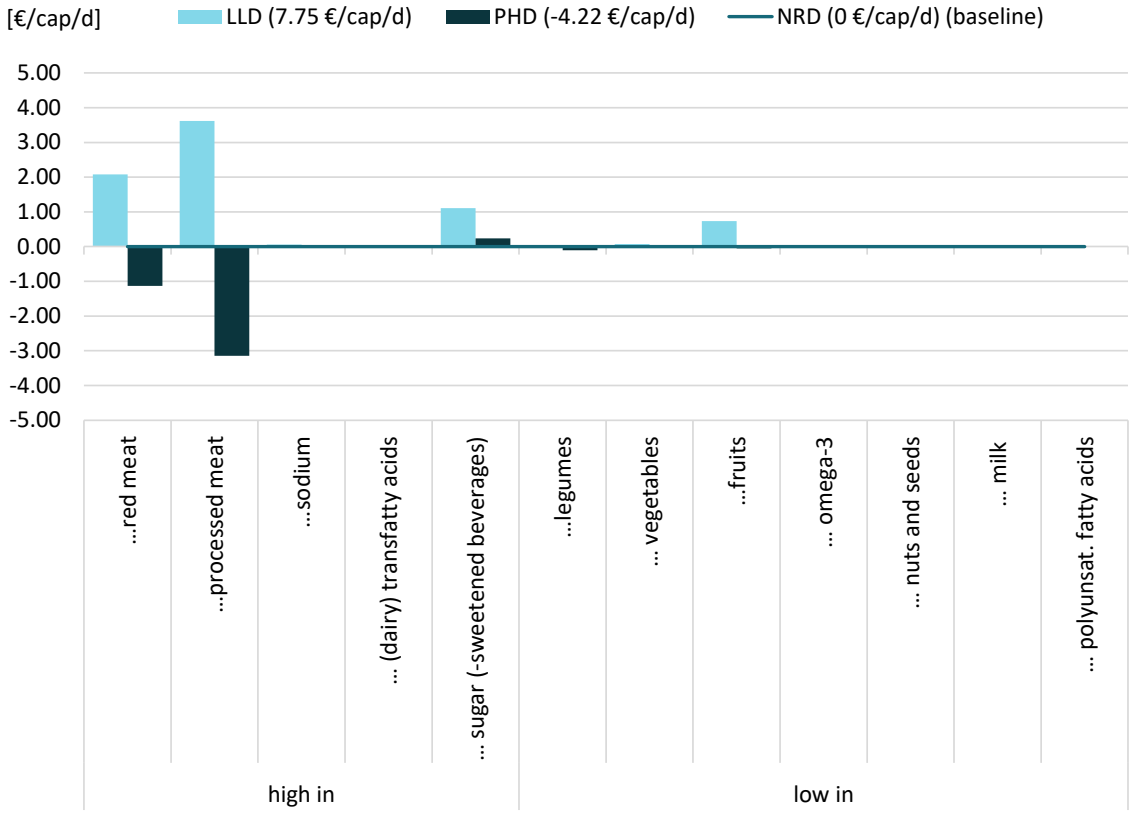


Figure A16: Health costs in France of all three diets (LLD, NRD, PHD) per person per day.



A2.3 Future Food consumption and production foresight scenarios for global, European and LL national levels

A2.3.1 GLOBAL LEVEL

At global level, the Agrimonde-Terra foresight project was first published in 2016 by INRAE and Cirad (Le Mouël et al., 2016). It included of eight foresight scenarios and is the only one to propose a scenario based on the impact of consumption of ultra-processed foods (UPFs) ("Metropolitanization" scenario). Among them, the Healthy C scenario is the most impactful one. It is notably based on sustainable intensification for cropping systems, agroecology for livestock systems and reduction of animal-based food consumption. As the authors write: "Only the 'Healthy C' scenario is likely to be able to ensure world food and nutrition security in 2050." An additional proposed notable pathway is the "Regionalization" scenario, which would involve the reconnection of the food industry to regional production within supranational regional blocs (i.e., traditional diets are promoted via a reconfiguration of supply and value chains at the regional level, with medium-size cities and small towns concentrating industrial and small-scale food processing). However, the feasibility of this scenario is questioned given that it involves strong mitigation objectives aimed at stabilizing climate change.

