Ref. Ares(2024)7762731 - 31/10/2024

True Costs and Benefits of 3 EU Dietary Patterns

Deliverable D3.3

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DELIVERABLE PLAN'EAT – D3.3
True Costs and Benefits of 3 EU Dietary Patterns

Project full name	Food systems transformation towards healthy and sustainable dietary behaviour
GA number	101061023
Start date of project	01/09/2022
Duration of project	48 months
Deliverable n° & name	D3.3 – True costs and benefits of 3 EU dietary patterns
Version	3
Work Package n°	3
Due date of the deliverable	M26 – 31/10/2024
Participant responsible	Töpfer, Müller, Gaßner GmbH (TMG)
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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
SEN	Sensitive, limited under the conditions of the Grant Agreement	
CI	Classified, EU RESTRICTED, CONFIDENTIAL or SECRET under the Commission Decision No2015/444	

Quality Procedure			
Date	**Version**	**Reviewers**	**Comments**
16/09/2024 – 23/09/2024	V1	Siranush Ghukasyan (TMG), Olivia Riemer (TMG), Gültaç Çınar (TMG), Marlene Ohlau (TMG)	Feedback on content and style
30/09/2024 – 13/10/2024	V2	Elin Röös (SLU), Anthony Fardet (INRAE), Raymond Gemen (EPHA)	Feedback on content and style

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Abbreviations

AHDB	Agriculture and Horticulture Development Board
cap	capita (person)
CBS	Centraal Bureau voor de Statistiek (eng: Central Bureau of Statistics)
COI	Cost of illness
CPI	Consumer Price Index
CREA	Council for Agricultural Research and Economics
CVD	Cardiovascular diseases
d	day
DALY	Disability adjusted life years
DEFRA	Department for Environment Food & Rural Affairs UK
DGE	Deutsche Gesellschaft für Ernährung (eng: German Nutrition Society)
DMI	Daily median income
EFSA	European Food Safety Authority
EU	European Union
EUROSTAT	European Statistical Office
EU-SILC	European Union Statistics on Income and Living Conditions
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
GLO	Global
INRA	Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement (eng: National Institute for Agricultural Research)
IR	Internal report (of the PLAN'EAT project)
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LL	Living Lab
LLD	Living Lab Diet
LU	Livestock Unit
Mrheq	Medium risk hours equivalent
NRD	National Reference Diet
PHD	Planetary Health Diet
PPP	Purchasing Power Parity
RoW	Rest of World
RSPO	Roundtable on Sustainable Palm Oil
SHDB	Social Hotspot Database
S-LCA	Social Life Cycle Assessment
SLU	Swedish University of Agricultural Sciences
T2DM	Type 2 diabetes mellitus
TCA	True Cost Accounting
WHO	World Health Organization

Executive summary

Objective and study design

This study presents a comprehensive evaluation of the environmental and health impacts, social risks and true costs associated with different dietary patterns across three European countries, using the True Cost Accounting (TCA) method. Focusing on three Living Labs (LL)—Germany, Ireland and France—the research compares the true costs of the average diets in these countries (Living Lab Diets, LLD) with their respective national dietary recommendations (National Reference Diets, NRD) and the Planetary Health Diet (PHD). By identifying the key contributors to external costs and social risks ('hotspots') within each diet, this study highlights the most impactful levers for driving sustainable dietary transitions in each country. Additionally, the affordability of each dietary pattern is assessed by examining the share of household income required to meet the respective dietary costs, offering insights into their economic feasibility.

Key results

The study finds that transitioning from current LLDs to the PHD offers substantial health benefits in all three countries. Health costs linked to poor dietary choices—such as excessive red meat, dairy and processed food consumption—are substantially reduced under the PHD. Environmental costs, driven by factors like land use, fine particulate matter formation and global warming, are also substantially lower for the PHD, although regional differences exist. In Germany, the NRD exhibits the lowest environmental costs, while in Ireland and France, the PHD performs best in this category.

However, when following the PHD also some social risks arise with the consumption of certain plant-based foods (e.g. beans or nuts), primarily due to social conditions in production countries. These risks can be mitigated by encouraging the consumption of socially certified products or sourcing from countries with high labour and human rights standards.

Despite regional variations, the results consistently show that health and environmental performance are closely aligned, suggesting no trade-off between sustainability and health. High-impact foods are particularly referring to animal products such as red and processed meat and some dairy products (e.g. cheese). A shift towards plant-based diets benefits both people and the planet. It should be noted that the recommendations from this study apply more broadly to the age groups in each LL (for environmental and social impacts) or to the general population of the LL country (for health impacts), rather than specifically to the LL population groups, though they are still relevant for them.

The study also finds that all three diets are generally affordable across the countries, with each requiring only a small share of daily mean income. While the PHD is currently the most expensive option, it remains within the 20–30% affordability threshold of net income, though the lowest-income groups would face a greater financial burden from transitioning to healthier, more sustainable diets.

Broken down by the countries analysed, the results can be quantified as follows:

In **Germany**, the shift from the LLD to the PHD could lead to a reduction in health costs from 7.75€/cap/d to health benefits of -4.22€/cap/d. Environmentally, according to the results the PHD could reduce the cost from 1.67€/cap/d (LLD) to 1.32€/cap/d. However, the PHD's focus on poultry, nuts and oils leads to slightly higher environmental costs (0.20€/cap/d higher compared to the NRD). Further, the German PHD demonstrates the highest social risk compared to local LLD and NRD, mainly caused by beans, rice and nuts imports. While the LLD is considerably cheaper (2.6%/dmi), the NRD (4.2%/dmi) and PHD (4.4%/dmi) offer a sustainable dietary pattern at a slightly higher but affordable cost.

Ireland also shows great potential in health cost reduction from 7.8€/cap/d under the LLD down to benefits of -6.48€/cap/d when transitioning to the PHD, mainly due to a shift away from excessive meat consumption, particularly beef and pork. The Irish PHD also has the lowest environmental cost, resulting in 1.02€/cap/d environmental cost savings compared to the LLD. The Irish PHD also performs better than the LLD regarding social risks, with similar moderate social risk levels as the NRD. The remaining social risks can be attributed to margarine, milk, beans and nuts consumption. All analysed diets are considered very affordable for Ireland, as even the PHD as the most expensive diet, is at 2.9%/dmi.

Findings for **France** also show a notable decrease in health costs when transitioning from the LLD to the PHD (from costs of 7.75€/cap/d to benefits of – 4.22€/cap/d).

The environmental cost would decrease by 0.77€/cap/d when adopting the PHD instead of the LLD. Despite this, due to imported beans, rice and nuts, the social risk of the French PHD is considerably higher than the LLD's and more than twice the French NRD's social risk. Compared to Germany and Ireland, French residents are paying a higher share of their mean daily income for the three analysed diets: 4.2%/dmi for the LLD, 5.1%/dmi for the NRD and 5.2%/dmi for the PHD. Despite this, all three diets fall well within the 20-30% threshold and are consequently considered affordable.

The cost estimates in this analysis are based on average consumption patterns, which inherently limits their ability to fully capture the variability in true costs. For example, the costs associated with the PHD can vary substantially depending on the specific foods consumed but are presented here as averages based on typical national consumption patterns.

Key recommendations

This report offers practical recommendations for policymakers and stakeholders to promote the development of more sustainable and equitable food systems. Recommendations for improving the environmental, health and social performance of current and recommended diets across all three countries include:

1. **Reduction of (processed) red meat and dairy consumption:**
    - Promoting increased consumption of legumes and plant-based alternatives to replace excessive intake of animal products, particularly (processed) red meat and dairy, which are associated with the highest health and environmental costs.
    - Due to high environmental costs and health risks, especially with hard cheese, dairy intake should be limited.
2. **Promotion of sustainable and fair consumption:**
    - Minimize consumption of exotic imported products (e.g. beans, nuts, rice, tea, coffee) to reduce social and environmental impacts. Prioritize foods produced under fair conditions, guided by established labels.
    - Emphasize locally sourced and seasonal[1] fruits and vegetables that can naturally be harvested and thus reduce the demand for resources or transportation and therefore cause lower environmental and social risks and improve health outcomes.
3. **Substitution of dairy products with plant-based alternatives:**
    - Given the health costs of trans fats in dairy and the high environmental impact, limit dairy consumption. Alternatives include tofu, broccoli, kale, calcium-fortified milk substitutes, mushrooms, spinach, iodized salt and seaweed to maintain nutrient intake.
4. **Highlighting sustainable vegetable choices:**
    - Promote root and collard vegetables due to their favourable environmental and social impacts, encouraging consumers to include these in their diet alongside other colourful vegetables.
5. **Refining the planetary health diet recommendations:**
    - The EAT-Lancet Commission should place greater emphasis on locally sourced plant-based foods, further highlighting the interchangeability of legumes, seeds and nuts, to avoid high-risk imports with increased social risks that might negate environmental benefits. For instance, promoting local seeds over nuts for plant-based fats can reduce environmental burdens.

These recommendations aim to steer food systems towards a more sustainable future while ensuring equitable access to healthy diets for all.

[1] Here defined as naturally harvested at its peak ripeness during a specific time of year in a given region, requiring fewer artificial resources.

1. Research Design

This study is structured to investigate the true costs of dietary patterns using a multi-faceted methodological approach. First, the study maps and models the actual diets of selected Living Lab (LL) populations (diet: LLD) and the authors' interpretation of the respective national dietary recommendations (diet: NDR) and the regionalised Planetary Health Diet (diet: PHD). These different patterns are then assessed for their environmental, social and health impacts. We are using Life Cycle Assessment (LCA) for environmental impact assessment and social risk assessment. Environmental impacts are monetized using the True Cost Accounting (TCA) approach and the health cost evaluation takes place through the cost of illness (COI) approach. The study aims to identify critical hotspots of environmental and health costs, as well as social risks within the different dietary patterns and geographic regions of the Living Labs. It helps to inform on the necessary changes to transition to a sustainable, healthy and equitable diet across the European Union (EU). In this context, hotspots refer to key activities, processes or contributions within the life cycle of the food products, or products within the evaluated diets, that contribute most substantially to the overall external costs; i.e. hotspots could be: food items that contribute the highest to the external costs (e.g. meat); environmental, health or social impacts that are of great concern within the diets (e.g. GHG, processed meat, labour rights). We also explore the reasons behind the hotspots.

Additionally, the study also assesses comparatively the dietary affordability across the three dietary patterns for each of the LL countries. It assesses the cost of the LLDs, the NRDs and PHDs adjusted for the local context of each country. To estimate the cost of the LLDs, the NRDs and the PHDs, it uses price data from the International Comparison Program's (ICP) Food Prices for Nutrition (FPN) applying the Cost and Affordability of a Healthy Diet (CoAHD) methodology outlined by Herforth et al. (2022). To assess the affordability, data on the median household income per capita (person) (cap) per day (d) is collected for each country from the European Statistical Office (EUROSTAT) via the European Union Statistics on Income and Living Conditions (EU-SILC) and the affordability is assessed by calculating the diet cost as a percentage of individual daily income. To assess absolute affordability, we compare this percentage against a predetermined affordability threshold according to Barosh et al. (2014), identifying which diets are financially accessible for the median income consumer. Additionally, we evaluate relative affordability by comparing the costs of the LLDs, the NRDs and the PHDs within each country. This analysis aims to guide interventions towards promoting more sustainable and healthier dietary behaviours in Europe by providing a clearer understanding of the economic feasibility of adopting these diets.

The findings of this report inform recommendations for dietary transitions towards sustainability and health, tailored to the local contexts of the three LLs.

1.1 Research Questions

The aim of PLAN'EAT's task T3.3 is to understand the impact of food consumption choices on various aspects of society and the environment by analysing hidden environmental and health costs and social risks of three dietary patterns (LLD, NRD and PHD) across three LL target groups.

Specific questions investigated in this study are therefore:

1. How much environmental and health costs do different dietary patterns incur across population age groups and geographic regions? What are the social risks of these diets?
2. How do the environmental and health costs and social risks of selected dietary patterns compare with those of established reference diets? How would the impacts and hidden costs change if the population followed national and international dietary recommendations?
3. Where are the most expensive environmental and health costs and highest social risk contributions (i.e. hotspots) within each dietary pattern, how do they vary across different regions and what causes these hotspots?
4. What are tangible recommendations to reduce the negative impact of different dietary patterns towards less environmental, social and health costs for all?

5. How do the costs and affordability of the LLDs, the NRDs and the PHDs compare across Ireland, Germany and France, and what are the economic implications for promoting sustainable and healthy dietary behaviours in Europe?

These questions provide a roadmap for investigating the complex relationships between dietary choices and their impacts on society, the environment and human health. Their answering can provide insights into the consequences of food consumption patterns and inform strategies and policy decisions that foster the transition towards more sustainable and equitable food systems. Applying the herein depicted method of TCA and social risk assessment, we give comprehensive answers to these questions and develop recommendations for policymakers and stakeholders of dietary and agricultural policies and key actors within the food chain (e.g. retailers, farmers) on opportunities for transition towards healthier and more sustainable food consumption.

1.2 Living Labs

The PLAN'EAT project encompasses a comprehensive exploration of nine LLs, each representing a unique cultural, geographical and socioeconomic context within Europe. These LLs serve as dynamic platforms for collaborative research, innovation and community engagement aimed at promoting sustainable and healthy food systems.

Table 1: Living Labs with cultural, geographical and socioeconomic contexts.

Living Lab	LL population*	LLD population**
Germany	Children living with obesity and adolescents (10-18 years) from all educational levels	Adolescents (10-17 years)
Ireland	Young adults attending University (18-30 years)	Adults (18-64 years)
France	Children and adolescents (6-15 years), studying in rural and urban areas	Adolescents (10-17 years)[2]
* Population of the respective living lab according to the PLAN'EAT project. ** Population analysed in this study.		