The EAT-Lancet PHD, released in 2019, was strongly focused on reducing animal-based food consumption (i.e. a low to moderate amount of seafood and poultry, and includes little or no red meat, processed meat, added sugar, refined grains and starchy vegetables) (Willett et al., 2019). Whilst recognized as transformative in addressing environmental impacts of diets, it has also been criticized for not being applicable to all regions of the world, which is why EAT-Lancet is working on regionalized versions of the PHD.

In 2020, INRAE published a conceptual framework (the $3V_{ALS}$ rule for Veritable, Vegetal, Varied foods, advocating for Agro-ecological, Local and/or Seasonal foods) for healthy and sustainable diets targeting the Horizon 2050 long-term strategy based on a synthesis of eight world foresight scenarios and eight protective diets for chronic disease (Fardet & Rock, 2020). The framework is based on the identification of four main levers (the first three for the diet, and the fourth one for the production) at a global level that define the relationship between diet, food system and global health:

1) Reducing ultra-processed food calorie consumption to maximum 15% daily (i.e. 1–2 servings per day);
2) Limiting animal-based calorie consumption to maximum of 15% daily (i.e. 3 servings per day);
3) Increasing food diversity to around 35 different foods per week; and
4) Increasing agro-ecology and organic farming, as well as local and seasonal products.

Overall, these three global scenarios seem to reach a consensus on reducing animal-based food and UPFs (and food high in added fat, salt and/or sugar (HFSS)) food consumption while increasing food diversity. Sustainable intensification, agroecology and/or organic farming could be the key agricultural practices to support.

A2.3.2 EUROPEAN (AND SCANDINAVIAN) LEVEL

The most comprehensive scenario analysis at European level was released in 2021 by French ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie/Environment and Energy Management Agency) and included a synthesis of 16 existing scenarios (ADEME, 2021). Among them, targeting Horizon 2030, the Future Nordic diets scenario, known as "sufficiency," is the most impactful, facilitating a reduction of the food footprint below "planetary boundaries." One of its main characteristics is a more extensive organic farming system where livestock feed production competes less with human food production. Overall, a large majority of scenarios are based on the reduction of animal protein consumption and the reduction of livestock farming, which appears to be a clear path to transition towards sustainability.

Targeting Horizon 2050, Billen et al. focused on an agroecological scenario, reducing nitrogen losses from synthetic nitrogen fertilizer to the environment and feeding the whole projected European population (Billen et al., 2021).

Again, the scenario is based on a dietary change toward reduced consumption of animal products but also advocates for an efficient recycling of human excreta, reusing it as fertilizer. In the same way, Schiavo et al. (2021) also proposed an agroecological scenario for Europe targeting Horizon 2030–2050 (Schiavo et al., 2021). It supports a dietary transition towards healthier and less calorie-dense diets with less animal foods and UPFs, increased legumes and coarse grains, with a relocation of vegetal protein production and a shift away from soybean imports.

Another emphasized dimension for healthy and sustainable diets in Europe targeting Horizon 2030 is the development of more local foods within the framework of the "Society Drives Sustainability—Consumers Enjoy a Green and Healthy Lifestyle" scenario (Voglhuber-Slavinsky et al., 2021). This scenario, where society is informed and concerned about food topics, involves connecting producers and consumers, reducing transport distances, and consequently relocating food processing. This scenario is the one with the greatest level of population engagement and participation, which would necessitate strong efforts in citizen education about healthy and sustainable diets.

Finally, the Nordic Council of Ministers has elaborated two impactful scenarios for Horizon 2030, focusing mainly on limiting livestock production to resources that do not compete with human food, as well as principles of organic farming (Karlsson et al., 2017). Additionally, the scenario accounts for food processing byproducts that are used to supplement feed for ruminants (cows) and monogastrics (poultry, pigs and aquaculture fish). More specifically, these two scenarios also proposed to reduce animal-based food, milk products, sugar, and imported foods, while increasing plant-based food consumption. However, it should be noted that the scenarios would likely result in higher food prices.

In conclusion, despite the diversity of European countries, scenarios for more sustainable European diets are generally based on the reduction of animal-based foods and the increase of plant-based foods. Local production and agroecology or organic farming are also preferred. In one scenario, the reduction in UPFs/HFSS food consumption is also proposed (IDDRI).

A2.3.3 LL NATIONAL LEVEL

The PLAN'EAT project includes nine LL countries: France, Germany, Greece, Hungary, Ireland, Italy, Poland, Spain and Sweden. Beyond the above-mentioned dimensions that apply at the European level, some specificities may emerge depending on the European country considered. Scenarios at country level are therefore considered below.

France

The most well-known French scenario is "Afterres2050," developed by Solagro (2014) among four different scenarios. It notably includes 62% plant protein and 38% animal protein (to cover all protein needs), 45% organic farming and 10% reasoned agriculture (both with respect to environment and efficient production),[6] with a focus on reducing food overconsumption and waste. Its main levers are:

- Promoting healthier eating behaviours;
- Emphasizing quality over quantity in food consumption;
- Reducing the intake of overly processed, energy-dense, and refined foods;
- Significantly increasing the consumption of plant-based products;
- Lowering sugar intake;
- Minimizing food waste and losses;
- Reducing total protein consumption by 25%; i.e. from 90 g to 70 g per day;
- Encouraging greater consumption of wholegrain cereals, nuts and legumes;
- Moderating fish consumption;

[6] An agricultural production system the primary objective of which is to optimize economic results by controlling the quantities of inputs, especially chemical substances (pesticides, fertilizers), in order to limit their impact on the environment.

- Increasing the intake of calcium-rich water;
- Adopting and generalizing agroecological practices; and
- Reducing soil artificialization.

However, the question of whether Afterres2050 could be applied across very diverse French regions remains open. For example, mixed crop and livestock systems cannot be generalized to the entire national territory.

In 2018, Billen et al. also proposed another impactful French scenario entitled "Changing towards Autonomy, Reconnection and a Demitarian Diet: The A/R/D scenario" (Billen et al., 2018). Its main levers are based on reducing animal proteins, suppressing synthetic fertilization and developing a demitarian diet (i.e. also called flexitarian diet)[7]. Such a scenario is in line with some of the global scenarios privileging food sovereignty and organic farming techniques and it would feed France with reduced environmental impact. In addition, it proposes the dominant crop rotation used for organic farming, taking into account the different regions of France.

Conclusions for French scenarios are similar to those at the European level, notably through an emphasis on an increase of agro-ecology/organic farming and plant-based foods (notably wholegrain cereals, nuts and legumes), with a reduction of animal protein consumption, food waste and losses, and overly processed, energy-dense and refined foods. Therefore, the development of a flexitarian/demitarian diet based on agroecology appears to be a strong potential lever to transition to healthy and sustainable food systems in France.

Germany

The most recent work for Germany proposes various potential Horizon 2050 strategies (fifteen scenarios) to make Germany's food system more sustainable, as well as assessing how effectively proposed policies could achieve environmental targets (Rasche et al., 2023). The "Alternative diets" scenario would likely be the most impactful, aiming to, by 2050, reduce average daily calories to 70% of 2010 levels (i.e. from 3,194 to 2,236 kcal/day), reduce sugar and fat consumption by 50%, as well as increasing vegetarianism to 20% of the population and veganism to 2%. Some propositions are as follows:

- Move towards plant-based diets to reduce livestock demand;
- Reduce livestock production to free up land and lower emissions;
- Convert farmland to ecosystems that store more carbon;
- Increase alignment from private sector actors and other stakeholders, to support changes;
- Decrease consumption of sugar and animal products by up to 70%; and
- Decrease consumption of industrially processed foods.