Among the nine available LLs, we choose Germany, Ireland and France for our analysis on two criteria: First, good availability of Life Cycle Inventory (LCI) data (cf. section 2.2.2) of the consumed food products and second, the alignment between the LL target groups and the age groups covered by the dietary surveys conducted by the EFSA, which are used by the PLAN'EAT project partner Council for Agricultural Research and Economics (CREA) (Rossi et al. 2024, also cf. electronic Appendix 2).

It should be noted that the dietary patterns of the LLDs represent average dietary patterns of age groups within the LL population, rather than the specific population groups of the respective LL of PLAN'EAT. This also influences NRD and PHD modelling (cf. section 0). Further, health costs due to malnutrition are calculated for the average population of LL countries, as the data used for COI (cf. Table 5) does not differentiate between socioeconomic differences. Therefore, all recommendations drawn from this study are more applicable to the LL's age groups (environmental and social) or the LL country's general population (health) rather than the specific LL population groups, although they remain relevant for the LL population.

[2] We believe it to be more accurately reflecting the LL population group of France when only considering adolescents, rather than also including the children group of France, which is the group from 0 months to 9 years (Dubuisson et al. 2017). This is because there is greater dietary difference between 0 to 6 y/o compared to 6 to 10 y/o, and therefore the 10-17 y/o group is better reflecting this LL group's (6-15 y/o) diet rather than 0-17 y/o. Therefore, we use the diet of only adolescents for this LLD.

1.3 European Dietary Patterns

Under the PLAN'EAT project, CREA mapped the dietary patterns per LL based on European Food Safety Authority food consumption survey data (EFSA 2011) and analysed the differences and peculiarities of local and/or national dietary patterns regarding age, gender, socio-economic status, critical foods, culture, region and country. The results were compiled into a dietary pattern mapping report (Rossi et al., 2024). Under Task 3.2, PLAN'EAT project partner Swedish University of Agricultural Sciences (SLU) explored the LLDs further with a specific focus on the environmental impacts from production inputs, including labour requirements and animal welfare (Röös et al. 2023, IR2). The LLDs prepared by CREA and SLU serve as the starting point for our analysis.

From the mapped dietary patterns, we derive the average dietary intake of the three LLs under analysis (Germany, Ireland, France) and compare these current dietary patterns to the NRDs and PHDs constructed based on the national food intake. Comparing PHD with LLD and NRD allows to draw practical conclusions regarding the potential for and pathways towards more environmental and social sustainability in dietary patterns and (national) dietary recommendations.

1.3.1 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.

As previously described, the population groups evaluated for the LLD by Rossi et al. (2024) are not entirely consistent with the LL populations. CREA assesses average consumption data for a country's general age group, meaning, that further socio-economic intricacies of the LL (e.g. health characteristics, geographical specificities) that characterize the LL population (e.g. in Germany "*children living with obesity* and adolescents") are not considered Rossi et al. (2024). This is due to the design of the EFSA's food consumption database that CREA uses in their mapping (Rossi et al., 2024). Therefore, we choose CREA's population strata most closely reflecting the LL population group. For Germany and France, we evaluate the LLD of adolescents (10-17 years), whereas for Ireland we evaluate the LLD of adults (>17 years) (cf. Table 1). In this report, we do not address issues of potential underreporting in dietary surveys, which are the basis of the EFSA food consumption data.

As a result, the LLDs in this study are modelled for the LL-specific age group, without further demographic distinctions. Consequently, the true costs calculated for these LLDs represent the external costs currently associated with the age groups in the Living Labs, rather than any specific population subgroup.

1.3.2 NATIONAL REFERENCE DIET – NRD

National dietary recommendations serve as guidelines developed by public health authorities to promote optimal nutrition and overall well-being for specific populations. In the best case, they are informed by scientific research and tailored to address prevalent health concerns, cultural preferences and dietary traditions within each country or population group (Fischer and Garnett, 2016). Ideally, they should adhere to all three dimensions of sustainability (environmental, economic and social), however, hardly any national dietary recommendations do so until today (James-Martin et al., 2022). National dietary recommendations shall guide consumers and other stakeholders towards healthier and more sustainable dietary patterns and food environments.

Calculating the true costs of dietary patterns following national dietary recommendations allows us to identify areas for potential improvement of countries' dietary recommendations. Utilizing national dietary recommendations as a benchmark for the LLD provides a framework for evaluating the nutritional adequacy, intake levels and healthiness of the LL's actual dietary patterns. It further enables comparisons between the established recommendations of the different LL countries about their environmental and social performance, thereby supporting the identification of mutual learning. By anchoring LL diets within the context of national dietary guidelines, PLAN'EAT can promote sustainable and healthy eating habits while respecting cultural diversity and local contexts.

No specific national dietary recommendations for the age groups of the herein-assessed LLs are provided by the respective health authorities. Consequently, we model the NRD based on the recommendations for the average population but adapt the consumption amount of the NRD based on the current consumption for the modelled age groups of the LL populations.

We use the following dietary recommendations to construct the NRDs: The German Society for Nutrition (Deutsche Gesellschaft für Ernährung, DGE) issues a recommendation for the general population of Germany. The newest issue from 2024 is citing environmental concerns as one principle for their recommendations (DGE, 2024). The French dietary guidelines were updated in 2019 and published by the Public Health Authorities (Santé Publique France) under the Programme National Nutrition Santé (PNNS4, 2019-2023). The Irish dietary recommendations are published by the Department of Health of the Irish Government and are provided as easy-to-follow food pyramids, however with elaborate tips on serving sizes per food group (GovIE, 2019).

1.3.3 PLANETARY HEALTH DIET – PHD

We also compare the impacts and true costs of the LLD and NRD with those of the PHD (Willett et al., 2019). The PHD, as proposed by the EAT-Lancet Commission, is a health-based dietary recommendation that has been evaluated for its environmental sustainability impacts. Therefore, besides some concerns, the PHD can be seen as the currently best available benchmark for a holistic sustainable dietary pattern.

In 2019, EAT-Lancet introduced a global PHD, emphasizing the need to adapt this broad guideline to regional preferences and conditions. The publication of the region-specific PHD recommendations is anticipated for 2025. However, since these were not yet available upon request, we developed a tailored 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 (cf. section 2.1.2). To achieve this, we modelled the PHD consumption patterns according to the consumption patterns of LLD, adjusting the appropriate amounts of food for the modelled age groups of the LL populations.

In conclusion, the NRD and PHD are underlying different recommendations. We use the same representative products to model these diets, however, use different amounts of representative products according to the differences in recommendations.

2. Methodological Approach

We first describe how we mapped and modelled the diets (section 0), then outline the methodology for the environmental assessment (section 2.2), the health cost assessment (section 2.3) and the social risk assessment (section 2.4). Lastly, we describe the methodology for assessing dietary affordability (section 2.5).

All data used for the execution of the methodology in this study is presented in Appendix 1.4 (Data sources).
Construction of dietary patterns

In order to assess the impacts and hidden costs of the different diets, the dietary intake of the LL's age groups had to be mapped and modelled to establish consumption values for LLDs, NRDs and PHDs. This modelling is described in the following sections.

2.1.1 DIET MAPPING (CATEGORIZATION) AND SELECTION OF REPRESENTATIVE PRODUCTS

Food intake of the LL population was derived from Rossi et al. (2024) which is based on EFSA (2011). The EFSA's food classification system operates on a hierarchy from L1 to L7 levels, offering a detailed taxonomy of food products. At the highest level (L1), broad categories such as 'fruit and fruit products' or 'grains and grains-based products' are defined. As it descends through L2 to L7 levels, the classifications become increasingly specific, encompassing groups, subgroups and individual food items. For example, at L5, 'fruit and fruit products" are subdivided into 'apple', 'strawberries" or 'nectarines' in addition to 85 other fruit products.

While EFSA's food classification system is very intuitive from a consumption perspective, e.g. similar to how products would be grouped on shelves in a supermarket, it posed some challenges for modelling dietary patterns for TCA purposes.

For example, from an environmental and social perspective, some of these groupings at higher levels are too broad – such as the environmental impact of ruminant meat is vastly different to that of poultry meat – whereas the lower levels were not feasible to be modelled satisfactorily due to lack of data. Furthermore, the lower hierarchy levels are not consistent with the levels at which NRDs or the PHD are designed.

To compare the TCA results across the three diets (LLD, NRD and PHD) and derive meaningful recommendations, the dietary pattern data for all three diets must be standardized to the same level of categorization. For this purpose, we have created a categorization system with 24 food categories to align EFSA data used for LLDs with the dietary recommendations provided in NRDs and PHDs (see Table 2). Therefore, the information provided in the national dietary recommendation and by EAT-Lancet (Willett et al., 2019) for the PHD was translated to the definition according to EFSA's L1 level whenever possible. In some cases, an EFSA L1 category matched more than one of our categories: for example, EFSA L1 category 11 is 'legumes, nuts, oilseeds and spices', whereas we have two separate categories, one for legumes and another for nuts and oilseeds, but no specific category for spices (as spices are not included in dietary recommendations, for example). In this instance, we tried to match the categories on the L2 level. If this still was not possible (since, for example in L2 11.81 'processed legumes, nuts, oilseeds and spices' are subsumed), we went along the exposure levels until we were able to properly disaggregate the L1 categories. For the given example, this would be L3 level, where we matched EFSA 11.81.69 'canned or jarred legumes' to our category of legumes and 11.81.296 'primary derivates from nuts and similar seeds' to our category 'nuts & oilseeds'. This resulted in a specific matching of all EFSA categories to our categorization (cf. Table 2). Often, the sensible aggregation level was L5. Nevertheless, many of the products consumed on the L5 level were rather similar (e.g.: wheat bread or wheat rolls). The effort required to model numerous similar products individually did not yield a proportionate accuracy or insight of TCA results. This suggests that the marginal gains in specificity and detail obtained from individualized models are not substantial enough to justify the extensive resources and time required, but a more aggregated approach is more efficient and equally informative for the purposes of the study. In addition, previous work on TCA shows that the main differences in environmental, health and social impacts are caused by differences in broader categories, like products being of plant- or animal origin (e.g. Michalke et al., 2023, Seidel et al., 2024, Michalke et al., 2022, Pieper et al., 2020). Therefore, we defined representative products for our categorization according to the type of products within each category. For example, we did not differentiate between wheat products (like wheat rolls, wheat flour, etc.), but modelled all wheat products as wheat. Specifically, we did not apply conversion factors and treated 1 kg of wheat roll as equivalent to 1 kg of wheat. Broadly speaking, we grouped products with very similar production processes, or products, which root in the same product of origin together.

Our category 'other' is miscellaneous products, that were not compatible with any of the recommendations and are mostly compound products with various indetectable ingredients. We sorted them into our categories as much as possible (e.g. we assigned 'Potato crisps or sticks' from L1 category 4 into 'starchy vegetables'), but some were impossible to sensibly group into another category (e.g. spices, sauces, baking supplies like food colouring, etc.). The 'other' category makes up well under 2% of all consumed products (weight-wise) and could hence sensibly be neglected from the impact and true cost analysis. To categorise all products in a way that aligns with the categorisation according to EFSA and that of the national dietary recommendations, we established a numbering system with three digits, where #1 refers to the food type, #2 food type sub-category and EFSA category and #3 the products representative for the food sub-category (see columns #1, #2, #3 of Table 2).

Using these representative products, we constructed the consumption patterns (LLD) and recommendations (NRD and PHD) for each country using data from EFSA (2011). For example, to construct the category '2.4 Fruit and fruit products' for the LLD, we assigned all consumed products from the EFSA database to each fitting representative product.

In the category 'fruit and fruit products' all consumed products were assigned to one of the five representative products: all pomaceous fruit were assigned the representative product 'apple', exotic fruit were assigned to 'banana', all berries were assigned to 'strawberries', etc. (for details regarding the allocation cf. Appendix 1.1 and see electronic Appendix 2). We then summed up the amounts consumed per representative product that then in turn made up the category of 'Fruit and fruit products'.

Table 2: Categorization of diets and selection of representative products per category.

#1	Type	#2	Category*	EFSA Categories	#3	Representative Products
1	Beverages	1.1	Warm drinks	3	1.1.1	Tea
					1.1.2	Cocoa
					1.1.3	Coffee (Arabica)
		1.2	Water	21 (except 21.109)	1.2.1	Tap water
		1.3	Sugary drinks	21.109	1.3.1	Soda
		1.4	Alcoholic drinks	1	1.4.1	Beer
					1.4.2	Wine
		1.5	Fruit juices	9	1.5.1	Juice (mixed fruit)
2	Carbohydrate sources	2.1	Cereal products	10	2.1.1	Wheat
					2.1.2	Rice
					2.1.3	Oat
					2.1.4	Rye
		2.2	Starchy vegetables	18	2.2.1	Potatoes
		2.3	Other vegetables and vegetable products	20	2.3.1	Fruiting vegetables (tomatoes)
					2.3.2	Root vegetables (carrot)
					2.3.3	Leafy vegetables (salad)
					2.3.4	Collard vegetables (white cabbage)
		2.4	Fruit and fruit products	8	2.4.1	Pomaceous fruit (apple)
					2.4.2	Exotic fruit (banana)
					2.4.3	Berries (strawberries)
					2.4.4	Citrus fruit (oranges)
					2.4.5	Stone fruit (peaches)
3	Protein sources	3.1	Beef	13	3.1.1	Beef
		3.2	Pork	13	3.2.1	Pork
		3.3	Poultry	13	3.3.1	Poultry
		3.4	Meat, other	13	3.4.1	Venison
					3.4.2	Beef and pork[3]
					3.4.3	Mix meat
		3.5	Eggs	5	3.5.1	Eggs (chicken)
		3.6	Fish and seafood	6	3.6.1	Marine fish (salmon)
					3.6.2	Freshwater fish (trout)
					3.6.3	Shellfish (mussels)

[3] Some mixed products are modelled as the product mix of their components. E.g. some processed meats (like some types of sausages) contain both pork and beef, therefore we define them as their mix with shares of half and half. Some products are composites of pork, beef and poultry, and we model them as their mix with shares of one third each. The same holds for 3.6.4 'fish mix', where included products are indefinable and therefore a mix of both marine and freshwater fish, again with shares of half and half, is applied.