Generally, many of the positive changes in the environmental indicators can be attributed to a decreased production of animal products, mostly triggered by a change in diet. For this study, interviewed stakeholder groups have indicated a high level of faith in the power of education and health-promoting policies to effect a change in consumption patterns, believing that, e.g. community gardening and urban agriculture projects could promote a change in diet.

Previously, Lorenz and Veenhoff reported four "Context Scenarios" and seven "Strategic Food Scenarios" (Lorenz & Veenhoff, 2013). They write that "a sustainable food strategy mainly based on trade, innovation, and technology"—i.e. a siloed approach—"would not be a realistic option under uncertain economic conditions." No conclusion was drawn for which would be the best scenario. The German scenario approach is more focused on the role of other actors/stakeholders than that of producers for the different scenarios. However, according to research done by the PLAN'EAT project, the Strategic Food Scenario 3 ("Think Global, Act Local"), which is described as a regional option and based on strong communities, appears the most impactful and holistic. In this scenario:

- The food industry has been required to adapt.

[7] The demitarian diet aims to halve the portion of meat consumed in a regular meal, or to not eat meat on certain days.

- The consumer is competent and aware, demanding healthy and sustainable (e.g. fair, regional and organic) products.
- Preparing meals at home is an important part of daily life leading to a renaissance in regional production and market.
- Demand for and acceptance of regionally available food increases, while demand for convenience and prepared food decreases.
- Agriculture has a regional focus, with innovations that support organic farming accepted and applied.
- Transboundary import and export, especially over long distances, does not take place on any major scale.
- The main driver for sustainability is the orientation and knowledge of consumers, whose informed purchasing decisions create regional markets.

Meanwhile, Scenarios 4 and 5 ("Organic Products Made in Germany and "It's My Choice") would both be very impactful, although they are breakup scenarios and therefore somewhat idealistic and difficult to achieve. The main difference between the two scenarios is that, in Scenario 4, organic fast food and convenience food are preferred, while in Scenario 5 people take time to cook and eat at home. Otherwise, the scenarios have very similar visions:

- The food industry, distributors and consumers share responsibility for sustainability.
- Consumers are conscious about nutrition and food quality and are highly ecologically sensitive.
- Higher prices are widely accepted.
- Self-sufficiency plays no role in food production, largely because there is no time or need for it.
- Food producers must comply with sustainability standards to succeed in the market.
- Agriculture is innovative and organic farming is standard practice, even on a large scale.
- Technology and renewable energy help make organic food available all year round, with imports limited to the minimum necessary.
- The main drivers for sustainability are the demand for and supply of sustainable products.
- Economy and society are the main players.

Conclusions for German scenarios are multidimensional, including numerous levers as proposed by stakeholders. The approach is therefore a holistic one, involving reduction of meat consumption, increased organic farming, the power of education and health-promoting policies, and an involvement of all actors, not only producers and consumers.

Greece

The FABLE consortium recently released the Scenathlon scenario related to pathways for food and land-use systems in Greece (Koundouri et al., 2024). It also highlights agroecology and an increase in areas of organic farming. It specifically recommends shifting to the PHD by 2050 (EAT-Lancet Commission). There is a strong focus on water management for 17.5% of agricultural land and water efficiency for 5% of irrigated land through irrigation infrastructure. The report also underlines the necessity of stakeholder engagement to collect information on food waste.

There were also four published scenarios specifically examining the environmental and economic performance of alternative, fermentable household waste management (Mathioudakis et al., 2022). The outcomes of the study were useful for the development of generic proposals that can be used as guiding principles by local authorities and policymakers in developing integrated and localized food waste valorization schemes.

In the Verdant Lighthouse scenario, Christofilopoulos et al. reported that "the transition from the existent diet to a lacto-ovo-vegetarian diet constitutes a drastic positive change towards mitigating greenhouse gases" (Christofilopoulos et al., 2022). Anagnostopoulos et al. also supported the lacto-ovo-vegetarian diet for a healthy and sustainable transition (Anagnostopoulos & VCKA, 2014).