					3.6.4	Fish mix
		3.7	Legumes	11.60, 11.81.69	3.7.1	Peas (garden peas)
					3.7.2	Lentils (brown)
					3.7.3	Beans (common beans)
					3.7.4	Chickpeas (chickpeas)
4	Fat sources	4.1	Nuts[4] and oilseeds	11.74, 11.81.296	4.1.1	Almonds
					4.1.2	Peanuts
					4.1.3	Sunflower seeds
		4.2	Dairy products white (i.e. low milk input)	14 (except 14.23)	4.2.1	Milk
					4.2.2	Yoghurt
					4.2.3	Processed milk
		4.3	Dairy products yellow (i.e. high milk input)	14.23	4.3.1	Hard cheese
					4.3.2	Soft cheese
		4.4	Vegetable oils and fats	2.5.406, 2.34.236, 1.34.51	4.4.1	Olive oil
					4.4.2	Sunflower oil
					4.4.3	Margarine
					4.4.4	Peanut oil
		4.5	Animal oils and fats	2.34.62, 2.5.25, 2.4	4.5.1	Butter
					4.5.2	Animal fat
5	Rest	5.1	Sweets	19	5.1.1	Chocolate[5]
					5.1.2	Sugar (beet sugar)
		5.2	Salt	17	5.2.1	Salt
6	Oth	6	Other	4, 7, 12, 16, 17, 11.92		

* Further definitions of product categories are provided in Appendix 1.1, Table 30.

** Due to the methodological approach of grouping products with similar production processes, or products, which root in the same product of origin together, we cannot take into account the processing stage. Modelling decisions and system boundaries of the representative products are further described within the subsequent methodological sections of the environmental, health and social assessment.

It needs to be acknowledged that based on this methodology, we do not consider the processing stage and therefore cannot account for the varying impacts of food processing, despite the substantial role it plays in shaping the environmental, social and health outcomes of food products. As a result, our analysis may underestimate the hidden costs associated with highly processed or discretionary foods, which have been shown to carry substantial health risks (WHO 2024).

[4] We account for nuts and seeds according to how they are defined as in dietary recommendations. Botanically, some products that are to consumers known as 'nuts' are legumes (e.g. peanuts) or the seed of stone fruit (e.g. almonds). However, since we are assessing dietary patterns, we define these products how they are referred to in culinary terms and dietary recommendations.

[5] We model chocolate sweets as composite products of sugar, cocoa and milk, including its necessary processing steps. We use an average chocolate recipe for this product to model the average shares of ingredients.

Box 1: A fictional example for better understanding how the diets were constructed:
Within the LL France the following products and amounts within the category 'Fruit and fruit products' are consumed:

Actually consumed product	Reference product	Amount [g/day]
Apples	pomaceous fruit (apple)	18
Fruit compote, apple	pomaceous fruit (apple)	13
Common banana	exotic fruit (banana)	10
Strawberries	berries (strawberries)	8
Mandarins and similar-	citrus fruit (orange)	7
Oranges	citrus fruit (orange)	5
Fruit compote, mixed fruit	pomaceous fruit (apple)	4

Each product is matched to a reference product. We then sum up the amounts consumed per reference product:

Reference product	Amount [g/day]
Pomaceous fruit (apple)	18+13+4=35
Exotic fruit (banana)	10
Berries (strawberries)	8
Citrus fruit (oranges)	7+5=12
Stone fruit (peaches)	-

We now evaluate the environmental and health costs, and social risks of 35 g of apple (representative for the costs occurred from all pomaceous fruit products consumed), 10 g of banana (representative for all exotic fruit consumed), etc. The costs for each reference products are then aggregated to assess the total cost of the food category 'Fruit and fruit products'.

2.1.2 DIET MODELLING

To model the NRD and PHD, we used the national dietary recommendations (DGE 2024, PNNS 2019, GovIE 2019) and the Planetary Health Diet (Willett et al., 2019) to determine the recommended intake per person per day.

Since most national recommendations specify consumption in 'portion sizes per day,' these portion sizes had to be converted into 'grams per day.' For this, we used supplementary explanations and data from the recommendations, or other literature (data sources are documented in electronic Appendix 2). Whenever there were ranges given in the recommendations (e.g. “1-2 servings of”, or “20-30 g of”,) we used the mean value, (e.g. in these cases 1.5 servings or 25 g, respectively).

When national dietary recommendations specified certain foods (such as sugar) to be consumed in “little” amounts, we interpreted this as a recommended intake of zero.

The information contained in the national dietary recommendation of Ireland, Germany and France and the information provided in EAT Lancet’s PHD (Willett et al., 2019) are on average on the same level of granularity as our proposed categorization specified in Table 2 and they do not provide any information on specific products that should be consumed. To model NRD and PHD for each country so that results are later comparable, we assumed and used the same diet modelled for the LLDs, adjusting only the quantities to align with the recommended amounts according to the national dietary recommendation and EAT Lancet’s PHD (Willett et al., 2019).

This means that the shares of the reference products within one food category stay in line with the consumption values of the LLD (because they reflect the dietary preferences in this specific country), but the share of the food categories in total is adjusted according to the recommended amounts in the national dietary recommendation and EAT Lancet's PHD (Willett et al., 2019).

In most cases, NRDs combine various products into broader categories, e.g. they recommend "5 servings of fruit and vegetables per day". To reflect country-specific consumption patterns, we applied the actual consumption shares from the LLD within these categories and standardized them to meet the recommended intake. This approach allowed us to tailor the recommended intake to the unique characteristics of each country's consumption habits. The same method was used to align the representative products with the PHD.

Box 2: A fictional example for better understanding the diet modelling approach:
Recommended consumption: "3-5 servings of vegetables per day" with one serving of vegetables being approximately 100 g.

1. We use the mean of 3 to 5: 4 servings of vegetables per day of 100 g equals 400 g of vegetables

Actual consumption: 40 g of tomatoes, 10 g of cabbage, 30 g of carrots, 40 g of lettuce, i.e. a total vegetable consumption of 120 g

2. We use the following share of vegetables per day: 33.33% tomatoes (40/120), 8.33% cabbage (10/120), 25% carrots (30/120), 33.33% lettuce (40/120)
3. We extrapolate to the recommended amount of 400 g per day: For each reference product, we multiply the share with 400 g. This results in 133.33 g of tomatoes, 33.33 g of cabbage, 100 g of carrots, 133.33 g of lettuce

If serving sizes vary within one category, e.g. a dairy serving size would be 200g of milk or 150g of yoghurt, we also account for this when extrapolating towards the recommended intake.a dairy serving size would

When interpreting the results, it is important to note that the NRD and PHD recommend food categories (e.g. vegetables) rather than specific items within those categories (e.g. tomatoes or cabbage). However, our methodology models and assesses specific items as representative products of these broader categories. This means that if tomatoes, for instance, have high environmental costs that raise the overall true costs of the PHD in a given country, this reflects assumed consumption patterns (based on LL data) rather than a specific recommendation to consume tomatoes. That means that the often generic recommendations in the NRD and PHD could be refined based on our results.

2.2 Environmental Life Cycle Assessment and True Cost Accounting

With the environmental Life Cycle Assessment (LCA) method, individual products are modelled to evaluate their environmental impacts. To model the complete diets, we assessed each representative product (cf., electronic Appendix 4) as consumed in each country.

The steps of the LCA method comprise (1) the definition of goal and scope, (2) the compilation of the Life Cycle Inventory (LCI), (3) conducting the Life Cycle Impact Assessment (LCIA) and (4) the interpretation of the results (Figure 1).

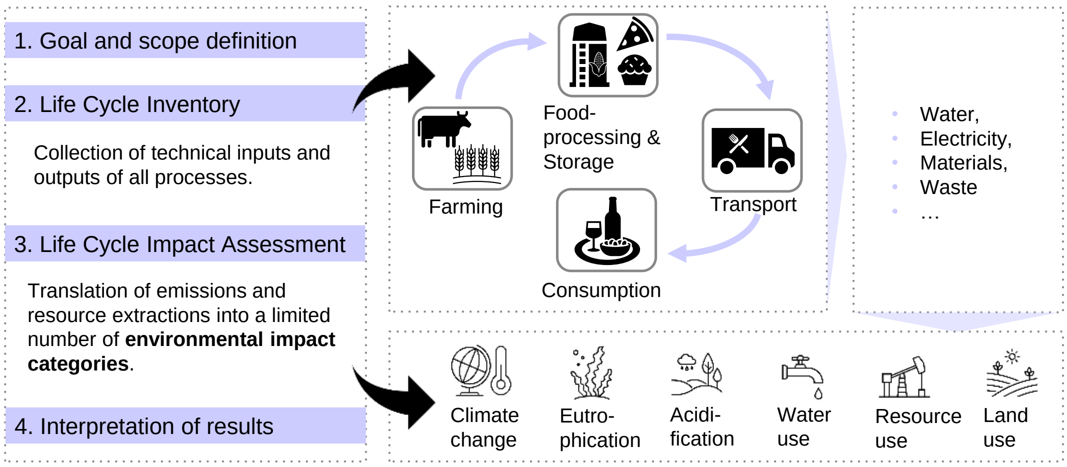

Figure 1: Steps of the Life Cycle Assessment method according to ISO 14040. Figure from PATOS.

2.2.1 GOAL AND SCOPE DEFINITION

The goal of the LCA was to assess the environmental impacts of each diet under investigation. This was done by modelling the representative products consumed within each diet in LCA software with LCA data to reflect the impacts of the diets as accurately as possible.

We defined the **system boundaries** of our assessment as cradle to processing gate; this includes all processes of resource extraction (like feedstock production, nitrogen fertilizer production, etc.), manufacturing and the transport processes in between. The manufacturing comprises all processes on farm, as well as primary processing steps beyond the farm gate and the transport thereto. The representative products are generally modelled as "consumption mixes, these include all steps required to transform raw agricultural products into consumable food items (e.g. milling of grains, slaughtering of animals). We excluded the processing steps of packaging, as data availability for the type and quantity of packaging of the products in LLD is not sufficient.

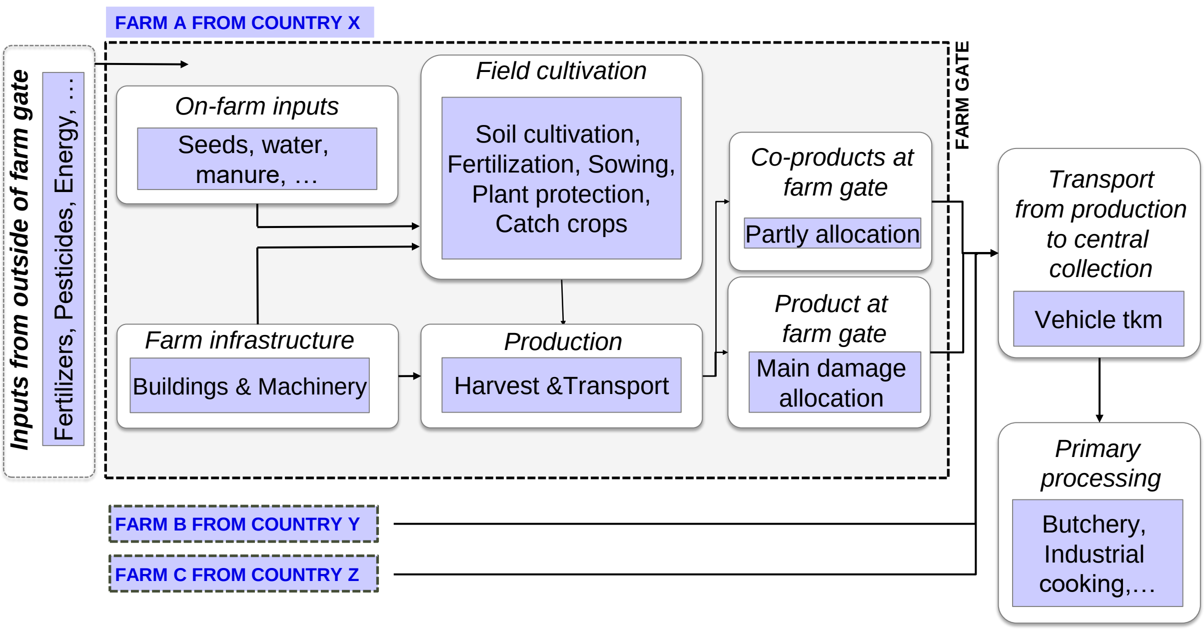

Figure 2: System boundaries of the LCA. Figure from PATOS.

2.2.2 LIFE CYCLE INVENTORY – MODELLING ASSUMPTIONS, UNCERTAINTIES AND DECISIONS

We based our environmental assessment on the **LCI database Agribalyse (v.3.1)**. Agribalyse offered product inventories that could be matched to the representative products to model the respective diets.

In general, 'consumption mix' processes were used, representing the first consumable product after primary production (e.g. wheat is based on the inventory process 'durum wheat, consumption mix') and meat is assessed as raw and bone-free.

These LCIs in Agribalyse were then adapted to be country-specific for each LL, e.g. transport processes were modelled according to the countries' food imports. For all modelling adaptations, see in the following, a) to g). Agribalyse is a French database but includes data for products from outside France as well. We largely followed modelling assumptions and decisions as stipulated in the modelling definition and framework of Agribalyse v.3.1. For all data, we used the most current available data, which in most cases is 2022. The year of data origin is stated within every sheet in the electronic Appendix 3.

A) IMPORT

Since the products consumed in the LL countries (Germany, France and Ireland) are not exclusively produced domestically, it is important to account for the environmental (and social, cf. 2.4) impacts across the entire value chain of these products. To do so, we modelled each product based on its country of origin. This includes the LL country itself when applicable, as some products are partially sourced domestically due to self-sufficiency. However, a large share of products is imported from other countries. These countries of origin are determined using import data (Röös et al. 2024). This had an impact on the environmental model (cf. b) as well as the transport model (cf. c).

For the import shares and self-sufficiency of the LL countries, we used the model of IR2 (Environmental performance of baseline diets from the Living Lab countries, IR2). To cite: "Foods and raw commodities in a diet are typically sourced from many different places. Here we account for this by using a weighted average of the footprints of RPCs [raw primary commodities] from different countries based on trade data from Schwarzmueller & Kastner (2022)." (p. 10, Röös et al. 2024). Likewise, we assumed that all food processing takes place in the consuming LL countries. Therefore, we use trade data for sunflower seeds, for example, to depict both the consumption of sunflower seeds and sunflower oil.

The number of importing countries varies for each food product, with some importing shares being marginal. Since these marginal imports do not largely influence the environmental performance of the end product, we modelled products according to the top five countries of origin. If a country of origin is among the top five origins for one LL country but is, for example, the sixth highest country of origin for another LL country, we included it in the model for the latter as well. The top five (or more) countries of origin represent at least 90% of all imported products. To determine the proportion of each country's contribution, we normalized the import values from these countries to 100%. These adjusted shares were then used to represent the composition of the product mix consumed in the LL country.

B) MODELLING PRODUCTS PRODUCED IN LL COUNTRIES AND IMPORTING COUNTRIES

We utilized LCI datasets from Agribalyse as the primary data source. For modelling the products from different countries of origin, we initially planned to follow the modelling decisions of Agribalyse v3.1 which uses different inventory databases[6]. After the first evaluations, however, we found that using different inventory databases (Agribalyse, Ecoinvent, WFLDB) as sources for the same products from different countries of origin would over- or underestimate certain impact categories in comparison to one another and therefore would not deliver comparable results between different countries.

Therefore, we used the Agribalyse datasets as the primary dataset for each product and adapted the following parameters:

- Yield
- Pesticide use (differentiated between herbicide, fungicide, insecticide, pesticide (NEC), plant growth stimulator)
- Irrigation levels
- Fertilizer use (differentiated under N, P_2O_5, K_2O)
- Transport
- Import

[6] Agribalyse approach: If production processes for LL (Living Lab) countries are unavailable in Agribalyse, resorting to Ecoinvent 3.8 (cut-off allocation); if no data is available in both Agribalyse and Ecoinvent, using the WFLDB (World Food LCA Database); if the process for a specific country is yet unavailable, using neighboring countries' datasets or those with similar climates as proxies.

We adapted these parameters to the underlying production system given in Agribalyse, except for yield, where we used the absolute value per hectare (i.e. not to the underlying system). This was done by adjusting the countries' inputs in relation to the French inputs. For products not typically grown in France, such as rice, coffee, cocoa, or bananas, we used the processes provided in Agribalyse (e.g. rice from Thailand) and adapted the relevant parameters about this baseline. This approach aligns with the modelling decisions made by Agribalyse, which often remodels base data from primarily French processes to describe production in other countries following the described parameter adjustment.

The data for yield, pesticide, irrigation and fertilizer use were derived from the FAOSTAT. All modelling input data is also shown in electronic Appendix 3.

C) TRANSPORT

For transport within LL countries, we followed the same method as Agribalyse for domestic transport. First, we defined processing to take place at a central collection hub within the country (cf. Figure 3). The domestic transport distances were modelled in Agribalyse for France as 187.85 tkm in total, which we extrapolated for every other country based on the countries' land area compared to France. This total distance was then divided towards different means of transport with modal shares of transport. EuroStat (European Commission, 2014) provides statistics for average transport modes for food goods within a country (modal share of air, sea and inland freight transport). We normed this split at 100% to only inland freight transport, therefore excluding sea transport since this is unlikely to occur within domestic transport. This EuroStat data therefore establishes the average domestic mode of transport for Germany, France and Ireland.

For international transport (transport from countries of origin to France, Ireland or Germany), we differentiated between EU-internal trade and EU-external trade. For EU-internal trade, we used the same data source as for domestic transport (modal split of air, sea and inland freight transport). We included sea transport into the share for Ireland (as it is an island) and only used rail, road and internal waterways for EU transport to France and Germany. We used EuroStat data on modal splits for food imports from outside of the EU, including sea shipping in addition to inland transport. We used the distance between centroids of the respective countries of origin to the LL countries as the total transportation distance. These total distances were then allocated to the modal shares of each means of transportation.

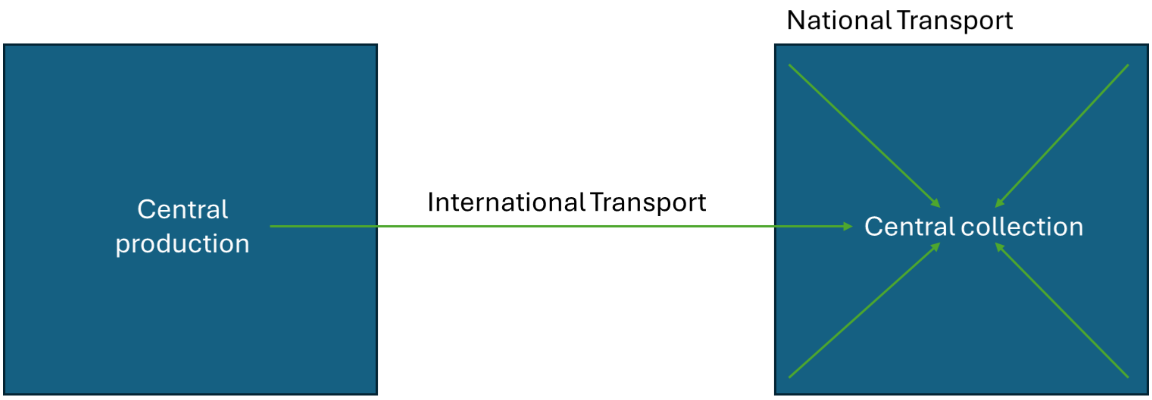

Figure 3: Simplistic presentation of international and national transport. We assume international transport from central production to central collection hubs. We assume national transport to central collection hubs. The central collection hubs are also where all processing takes place.

We included air transport into the transportation scheme of exotic fruits to depict the environmental differences depending on the consumption of product of airfreight and other transformation modes. This is specifically targeting recommendations for consumers aiming to reduce their diet's environmental footprint. For this, we included air travel into the modal transportation shares for our LCI models of exotic fruit.

D) IRRIGATION

For irrigation data, we used the AQUASTAT database of the Food and Agriculture Organization of the United Nations (FAO) and World Bank Data (see electronic Appendix 3). Here, data on cropland and agricultural water withdrawals provide insight into the actual irrigation activities in a producing country on cropland. However, the data sources do not provide specific irrigation information for the respective production of a specific food product.

To assign irrigation levels to a specific food value chain in a respective production country, we estimated the average irrigation levels for the respective food product based on data from Agribalyse (usually France) and put this value in relation to the total irrigation levels on cropland in the respective production country using AQUASTAT and World Bank data. Through this ratio, we estimated the share of irrigation used for the specific product in a respective country. We then adjusted the LCI for irrigation quantities according to this ratio. We used the most recent ratio available, so optimal irrigation per area of cropland from 2022 from country A (country of origin) in relation to country B (model in Agribalyse, mostly France). However, oftentimes data on water withdrawal was not as recently available as in 2022. We tried to draw the ratio between the countries in the same year, however, if this was also not possible, we drew the ratio between the most recently available years. With the same ratio, we adapted energy consumption for irrigation on the field accordingly. The type of water basins of which irrigated water is drained (e.g. river, well, groundwater, etc.) was adapted for each country.

For rice production, we left the irrigation value as is in the baseline inventory (Thailand). This is because rice fields are mostly flooded and therefore using the irrigation value per hectare as modelled in Agribalyse for this activity would have underestimated water consumption. This could potentially mean, that in certain areas irrigation for rice would have been close to zero simply because in this area compared to the basis inventory of Thailand, irrigation for other agricultural practices is comparably low.

E) ELECTRICITY

We adapted all used electricity in the inventories to the electricity mix of the country as modelled in Agribalyse. If this mix was not available, we used comparable proxies (like neighbouring countries or 'Rest of World'[7]).

F) GROWN UNDER GREENHOUSE

Crops grown under greenhouses, runners or tunnels (such as is often the case for lettuce, tomato and strawberry) include different inputs than open field crops. This is, for example, the metal and plastic used for the greenhouse structure, or the energy input needed for heating the greenhouses (particularly in colder regions). Therefore, differentiating between greenhouse processes and open-field processes within the producing countries influences the environmental impacts of these products.

For all greenhouse processes, we kept the irrigation levels as modelled in the Agribalyse baseline process (meaning we assumed the same situation as in France). The irrigation needs of the same crop are similar regardless of the location of the greenhouse. Therefore, we decided to have equal irrigation levels for the same crop for all greenhouses regardless of the producing country. Further, the greenhouse processes in Agribalyse are not modelled per ha, as are all other crop processes. Therefore, we used yield ratios for the producing countries of France instead of certain yield per ha values to depict the yield differences.

Furthermore, for tomato production, there is a differentiation between non-heated and heated greenhouses. For this, we assumed that all 'colder' countries use heated greenhouses (i.e. Netherlands, Ireland), whereas all 'warmer' countries use non-heated greenhouses (i.e. Spain, France, Italy, Morrocco, Portugal, USA; assuming that in France and USA where there are colder and warmer areas, tomatoes would be produced where it makes climatic sense, therefore in non-heated greenhouses).

[7] The 'Rest of World' or RoW process is calculated as a difference between 'Global' or GLO and regional datasets (mostly FR). GLO represents activities which are considered to be an average valid for all countries in the world. (Agribalyse 3 documentation).

Please find the shares of crops grown in greenhouses and open fields in Table 3.

Table 3: Greenhouse and open field crop shares for all countries of origin.

Product	Country	Open field		Greenhouse	
		in tonnes	share	in tonnes	share
Tomato	Germany[a]*	0	0%	102180	100%
	France[8]*		24%		76%
	Spain[9]**	3347980	53%	2971650	47%
	Netherlands[b]*		0%		100%
	Italy[c]*	547000	50%	545000	50%
	Portugal***		53%		47%
	Ireland***		0%		100%
	USA[d]*		63%		37%
	Morocco***		53%		47%
Lettuce	Germany[a]*	42850	95%	2437	5%
	Netherlands[10]**	169812	7%	2217096	93%
	France***		24%		76%
	Belgium***		7%		93%
	Italy***		50%		50%
	Spain***		53%		47%
	Ireland***		7%		93%
	United Kingdom***		7%		93%
Strawberries	Germany[a]*	92695	71%	37955	29%
	Netherlands[e]*	27380	31%	59700	69%
	Spain***		53%		47%
	Italy***		50%		50%

[8] From Agribalyse: "76% of the in-season tomatoes consumed in France are tomatoes produced in non-heated greenhouses of France. The rest is coming from elsewhere or produced differently but is excluded from this mix due to the cut-off-rule '70 % cut-off'-threshold for consumption origin breakdown" (see p. 26 of methodological report).

[9] The Spain Commercial Greenhouse Market Size and Share Report in 2022 describes that in Spain, greenhouse tomatoes are cultivated on a total of 18,010 ha (in 2019). 56,940 ha in Spain are cultivated with tomatoes in total (FAOSTAT 2022). Using the tomato yield found in Munoz et al. 2008, we can derive that 53% of tomatoes are cultivated in open-field and 47% are cultivated under greenhouse in Spain.

[10] Blom et al. (2022) find the average yield of lettuce under greenhouse production at 290.5 t/ha (soil-based greenhouse), and the average yield of open-field production at 89 t/ha. We assume that 80% of cultivated lettuce area is covered by greenhouses (source). This accounts for 7,632 ha in 2022 (FAO), whereas the rest, 1,908 ha, are cultivated on open field. This results in production value under greenhouse of 2,217,096 t and 169,812 t on open field. (Nature Rising 2024)

	Morocco***		53%		47%
	Belgium***		31%		69%
	Ireland***		31%		69%
	Egypt***		53%		47%
	France***		24%		76%

Sources: a: BMEL (2024a); b: Dodde (2022); c: Hortidaily (2022); d: Cook (2005); e: CBS (2024)

* Robust data from official source
** Calculated data from several sources, see above
*** Approximation based on climatic conditions (Portugal, Morocco and Egypt are approximated with Spanish shares; Ireland, Belgium and UK are approximated with Dutch shares; if shares are available for only one crop, they are used for the other crops as well)

G) ANIMAL HUSBANDRY

For livestock production, we made modelling decisions regarding housing (and feeding habits) and feedstock. The livestock diets are the same in each country, but the origin of the food products varies between countries. Additionally, we distinguish between different forms of animal husbandry, such as grazing or stable-based systems, which also affect the type of feed given to livestock.

Different housing (and according to feeding habits) has different impacts on the environment. For example, some dairy cows are kept on pasture, partly kept on pasture or only kept in housing; similarly, some chickens are kept in cages, barns with or without outdoor free-range access. We adapted the shares of housing (and according to feeding habits) based on available shares in the countries of origin. Different impacts on the environment are, for example, the resource input into grain-feed production compared to natural pasture, or the energy consumption of housing and according to infrastructure. We used models from Agribalyse that differentiate between such conditions and adapted the shares of different housing conditions for the countries of origin. See data for this in Appendix 1.2.

For livestock fed with grain feed, we also adapted Agribalyse processes of feed according to the countries of origin. For this, we took the assumption that for the livestock produced in the LL countries (Germany, France and Ireland), the feed has a similar origin to grain for human consumption. We therefore used the modelled grain products (which are mixes from different countries of origin) from the categories 'cereals' and 'nuts and oilseeds' to build the domestic grain feed. For the livestock produced in other countries of origin, we used the modelled grain products in these countries of origin (which are not mixes, but processes depicting grain production in these specific countries) to build the foreign grain feed.

Find further modelling decisions and therewith associated uncertainties for specific food products in Appendix 1.2.