Partalidou et al. developed a local food system scenario in an attempt to achieve food sovereignty and minimize the distance (geographical, social and economic) between rural and urban regions and between producers/farmers and consumers/urban dwellers. This scenario supports the concept of Community Supported Agriculture; i.e. solidarity movements between customers and farmers, based on mutual trust and self-distribution (Partalidou et al., 2015). Notably, to overcome the effects of the economic crisis and change the role of the dominant agro-food system, farmers believe they can survive without middlemen.

Conclusions for Greek scenarios are focused on agroecology, water management, reducing meat consumption towards a lacto-ovo-vegetarian diet and increasing local food systems.

Hungary

As for Greece, Balázs et al. proposed for Hungary a trend scenario based on the improvement of Community Supported Agriculture (Balázs et al., 2016). This means a community built around food, leading to healthy, diverse, and joyful communities with a contemporary focus on residential food production, buying groups, farmers' markets, urban food councils, local food systems, farm-to-school programs, etc.

This also implies the development of local food systems and short food supply chains based on community-based local food shops, gardens and a transformation of public food procurement (Balázs, 2012), with:

- Relocation and small-scale production;
- Reconnection strategies to bring consumers closer to the origins of their food; and
- Direct contact between farmers and consumers.

As a result, local food systems would produce, process and retail foods within a defined geographical area.

Another trend scenario was based on the creation of a domestic organic action plan (Drexler & Dezsény, 2012) that would involve:

- Subsidies for organic conversion and yearly certification costs;
- Organic producers receiving priority from the Rural Development Ministry; and
- Marketing campaigns to disseminate credible info and to develop consumer awareness.

Conclusions for Hungarian scenarios are mainly based on the development of more local food systems and shorter supply chains, while supporting organic conversion.

Ireland

At present, there are no foresight scenarios for Ireland, and some of the sources/data provided are in an abstract form only as the full paper is not yet published.

First, Leydon et al. recommend that principles of DASH and Mediterranean diets could reduce diet-related disease and dietary GHG emissions (Leydon et al., 2024). They reported that "red meat, offal, and carbonated beverages are the greatest dietary causes of GHG emissions and blue water use" and concluded that higher quality diets can reduce GHG emissions but can simultaneously increase blue water use.

Another recent online article reports that research is ongoing to identify healthy eating guidelines for sustainable diets that are beneficial for both personal and planetary health (Conway et al., 2023). Propositions include:

- Replacing discretionary food with three portions of fruit/vegetable; and
- Reducing meat intake could reduce GHG emissions by 1.6k CO_2/day.

The authors concluded that changes are required to national eating habits.

In conclusion, foresight scenarios are still needed for Ireland. However, the country already appears aware of some relevant diet changes necessary to move towards more sustainable diets and food systems.

Italy

The aim of the study by Kalmpourtzidou et al. (2022) was to investigate the nutritional adequacy and environmental impact of Italian adults' diets by comparing current dietary habits with new alternative dietary scenarios. The objective of the optimization study was to build optimal sustainable dietary models for the adult Italian population, using the current Italian diet as baseline diet and taking into consideration the Italian food-based dietary guidelines (FBDGs) and the National Recommended Energy and Nutrient Intake Levels (LARN). Comparing current diet to sustainable and health scenarios, meat and dairy product consumption should decrease, while fruit, vegetable, fish and egg consumption should increase. However, authors pointed out that a balance between health and sustainability is necessary, as environmentally sustainable diets could lack essential nutrients, increasing the risk of malnutrition and disease.

Poland

The most recent Polish foresight report first emphasized that global climate change will likely limit the availability of certain products (e.g. cocoa, coffee), lead to a decline in agricultural production in areas most affected, and lead to fluctuations in local production yields, with a threat to food security (Karaczun & Kozyra, 2020). Polish agriculture is already suffering from climate change consequences, notably the reduction of yields, especially for potatoes and wheat, implying that food security will decrease in Poland. Among several proposed measures to address this issue, the most notable are:

- Strengthening the farm advisory system and veterinary services that must support farmers in adapting to new production conditions and limit the risk of new diseases and pests spreading;
- Supporting natural methods of water retention (restoration of mid-field ponds, wetlands, swamps, protection of peatlands, retention of water in drainage ditches, support for soil retention, etc.); and
- Adopting production systems that aim to protect organic components in the soil, rationalize fertilization and irrigation, and (in animal production) ensure animal welfare under thermal stress.

In 2019, the Polish Department of Development Strategies also proposed four foresight scenarios for Horizon 2050 to face climatic change and pandemic development (Nosarzewski et al., 2019).

Among them, the "Realists' utopia—on the path of sustainable development" scenario should be the most impactful by 2050. It is based on mitigating or limiting climate change and is characterized by:

- A transformation of agriculture via innovations in reducing the amount of nutrients discharged into the aquatic environment to positively impact water quality;
- A decline in meat production and the use of new crop technologies, which make it possible to significantly reduce crop aerials and significantly reduce the use of pesticides and fertilizers; and
- A relocation of some agricultural production to cities, where a significant portion of food is independently produced.

In 2018, in collaboration with The Boston Consulting Group, World Wild Fund for Nature (WWF) Poland published a report with two scenarios for Horizon 2050 that went beyond food and diets (WWF, 2018). Concerning foods, the report emphasized the importance of fish, noting that "A Baltic Sea full of fish will also contribute to Poland's food security, making Poland less dependent on fish imports."

In 2011, several drawbacks of Polish food systems were pointed out (Fronia et al., 2011):

- Farmers' low skills in ecological production;
- An increase in the number of genetically modified crops;
- Overeating, consuming "empty" calories, limited physical activity; and
- Increasing competitiveness from emerging Asian economies.

In the end, Polish scenarios are particularly focused on climatic changes and how to adapt to them, alongside sustainable fish production in the Baltic Sea.

Spain

For Spain, six foresight food scenarios were published in 2022 (Aguilera et al., 2022). Among them, the "AE_SAA (Agroecological + self-sufficiency)" is the most impactful. It is based on a 31% reduction in meat consumption and a 56% reduction in dairy, alongside a tripling of legume consumption. It also supports reducing food waste and an agroecological transition toward self-sufficiency to feed the population, while drastically reducing environmental impacts. The main idea is to combine agroecological practices (e.g. organic agriculture and extensive livestock) with a Mediterranean diet, where pulses replace red meat. However, challenges include bringing about the necessary energy transition, reduction of imports and social acceptance of dietary shifts (less meat, more vegetables).

Sweden

For Sweden, among four Horizon 2045 foresight scenarios, two are suggested to achieve the more ambitious targets for nutrition and health and for climate ("Food as Food Tech" and "Food Forgotten"), while only one achieves the more ambitious level for biodiversity ("Food as Culture") (Gordon et al., 2022). As expected, the main conclusions are to reduce meat consumption and increase fruit, vegetable and legume consumption. The "Food as Food Tech" scenario was characterized by:

- A decrease in agricultural land use via a large reduction in animal production heavily reduced, maintaining just enough for grazing of semi-natural pastures;
- A reduction in dairy and beef productivity;
- Enhanced animal welfare; and
- New technology to reduce methane emissions (by 10% per animal).

In this scenario, targets were met primarily through an increase in dietary demands for products with lower GHG emissions alongside a reduction of GHG emissions in the production of most products. The most ambitious consumption-based biodiversity targets were met through a reduction of land area needed for food production, via a plant-based revolution, novel food sources, and new types of production that require no or substantially less land. The most ambitious nutrition and health target was achieved by an interpretation of the PHD, adapted to include the same type and amount of macro- and micro-nutrients, but with a substantially increased intake of novel foods.

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