2.2.3 LIFE CYCLE IMPACT ASSESSMENT (LCIA)

The LCIA translates the inventory (the flow of elementary inputs and outputs) to their respective environmental impacts. Inventory results are first grouped according to their effect(s) on the environment (i.e. classification) and then multiplied with the relevant impact factors to calculate their contribution to a midpoint (i.e. characterization). For the classification and characterization of the inventory results, we used the method ReCiPe 2016 (Hujibregts et al., 2016) and evaluated the 18 environmental impacts included in ReCiPe, as shown in Table 4.

2.2.4 INTERPRETATION OF RESULTS – TRUE COST ACCOUNTING

The environmental true costs are expressed with marginal damage cost approaches, which reflect both the restoration and compensation costs resulting from environmental damage. Restoration costs are incurred to return a system to its original or target state, such as through afforestation after land-use changes. Compensation costs, on the other hand, represent the economic or non-economic burden borne by society due to the environmental impacts of production or consumption.

These costs include damage to infrastructure, environment and society (people) due to environmental impact (Amadeit et al., 2021). The results of ReCiPe 2016 were monetised using the **Environmental Prices Handbook** (CE Delft, 2023). The Handbook is the only source providing cost estimates for all ReCiPe environmental impacts and is rooted in the NEEDS model, resulting from the EU project NEEDS (2009)[11]. We adjusted the damage estimates for inflation[12] to the year 2022 according to the inflation rates for the three LL countries, since CE Delft evaluates prices for EU27 and 2016. With this, we ensured that external costs reflect the current economic conditions to make the results more useful for contemporary policy formulation. There is one exception for this costing scheme: For the global warming impact, we used the German Federal Environmental Agency's (UBA) central estimate, as CE Delft use abatement cost instead of damage cost for their global warming impact factor. Whilst abatement costs describe the cost incurred through the reduction or prevention of additional emissions, damage costs describe the costs incurred through damage due to environmental impact (Amadei et al., 2021). For this study, we only used **damage cost approaches** as this is consistent with the message we want to convey to readers, namely how expensive diets are, for nature, society and human health. Some of the environmental impact categories assessed here are also related to human health (such as particulate matter formation or toxic emissions). These are included because they reflect the environmental consequences of pollution and resource use, which indirectly affect human health. However, the method does not assess the direct health effects of diet on individuals, which is the focus of the subsequent health assessment. Instead, it evaluates how environmental stressors, caused by human activities, contribute to broader environmental and health-related impacts.

Table 4 shows the external cost factors for ReCiPe environmental impact categories for EU27 in $€_{2022}$ (CE Delft, 2023).

Table 4: Environmental Cost Factors adjusted for country-specific inflation with Consumer Price Index (CPI) from 2021 (from CE Delft) to 2022

Environmental impact	Definition	$Cost_{EU27, 2022}$*	Unit
Global warming	Long-term changes in global or regional climate patterns, primarily caused by human-generated greenhouse gas emissions.	0.14	€/kg CO_2-eq
Stratospheric ozone depletion	The reduction of the ozone layer in the stratosphere due to chemicals like CFCs, leads to an increase in UV-B radiation reaching the Earth's surface.	31.10	€/kg CGC-11-eq
Ionizing radiation	Radiation with enough energy to ionize atoms or molecules, which can result in biological damage.	0.005	€/kBq Co-60-eq

[11] The main objective of the NEEDS Integrated Project (IP) is to evaluate full costs and benefits (i.e. direct and external) of various policies and systems, advancing knowledge in LCA, monetary valuation of externalities, and the integration of this information into policy formulation and scenario building.

[12] We adjust all results and prices to the year of 2022, since most LCA data is gathered for this year. We use the Consumer Price Index (CPI), which is designed to measure the average change over time in the prices paid by consumers reflecting the general price level that affects consumers' purchasing power. The CPI is widely used as the standard measure of inflation by governments, economists, and policymakers, yet also captures changes in the cost of living, which is crucial for understanding the economic impact on individuals and households.

Ozone formation, Human health	The creation of ground-level ozone, which can negatively impact human respiratory health.	2.32	€/kg NOx-eq
Fine particulate matter formation	The formation of fine particles (PM2.5) that can be inhaled and lead to various health issues.	106.01	€/kg $PM_{2.5}$-eq
Ozone formation, Terrestrial ecosystems	The generation of ground-level ozone, which can harm plants and terrestrial ecosystems.	0.44	€/kg NOx-eq
Terrestrial acidification	The acidification of soils and water bodies is caused by the deposition of acidic compounds, that adversely affect terrestrial ecosystems.	5.63	€/kg SO_2-eq
Freshwater eutrophication	The excessive enrichment of freshwater bodies with nutrients, especially phosphorus, leads to algal blooms and reduced oxygen levels.	4.00	€/kg P-eq
Marine eutrophication	The over-enrichment of coastal and marine waters with nutrients, mainly nitrogen, resulting in algal blooms and oxygen depletion.	15.23	€/kg N-eq
Terrestrial ecotoxicity	The harmful effects of pollutants on terrestrial ecosystems and their organisms.	0.001	€/kg 1,4-DCB-eq
Freshwater ecotoxicity	The damaging impacts of pollutants on freshwater ecosystems and the organisms within them.	0.02	€/kg 1,4-DCB-eq
Marine ecotoxicity	The toxic effects of pollutants on marine ecosystems and their living organisms.	0.003	€/kg 1,4-DCB-eq
Human carcinogenic toxicity	The potential of certain substances to cause cancer in humans.	4.26	€/kg 1,4-DCB-eq
Human non-carcinogenic toxicity	The ability of substances to cause adverse health effects in humans, excluding cancer.	0.08	€/kg 1,4-DCB-eq
Land use	Human-induced changes in land use and land cover, impact biodiversity and ecosystem functions.	0.11	€/m^2 a crop-eq

Mineral resource scarcity	The depletion of mineral resources is due to excessive extraction and consumption.	0.01	€/kg Cu-eq
Fossil resource scarcity	The declining availability of fossil fuels is due to overuse.	0.03	€/kg oil-eq
Water consumption	The use and withdrawal of water resources, lead to a reduction in available freshwater.	0.43	€/m³

Notes: *Costs apply to Germany, Ireland and France. Although some environmental impacts are measured in the same unit, the respective damage costs per unit can differ due to the different damage costs caused in the respective ecosystem.

2.3 Health Cost Assessment

The following describes the herein-taken TCA approach for external health costs of the evaluated dietary patterns.

2.3.1 METHODOLOGICAL APPROACH

As the basis of our health cost assessment, we used the method by Seidel et al. (2023). This approach employs the **cost of illness (COI)** to describe the true costs of (mal)nutrition, or potential cost savings due to healthier diets (e.g. Springmann et al., 2021).

First, the most common diseases caused by malnutrition were identified as **cardiovascular diseases (CVD)**[13], **type 2 diabetes mellitus (T2DM)** and **neoplasms** (cf. Seidel et al., 2023). For these diseases and every reference country, Disability Adjusted Life Years (DALYs) 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 COI in LL countries in $€_{2022}$/person is presented in Table 5.

Table 5: COI in LL countries in $€_{2022}$ per person. This is not differentiated for gender but the average COI.

	Germany	Ireland	France
CVD	812.74	430.39	397.32
T2DM	9,090.57	5,917.48	6,255.63
Neoplasm	627.97	446.46	544.85

Direct and indirect COIs vary between the different LL countries within a reasonable range. These differences could be explained due to methodological differences within the underlying cost studies.

This influences the results of the overall diet's health costs. Likely costs of the German LL diet will be higher than that of France or Ireland, as the German COI is higher throughout all three observed illnesses compared to France and Ireland.

[13] Stroke is included herein.

The COIs were then standardized to specific **dietary risk factors** (e.g. nutrient deficiencies, excessive consumption, unbalanced diets, specific foods; see Table 6 for the risk factors considered in this study) with a ratio that relates the "disease-adjusted life years lost due to a risk"[14] to the "total disease-adjusted life years lost due to the respective disease"[15]. This helps in understanding the relative importance of dietary risks in the overall burden of the disease.

All products in the diets evaluated in this study were then sorted according to the following dietary risk factors in Table 6.

Table 6: Dietary risk factors and product categories from the diets sorted according to the dietary risk factors they most likely resemble.

Dietary risk factors		**Product categories***
Diets high in…	Red meat	Beef, Pork, Venison
	Processed meat	Meat (meat mix)
	Sodium	Salt
	Trans fatty acids	Dairy products yellow[16], animal oils and fats, vegetable fats
	Sugar (-sweetened beverages)[17]	Soda, Sugar
Diets low in…	Whole grains	-
	Legumes	Legumes
	Fruits	Fruit and fruit products
	Vegetables	Other vegetables and vegetable products
	Nuts and seeds	Nuts and oilseeds
	Omega-3	Fish and Seafood
	Polyunsaturated fatty acids	Vegetable oils
	Milk	Dairy products white
	Calcium	-
	Fibre	-

*Further definitions of product categories are provided in Appendix 1.1, Table 30.

We refrained from sorting products into the dietary risks of low in whole grains, calcium and fibre, as there is no certain product category that would fit this description.

From the EFSA data on dietary intake studies, there is no certain assertion possible on whether products consumed are wholegrain or not. Further, not one product is considered as 'high or low in fibre', specifically, its fibre content would have to be calculated on a product level, which is not feasible within this study. The same goes for the intake of calcium.

[14] This measures the number of life years lost due to a specific risk factor (like poor diet). It adjusts for both the severity of the disease and the years of life lost.
[15] This is the total number of life years lost due to the disease overall, considering all risk factors and not just dietary ones.
[16] This only includes hard cheese.
[17] There is no dietary risk factor for sugar specifically. Therefore, we classified all sugar into the 'sugar-sweetened beverages' category.

Due to methodological restrictions, warm drinks (i.e. coffee, tea) are not sortable into one of these dietary risks and hence are excluded from the health assessment. Some go for alcoholic drinks, which implies that the health costs associated with the LLD (so the actual consumption levels) are likely underestimated since alcohol consumption is connected to health detriments and therefore health costs. Fruit juices are both 'sweetened beverages' as well as 'fruit and fruit products'; as sorting into either or the other dietary risk would likely distort results, we refrained from including fruit juices in the health assessment. Poultry is also not sortable into these categories and hence excluded from the health assessment. Within the group of poultry, there are likely processed meat products (see second dietary risk factor), however at the level of aggregation of the diets this share is not able to be differentiated from the rest. Therefore, health costs are likely underestimated for LLDs. It should be noted that these assumptions likely underestimate the health costs of all constructed diets.

Next, a baseline/threshold had to be defined that clarifies what amount of intake is harmful or beneficial. Supposedly, there is a baseline of consumption that is neither good nor bad and this should be reflected in recommendations for healthful dietary intake. First, we defined a linear dose-response relationship for the products, meaning that every additional intake is equally as good or bad as the previous and next, or in other words has the same cost effect on external health costs (cf. Springmann et al., 2021). We then defined the country's healthy consumption as the recommended intake by its national health authorities, so each country's NRD. This means that the consumption-related health costs of NRDs of each country amount to zero. All differing actual consumption (LLD) or recommended consumption for planetary health (PHD) is therefore beneficial or detrimental to health and consequently increases or decreases health costs.

Occasionally, consumption levels (LLD) are higher than the recommended intake (NRD) within dietary risk factors 'low in…' (France: milk, polyunsaturated fatty acids; Ireland: legumes, omega-3, nuts and seeds, polyunsaturated fatty acids). Due to how the method is set up, this would imply that a health benefit is achieved in these dietary risk factors. From the COI data and dietary risk data, we can nevertheless see that costs are incurred for every dietary risk in every country, contrasting the aforementioned notion. We believe that our mapping of consumed products to the representative products and likewise into subordinate product categories is one reason for this overconsumption of beneficial foods in LLD. For example, not all products defined as milk are actual milk and have the same health benefits, e.g. condensed milk. In these cases where we see an overconsumption of beneficial products on the one side, but incurring costs from the COI data on the other side, we set dietary risk costs of the overconsumption as zero, as we do not deem it logical to assign them either cost or benefit.

Data on DALYs overall and for the dietary risk factors is from the Institute for Health Metrics and Evaluation of the University of Washington. The direct and indirect health costs are calculated in studies about countries' healthcare costs (Institute for Health Metrics and Evaluation, 2024).

2.3.2 UNCERTAINTIES

Firstly, the cost of illness for every country is based on different scientific articles that likely all employ somewhat different methodologies and underlying data sources. This in turn influences the COI factors used for further calculations.

As this method focuses on the three dietarily most relevant illnesses (CVD, T2DM, neoplasms), the occurrence of other illnesses through dietary risks (e.g. the occurrence of bacterial infections like salmonella due to food consumption) is excluded and not calculated. This likely underestimates the health costs arising from the herein-assessed diets.

Further, the definition of a 'healthy consumption'-baseline substantially influences the results. For instance, defining healthy consumption based on the World Health Organization's (WHO) recommendations or the PHD would yield vastly different results. Therefore, these health costs have to be taken into consideration always in comparison to the national dietary recommendations of the LL countries. Likewise, defining a linear dose-response relationship and setting a baseline for harmful or beneficial intake can oversimplify complex dietary impacts on health. Nutrients and foods may have non-linear relationships with health outcomes, exemplified by the principle "the dose makes the poison". For example, while fruit consumption is generally considered healthy, consuming only fruit may likely result in excessive (fruit-)sugar intake, which can be detrimental to health.

Lastly, sorting products into the most fitting dietary risk factors is also rather limiting. For example, some products may not fit neatly into one category, or their health impacts might be influenced by factors like preparation methods (i.e. degree of processing) and portion sizes. Some products may belong to multiple categories (e.g. fruit juices as both 'sweetened beverages' and 'fruit and fruit products'). Excluding these can underestimate health costs. Further, the exclusion of warm drinks, alcoholic drinks and poultry from the categories due to non-existent dietary risk factor data can lead to an underestimation of health costs, as these items can have substantial health impacts. Contrasting to that, the inability to sort products based on their content of whole grains, fibre, or calcium introduces uncertainty. These nutrients have well-documented health impacts, and their omission can distort overall health cost estimates.

These necessary assumptions, yet clear limitations lead us to recommend taking the health-related true costs “with a grain of salt”.

2.4 Social Life Cycle Assessment

Besides the environmental and health impact assessment, we also assessed the social risks connected with the diets reviewed in this study. For this, we applied the S-LCA method. Since S-LCA approaches are rather new methods for impact quantification, monetization approaches are only now being developed. Therefore, our s-LCA was assessed quantitatively but interpreted only on a qualitative level, rather than monetizing the social risks.

2.4.1 THE SOCIAL HOTSPOT DATABASE (SHDB)

We based the Social Life Cycle Assessment on data from the Social Hotspot Database (SHDB). The SHDB aims to identify and assess social risks associated with global supply chains. This includes understanding labour conditions, human rights issues, community impacts and other social dimensions affected by production and consumption activities. It is one of the first approaches to quantify social impacts; other databases are, for example, the PSILCA (Product Social Impact Life Cycle Assessment) database. The SHDB covers a wide range of industries and sectors where social risks are prevalent. These may include agriculture, manufacturing, mining, construction and others identified through their potential impacts on labour conditions, human rights and communities.

Data sources for the SHDB include a wide range of reputable sources, including international worker organizations (e.g. International Labour Organization), NGOs, governmental reports, academic studies, or industry-specific data. It covers global supply chains, focusing on key sectors rather than specific products, however capturing variations in social risks across different regions and industries.

Table 7: Social impact categories and sub-categories assessed by SHDB.

Social impact category	Social impact sub-categories
Labour Rights and Decent Work	Wage assessment Workers in poverty Child labour Forced labour Excessive work time Freedom of association Migrant labour Social benefits Labour laws/conventions Discrimination Unemployment
Health and Safety	Occupational toxics and hazards

	Injuries and fatalities
Society	Indigenous rights Gender equity High conflict zones Non-communicable diseases Communicable diseases Poverty and inequality State of env. sustainability[18]
Governance	Legal system Corruption Democracy & freedom of speech
Community and Infrastructure	Access to drinking water Access to sanitation Children out of school Access to hospital beds Smallholders Access to electricity Property rights

The SHDB utilizes a comprehensive set of social indicators (160) to assess various aspects of social sustainability, or in other words social impact (sub-)categories (cf. Table 7). These indicators are selected based on their relevance to social impact and their ability to reflect different stages of the supply chain. The indicators describe the severity of the presence of a situation or opportunity that poses risk along the value chain. The SHDB includes the following three data components to comprise and evaluate the social risk indicators:

1. Information on the trade flows (supply chain composition) between the economic sectors of each country (with the Global Input Output Model also called Multiregional Input Output or MRIO):

$C_{c,s}$ for all countries (c) and sectors (s) associated with the product in [USD/kg]

2. Information on the economic sector's labour intensity (worker hours) for each country by dollar of output:

$LI_{c,s}$ in [work hours / 1 USD of output]

3. Information on social risks and opportunities by country and economic sector:

$RF_{c,s}$ in [mrheq / work hours]

With the SHDB's own LCIA method, the Social Hotspots Index, the following calculation is made: The (1.) product's supply chain's (2.) labour intensity information is characterized by (3.) the risk levels, to express social risks and opportunities in medium risk hours equivalent (mrheq).

$$Social\ risk = \sum_{c,s} C_{c,s} \times LI_{c,s} \times RF_{c,s}$$

Therefore, social risk is expressed in [mrheq / kg], so medium risk hour equivalent per kg of product. This is the unit used to express the results of the SHDB for each main social impact category and its 30 subcategories.

[18] This subcategory evaluates the social impacts connected to environmental conditions, including factors such as the strength and enforcement of environmental laws, resource management, and access to essential resources like water. It specifically addresses environmental aspects that are closely linked to social sustainability and does not evaluate environmental sustainability as such.

The mrheq is developed by SHDB to indicate how likely each risk is to occur (per working hour) in the sector of each country compared to a medium level of risk (medium level of risk = 1 mrheq). Mrheq is a holistic measure that combines the likelihood of risk occurrence (due to large work hours) with the potential impact of that risk (severity). When analysing mrheq values, it's crucial to consider both factors to develop appropriate risk management strategies.

Trade flows are measured in USD/kg and the working hours required to produce one USD. Therefore, the functional unit is USD/kg of product (contrary to environmental assessment, where it is kg of product) and the unit social indicators are measured is always mrheq (contrary to environmental assessment, where every midpoint is measured in its unit).

The indicators are normalized and weighted (generally equally) to provide a balanced assessment of social risks for each country. This allows for comparative analysis and prioritization of social hotspots within supply chains.

2.4.2 SOCIAL RISK ASSESSMENT WITH THE SHDB

To conduct the social risk assessment of each diet, the following data points regarding the supply chains' trade flows of products were gathered:

- **Mapping of representative products to one of the 57 GTAP sectors** included in the SHDB (cf. electronic Appendix 6).
- **Cost of each representative product per country of origin** (producer prices 2011 in USD/kg were derived from FAOSTAT and EUROSTAT; SHDB uses the Global Trade Analysis Project (GTAP) global economic equilibrium model version 9, which uses 2011 as reference year and therefore, prices must also be from 2011 for correct economic allocation). If prices for certain countries of origin were missing, we used prices from prior years. If these were yet missing, the average price from the remaining countries of origin for that specific product was used (cf. electronic Appendix 6)
- **Diet composition** analogously to the environmental assessment: LLD, NRD and PHD per country, based on representative products and respective amounts consumed (cf. electronic Appendix 2 and 3). If representative products are processed from other underlying products, e.g. yoghurt is processed from milk, we used the social risk of the underlying product (milk) and multiplied it with the input needed for the representative product (yoghurt).
- **Countries of origin** (producing countries) of each representative product analogously to the environmental assessment. Processing is assumed to take place in each LL country itself. For example, processed cheese is not imported, however, milk is partly imported: processing of milk into cheese is taking place in the respective LL country.

Based on these data points for each social indicator risk hours were extracted from the SHDB for each representative product and each country of origin.

2.4.3 INTERPRETATION OF RESULTS

The results from the SHDB describe the level of risk for the diet's food products for each country of origin. For each representative product consumed within a diet, we modelled the top five sourcing countries, so first we aggregated the risks per representative product for each country of origin weighted with the respective production share. Then, we aggregated social risks of all representative products consumed within a diet, weighted with the respective amounts consumed (LLD) or recommended (NRD, PHD) for Germany, France and Ireland, respectively. This provided the quantitative measure of social risks from the three diets for each LL country.

There are different options for aggregating impacts from the social impact subcategory (i.e. for specific risks, like child labour) towards the category level (i.e. for broader stakeholder issues, like labour rights) (cf. Table 7) or there is the option to aggregate all social impact categories into a single cumulated social risk score. For example, Santos et al. (2020) and Backes et al. (2024) aggregate subcategories without weighting, whereas Dong et al. (2015) and Subramanian (2018) weight the subcategories according to their importance (determined with questionnaires) and Du et al. (2019) use a weighted sum approach.

The choice of aggregation method depends on the aim of the analysis. Since we aimed to assess the entirety of impacts arising within each diet, we weighted subcategories equally into their respective category and then aggregated all impacts into a cumulated risk score (like Santos et al. 2020 and Backes et al. 2024). This means that some subcategories have less influence when analysing on aggregation level of categories (because, for example, there are 11 subcategories describing 'Labour Rights and Decent Work', whereas only 3 subcategories describing 'Governance') than when an evaluation is done on level of subcategories. This needs to be considered throughout the interpretation.

The social risk assessment can be used to compare risks across different products (like beef, pork, poultry, etc.) or product categories (like meat, vegetables, fruit, etc.) and therefore identify hotspots within certain diets – either specific products that contribute majorly to the risk of a diet, or entire product categories. Stages in the supply chain with the highest social risks can be also flagged (e.g. a specific country of origin that causes higher risk than others within one product's import mix), to guide targeted recommendations for improvement.

2.4.4 UNCERTAINTIES

When interpreting risks using the s-LCA approach based on data from the SHDB, several uncertainties must be taken into account.

Primary uncertainties stem from the characterization models used in the SHDB. These models serve to interpret the raw data to estimate risk levels, often through aggregating both qualitative and quantitative information. The nature of these models introduces uncertainty: As the SHDB applies general risk classifications (e.g. low, medium, high, very high) based on expert judgment, data distribution across sectors and countries and literature, these classifications may vary in their accuracy depending on the availability and quality of the underlying data. Additionally, the scaling of risks, for instance, is not always clear. For example, risks related to certain factors (such as child labour or working conditions) may show substantial jumps in risk values (e.g. from 1 to 10) due to the nature of the hotspot identification process. This lack of clarity in scaling can confuse readers, especially when large ranges of risk factors are involved. Moreover, since the SHDB characterizes risk based on generic data, the approach may mask nuances in specific cases. The models aggregate information across wide ranges, which may oversimplify complex socio-economic mechanisms. This is particularly important to consider when interpreting results related to specific products or sectors, where the risk may be disproportionately high due to the generic nature of the data or the focus on hotspot identification.

Another uncertainty stems from the underlying trade data used in this study. The import data for food products, such as legumes, does not distinguish between their intended uses. For instance, the same import data is applied whether the legumes are meant for human consumption or animal feed. This lack of differentiation can skew the risk assessments. For example, if legumes imported for livestock feed are primarily sourced from countries with higher social risks, this could lead to an underestimation of risks in cases where the products are assumed to be for human consumption.

Conversely, it might result in an overestimation of risk for certain products if the data incorrectly assumes they are sourced from riskier regions. In reality, these differences in sourcing and intended use might have a substantial impact on the social risks tied to the final product, especially in the case of animal-based goods.

Another uncertainty in the risk assessment comes from how certain products are grouped into broad sectors within the SHDB. For example, legumes are categorized under the sector vegetables and fruits, as are all other vegetables and fruit products. This means that the social risks associated with legumes, such as beans or chickpeas, are not specific to those products but are instead the same risks applied to all fruits and vegetables. As a result, the risks are generalized for the entire sector and there is no differentiation based on the unique production conditions or risks of specific types of legumes. The only factor that might change the risk level is the monetary profitability of the different products per working hours required. This approach could lead to an oversimplification, as it overlooks potential differences in social risks that may be more specific to certain crops or regions.

Additionally, please note that this assessment does not include considerations of animal welfare, as the SHDB does not cover this specific area. Therefore, any conclusions drawn from the social risk assessment should be understood within these limitations.

2.5 Diet affordability

2.5.1 METHODOLOGICAL APPROACH

The primary objective of this analysis is to estimate the affordability of three distinct dietary patterns - LLD, NRD and PHD- across Germany, Ireland and France. The methodology of assessing the affordability of diets involves three key steps: (1) matching the food categories used in the diet modelling in this study to align with the International Comparison Program's (ICP) Food Prices for Nutrition (FPN) categories, (2) calculating the diet costs based on these aligned food categories and (3) evaluating diet affordability based on household income data. The first step involved converting the food categories used in the study to align with the FPN categories reported by the ICP. The FPN database categorizes food costs under groups such as fruits, vegetables, starchy staples, animal-sourced foods, legumes, nuts and seeds and oils and fats. Representative foods were designated for each category following the Health Diet Basket (HDB) by Herforth et al. (2022). Herforth et al. (2022) created the HDB as a global standard for measuring the cost and affordability of a healthy diet. They identified common food groups across Food-Based Dietary Guidelines (FBDGs) and for each food group, they calculated the median recommended amounts. The amounts were scaled to meet a consistent dietary energy intake target of 2,330 kcal per day. They chose reference foods for food categories to equate calories to grams as follows: For starchy staples, dry rice; for animal-sourced foods, eggs; for legumes nuts and seeds, dry beans; for oils and fats, oil and for fruits and vegetables, fruit and vegetable (Table 8).

The conversion of food categories from LLDs and NRDs to match the FPN categories follows the methodology outlined in the EAT-Lancet Commission's 2019 report (Hirvonen et al., 2020). However, unlike the EAT-Lancet report, which uses ideal daily gram consumption based on global dietary guidelines and sustainability boundaries, our study replaces these standardized values with the actual daily gram consumption observed in the LLDs and recommended in the national dietary recommendations of each country. This modification ensures that the cost estimates reflect the real and recommended consumption patterns of the populations under the study.

Due to the unavailability of detailed retail food price data from the ICP at the time of this study, we employed an alternative methodology which uses the FPN dataset reported by the ICP. The FPN is the same source utilized by the FAO for its Cost of Affordable and Healthy Diet (CoAHD) assessment in the State of Food Security and Nutrition in the World (SOFI) report. The methodology behind the cost estimates follows the framework provided by Herforth et al. (2022) in their background paper for the SOFI 2022 report, which calculates the cost of average food group quantities recommended in dietary guidelines. The FPN dataset reports the costs of the food groups based on daily consumption quantities in grams per day (g/day) for an average adult across six food groups. The food groups and quantities used in Herforth et al. (2022) are presented in Table 8.

Table 8: Food group quantities in grams per person per day according to Herforth et al. (2022) and authors' representative food per food group.

Food Group	Representative food	Quantity [g/cap/d]
Fruits	Fruits	254
Vegetables	Vegetables	367
Starchy Vegetables	Dry rice	322
Animal-Sourced Foods	Egg	210
Legumes, Nuts and Seeds	Dry bean	85
Oils and Fats	Oil	34

Next, the cost of the diets was estimated by applying food prices from the FPN dataset to the corresponding food categories in each diet. The cost calculation methodology is based on the approach described in the background paper by Herforth et al. (2022) for the SOFI 2022 report.

This approach calculates the cost of the average quantities recommended for each food group in the dietary guidelines. For the LLDs, NRDs and PHDs the actual consumption data – that is the data from EFSA (2011) – was used to determine the daily cost per capita.

This study considered 54 food items comprising the modelled diets of the three LL countries (Germany, Ireland and France). These food items were mapped to the six food groups listed in Appendix 1.3 and the corresponding costs were extracted from the FPN dataset in 2021 PPP USD per person per day for each food group. To convert the costs from 2021 Purchasing Power Parity (PPP) USD/person/day to 2021 PPP €/person/day, the PPP conversion rate between USD and EUR for the year 2021 was applied. To arrive at the cost per gram for each food group (2021 PPP €/person/g/day), the total cost of the food group (in 2021 PPP USD/person/day) was divided by the respective quantity of the food group (c.f. Table 8, g/person/day). The cost per food group (c.f. Table 9) was then multiplied by the consumption levels per food group according to LLD, NRD and PHD (c.f. Table 8) and added up across all food groups to calculate the total costs of the LLD, NRD and PHD (c.f. Table 10).

According to FPN cost data, Ireland has the lowest costs per food group compared to Germany and France. However, the Eurostat Price Level Index for food indicates that Ireland's price levels are slightly higher than those in Germany and France (EUROSTAT 2024a). Therefore, the prices calculated in Table 9 should be interpreted with caution. Despite this, it is expected that these prices remain within the range of affordability.

Table 9: Costs per g and kg units of the food groups across the three LL countries based on FPN food quantities

FNP food groups	[€/g FNP] Germany	[€/g FNP] France	[€/g FNP] Ireland	[€/kg FNP] Germany	[€/kg FNP] France	[€/kg FNP] Ireland
Fruits	0.0025	0.0024	0.0018	2.48	2.43	1.79
Vegetables	0.0016	0.0018	0.0011	1.64	1.81	1.07
Starchy vegetables	0.0007	0.0006	0.0006	0.65	0.63	0.63
Animal-sourced food	0.0022	0.0019	0.0015	2.20	1.93	1.53
Legumes, nuts and seeds	0.0026	0.0022	0.0018	2.64	2.22	1.81
Oils and fats	0.0014	0.0014	0.0012	1.44	1.44	1.24

Source: Authors' elaboration based on ICP Food Prices for Nutrition

Table 10: Costs of the FPN food categories and total LLD, NRD and PHD costs across three countries.

FPN Food categories	Cost Germany [€/cap/d]	Cost France [€/cap/d]	Cost Ireland [€/cap/d]
Fruits	0.63	0.62	0.46
Vegetables	0.60	0.67	0.39
Starchy vegetables	0.21	0.20	0.20
Animal-sourced food	0.46	0.41	0.32
Legumes, nuts and seeds	0.22	0.19	0.15
Oils and fats	0.05	0.05	0.04

The last step involves the assessment of the affordability of the diets. There are several approaches to assess the affordability of a diet. The approach employed in this study and commonly used in the context of high-income countries (such as Germany, Ireland and France), assesses the affordability based on the share of a household's or individual's income needed to meet the diet's cost. This approach aligns with methods used in various studies, such as those by Hirvonen et al. (2020), which focus on determining whether a diet is affordable by comparing its cost against a certain percentage of income.

In high-income countries, such as Germany, France and Ireland, the threshold for determining affordability varies but is generally lower than in low-income countries due to the higher overall income levels and different spending patterns. For example, studies often use a threshold of around 20-30% of income to evaluate whether a diet is affordable (Barosh et al., 2014). This lower threshold reflects the fact that households in these countries typically spend a smaller proportion of their income on food, with more of their budget dedicated to non-food items such as housing, transportation and healthcare.

The affordability of the three diet types was assessed by comparing the daily cost of each diet with the daily median equivalised net income[19] for a single person with dependent children[20] in Germany, France and Ireland, respectively. According to the 2021 EU-SILC database (EU-SILC 2024), the income of a single person with dependent children is significantly lower compared to that of two adults with one dependent child. Therefore, we selected single-person households with dependent children for a more conservative analysis. This choice reflects the fact that households with dependent children generally have lower disposable income than single-adult households, making this a cautious approach to assessing the affordability of diets. Given that the target group of the LLs are children adolescents and students, we believe this is a suitable choice. The annual net income data extracted from the EU-SILC was then converted to daily net income. The threshold for affordability was set between 20-30% of daily income spent on food which aligns with the literature (Barosh et al., 2014).

2.5.2 UNCERTAINTIES

Several modelling decisions and assumptions were made during the mapping and cost calculation process:

1. Exclusion of certain food items: beverages, sweeteners and condiments present in the diets were excluded from the final cost calculations due to the unavailability of price data for these items. This is likely to result in an underestimation of costs, especially the cost of LLD as this diet includes the highest consumption levels for those products.
2. Price extrapolation: A key assumption was the extrapolation of the price of eggs, a reference animal-sourced product, to other animal-sourced products, including meat, dairy and fish. This modelling choice had to be made as FPN (Herforth et al., 2022) did not include the price for other animal-sourced products, as FAO does not deem other animal-sourced food items as necessary for a healthy and sustainable diet. This price extrapolation is likely to result in an underestimation of the costs of diets high in animal-sourced food (often LLDs), given the big variability in the prices of the food items under this food category (e.g. the difference in price between egg, dairy, meat and fish).

3. Results and discussion

Figure 4 shows the comparative analysis of the true environmental and health costs across the three dietary patterns in Germany, France and Ireland. Social risks are described in the following.

[19] Equivalised income is a measure of household income that takes account of the differences in a household's size and composition. Net income refers to the income that a household has at its disposal after tax and other deductions and receipt of social transfers.

[20] **Dependent children** are individuals aged 0-17 years and 18-24 years if inactive and living with at least one parent (EUROSTAT 2014).

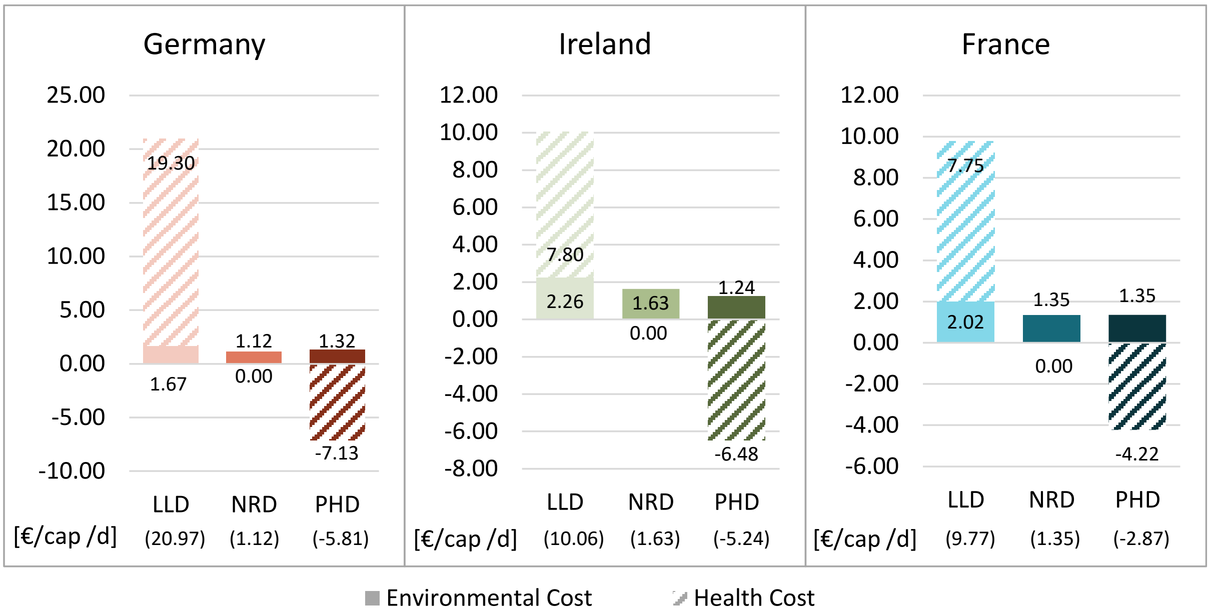

Figure 4: Environmental and health costs per person per day of all three diets (LLD, NRD, PHD) across the three LL countries Germany, Ireland and France.

The figure presents the cumulative environmental and health costs associated with different dietary patterns across the three LL countries (Germany, Ireland and France). It is important to interpret these findings with caution. The methodologies employed to calculate health and environmental costs are fundamentally different, reflecting distinct metrics, data sources and assumptions. As a result, directly summing these costs to derive an overall cost figure may lead to oversimplifications or misinterpretations. However, this representation gives a general overview of external costs from different sustainability perspectives.

What is evident, is that ado

pting the PHD in all three countries results in substantial health cost savings with the highest possible savings seen in Germany. Transforming current consumption towards recommended diets – both NRD and PHD – would also result in environmental cost savings in all countries. Interestingly, Germany shows even better environmental performance when adhering to the NRD (cf. 3.1.2).

These overall findings underscore the complex interplay between dietary choices, environmental sustainability and health benefits, with each country showing unique patterns and challenges.

These individual results are presented and discussed in the following sections for Germany (cf. 3.1), Ireland (cf. 3.2) and France (cf. 3.3).

Before presenting the results of the environmental and health cost assessment and the social risk assessment of the LLD, NRD and PHD, we first present the amounts consumed or recommended under each diet. With a clear understanding of the baseline consumption and recommendation patterns, major differences between the actual dietary intake (LLD) and the recommended diets (NRD and PHD) are highlighted. This also contextualizes the subsequent environmental and health cost assessments by demonstrating the underlying consumption and recommendation data that drive the results. With this, the cost and impact assessments can be interpreted properly as they give an understanding of how variations in dietary patterns influence environmental and health outcomes.

For the evaluation of the LL countries' environmental and health-related external costs and social risks, we first compare the three diets (LLD, NRD, PHD) to identify potential areas for dietary transition. Next, we highlight key hotspots within each diet and specific products, pinpointing areas with the greatest potential for impactful dietary change. This analysis is conducted individually for each impact area (environmental, health, social) and each country (Germany, Ireland, France). Based on these findings, we identify the largest levers for each country's dietary transition and compare the three impact areas in terms of their relevance to the external costs and sustainability impacts. Finally, an analysis of the diet's affordability closes the result section for every country.

Comparative analysis of the cost and affordability of the three dietary patterns in Germany, Ireland and France

Table 11: Costs and affordability of the German, French and Irish LLDs, NRDs and PHDs

Country	Diet type	Cost [€/cap/d]	Median daily income [€/cap/d]	Share of diet cost in income [%]
Germany	LLD	1.40	52	2.6
	NRD	2.18	52.34	4.2
	PHD	2.31	52.34	4.4
Ireland	LLD	1.34	56.54	2.4
	NRD	1.64	56.54	2.9
	PHD	1.66	56.54	2.9
France	LLD	1.76	42.08	4.2
	NRD	2.13	42.08	5.1
	PHD	2.20	42.08	5.2

Source: Author's own elaboration based on ICP FPN data

Table 11 summarizes the analysis of the costs and affordability across the three diets in Germany, Ireland and France. In all three countries, the LLD diet is the cheapest. Ireland has the lowest diet costs across all three diet types, while Germany has the highest NRD and PHD costs among the three countries due to high amounts of legumes, nuts and seeds, fruits and vegetables. The PHD is the most expensive diet in all three LL countries.

For all three diet types in all three LL countries, the share of the dietary cost in median income is far below the affordability threshold (20-30%) for food expenditure in high-income countries and hence can be considered affordable. In Germany, all three diets fall between 2% and 5% of the median daily income. Ireland, on the other hand, shows the highest affordability with diets costing only between 2.37% for LLD and 2.94% for PHD of the daily income.

This is explained by the combination of lower food costs and higher income levels in Ireland. France has the highest proportion of income required for diet costs, with PHD costing 5.23% of daily income in comparison to 4.18% for LLD.

The most affordable EAT-Lancet diet had a global median cost of 2.84 USD per person per day in 2021, representing a small fraction of average incomes in high-income countries (Hirvonen et al., 2020). The affordability of these diets, as a proportion of mean daily household income per capita, was 6.1% in high-income countries (Hirvonen et al., 2020). This estimate is slightly higher than our analysis, likely because their figures represent an average across all high-income countries whereas our analysis focuses on three specific countries. Nevertheless, their findings support our conclusion that healthy diets remain within the affordability range. Additionally, according to SOFI 2024, the cost of a healthy diet in Germany, France and Ireland was estimated at 3.10, 3.04 and 2.24 PPP USD per person per day, respectively. While these figures are slightly higher than our estimates, they are still within the range of affordability.

The next sections will describe in more detail the main drivers of the cost differences, which are the food prices, food quantities consumed within each diet and the differences in the income levels in the three countries.

3.1 Germany

First, we present results for the LL country Germany.

3.1.1 CONSUMED AMOUNTS OF LLD AND RECOMMENDED CONSUMPTION UNDER NRD AND PHD

In the following table, the consumed amounts of food (LLD) are presented with the recommended amounts for NRD and PHD.

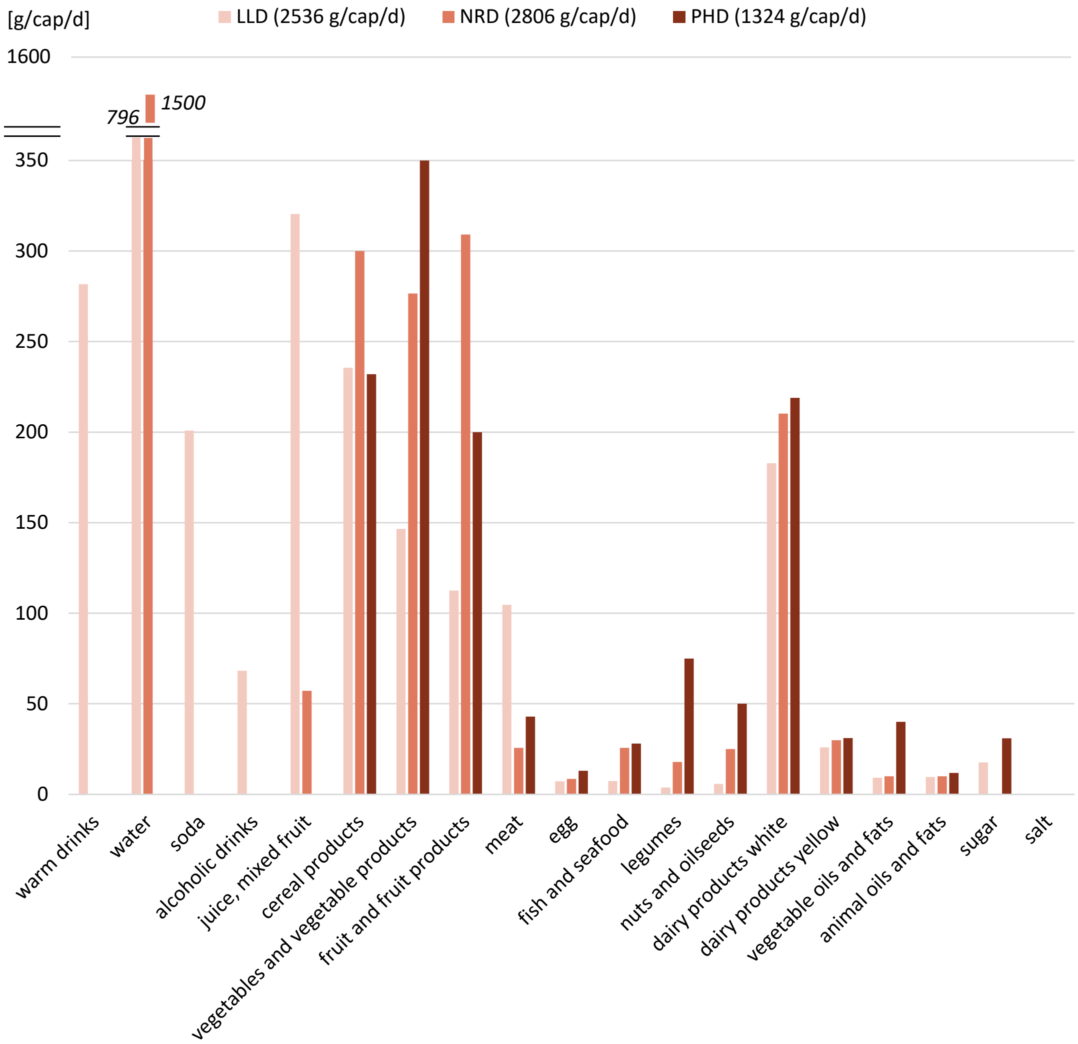

Figure 5: Composition of consumption values (LLD) and recommended intake (NRD, PHD) in Germany per person per day. Some food categories are not recommended within the NRD or PHD and columns therefore missing (e.g. warm drinks).

Table 12: Composition of consumption values (LLD) and recommended intake* (NRD, PHD) in Germany per person per day. Some table cells are grey since there are no values recommended for these respective products.

Category	#	Product**	LLD [g/cap/d]	NRD [g/cap/d]	PHD [g/cap/d]
Beverages	1.1	Warm drinks	282		
	1.2	Water	796	1500	[21]
	1.3	Sugary drinks	201		

[21] PHD does not give information on water consumption.

	1.4	Alcoholic drinks	68		
	1.5	Fruit juices	320	57	
Carbohydrate sources	2.1	Cereal products	236	300	232
	2.2	Starchy vegetables	59	36	50
	2.3	Other vegetables	88	241	300
	2.4	Fruit and fruit products	113	309	200
Protein sources	3.1	Beef	9	2	2
	3.2	Pork	45	11	12
	3.3	Poultry	12	3	29
	3.4	Meat, other***	39	10	[22]
	3.5	Eggs	7	9	13
	3.6	Fish and seafood	7	26	28
	3.7	Legumes	4	18	75
Fat sources	4.1	Nuts and oilseeds	6	25	50
	4.2	Dairy products white	183	210	219
	4.3	Dairy products yellow	26	30	31
	4.4	Vegetable oils and fats	9	10	40
	4.5	Animal oils and fats	10	10	11.8
Rest	5.1	Sugar	[23]18		31
	5.2	Salt	[24]0		

* Numbers are represented as in the original recommendations.

** Further definitions of product categories are provided in Appendix 1.1, Table 30.

*** 'Meat, other' encompasses venison, beef and pork and mixed meat, more detailed consumption data is provided in the digital Appendix 2.

Germany's consumption levels differ dramatically in some categories from the recommended diets. For example, meat and especially pork, is consumed to a higher extent.

It needs to be noted that the share of beef consumption might be underestimated in the NRD and PHD, as substantial amounts of beef can be assumed to fall under the 'other meat' category and are therefore not accounted for based on the division of meat types by current consumption patterns. For vegetables, legumes and nuts, as well as seafood, consumption levels are much lower than both NRD and PHD recommended levels. The same holds for dairy products. Further, the consumption of all beverages (except water) far exceeds that of recommended amounts. Warm drinks (coffee, tea, cocoa) are not considered under NRD or PHD, whereas rather high levels are consumed.

[22] The PHD explicitly states that processed meat should be avoided. We therefore allocated only to 'primary' meat sources.

[23] This value seems quite low. However, one needs to consider that a lot of sugar is consumed within the 'Sugary drinks' category (1.3).

[24] Please note: the consumption value for salt under LLD is so small that it does not show as a column in the representation of Figure 5.

In other categories, however, consumption levels are quite similar to what is recommended. For cereal products, for example, consumption is very close to PHD recommendations (disregarding the distinction between whole grain and refined grain). Animal oils and fats are similar across all three diets.

When comparing PHD and NRD, it is notable that the German NRD recommends an even lower meat intake than the PHD.

3.1.2 ENVIRONMENTAL IMPACTS AND COSTS

Table 13: Environmental costs of all three diets (LLD, NRD, PHD) per person per day in Germany.

Environmental costs	Germany [€/cap/d]
LLD	1.67
NRD	1.12
PHD	1.32

A) DIET COMPARISON

Despite the PHD being designed to enhance environmental sustainability, the NRD achieves the lowest environmental costs. This is attributable to Germany's updated dietary guidelines (cf. NRD, Table 13), which emphasize both health and environmental considerations. The PHD causes 0.20€/cap/d per person per day more in environmental costs compared to NRD, primarily due to its recommendation of larger portions of poultry (0.06€/cap/d), nuts (0.06€/cap/d) and vegetable oil (0.11€/cap/d) compared to the NRD.

Transitioning from the LLD to the NRD has the potential to reduce environmental costs by 0.55€/cap/d. Switching from LLD to PHD saves 0.35€/cap/d. This means cost savings per person per year of 199.47€ from LLD to NRD and 128.72€ from LLD to PHD. For Germany with a population of 83.8 mio. people, this results in total environmental cost savings of more than 16.71 billion Euros per year for NRD and about 10.79 billion Euros per year for PHD.

Figure 6 shows a comparison of the three diets for all product categories and their respective cost contribution to the diets. It becomes clear that different categories contribute to the environmental costs in varying degrees. While meat consumption is the largest contributor to the LLD, the NRD and PHD show a more balanced distribution of environmental impacts across all food categories.

In the following, we will describe and discuss hotspots within each diet in more detail.

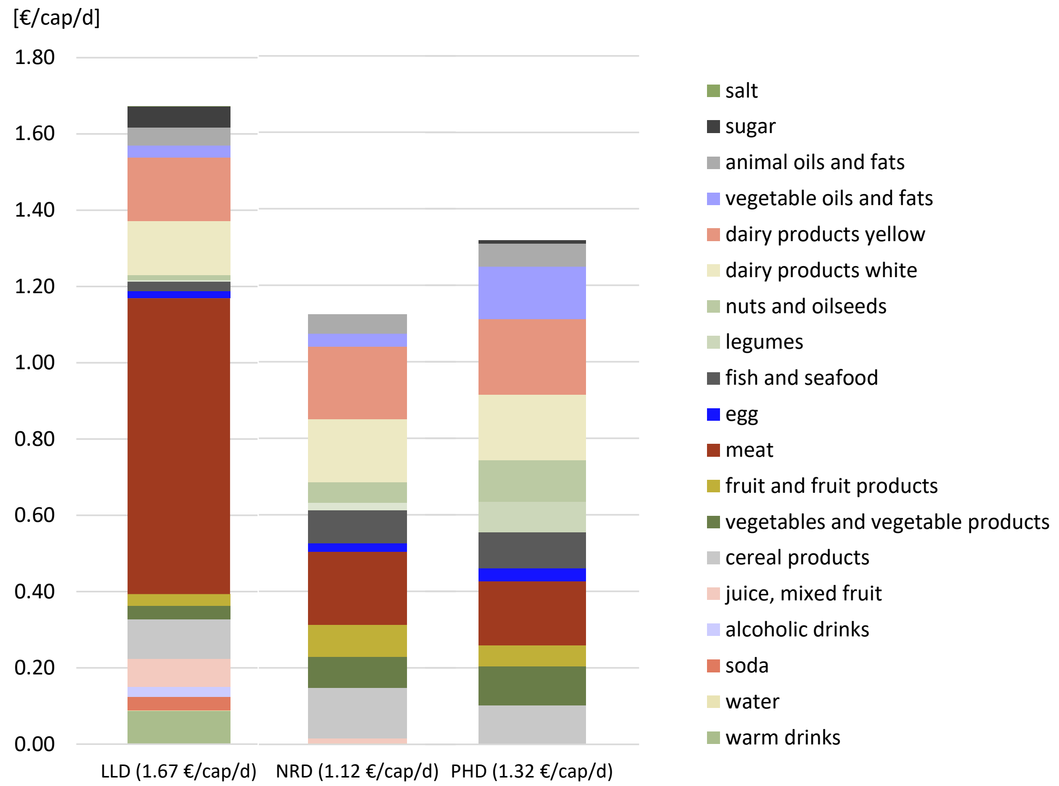

Figure 6: Contribution of the different food categories to the daily per capita environmental costs of LLD, NRD and PHD in Germany.

B) HOTSPOTS

In the following, environmental costs for carbohydrate sources (Figure 7), protein sources (Figure 8), fat sources (Figure 9), beverages and other products (Figure 10) are shown and their results are presented and discussed.

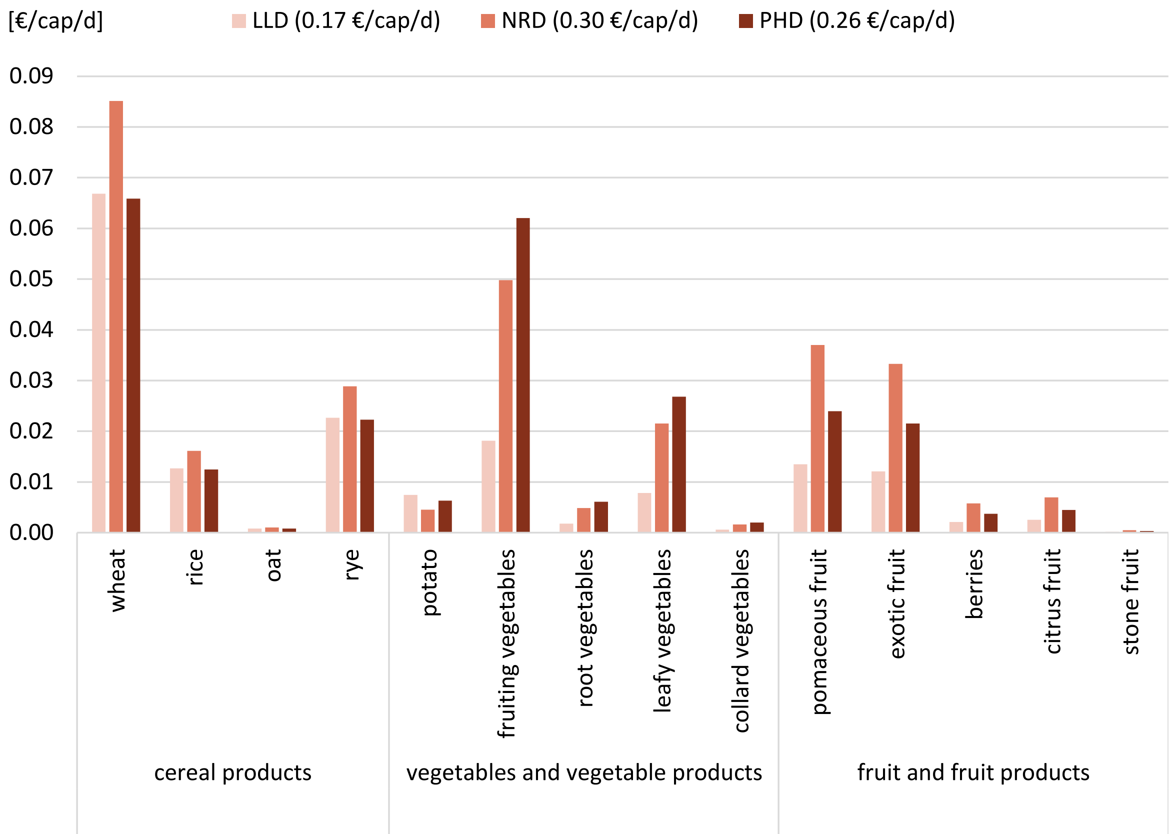

Figure 7: Daily per capita environmental costs of the LLD, NRD and PHD for carbohydrate sources in Germany.

Within the food group of carbohydrate sources, the highest cost contribution stems from wheat (or wheat products in general), contributing up to 0.09€/cap/d to the NRD and 0.07€ to both LLD and PHD per person per day. This is due to the high consumption or recommended intake levels per day rather than the environmental costs caused by wheat (per kg) which along with other cereal products is the most cost-efficient option with 0.37€/kg. Other cereals range between 0.57€/kg (rye) to 1.05€/kg (rice) costs.

Another high-cost contribution is associated with fruiting vegetables such as tomatoes within the vegetable category. This is primarily due to their high consumption values rather than their underlying environmental costs. However, the substantial cost contribution indicates the need for caution when sourcing fruiting vegetables, as they are often grown in greenhouses, which increases environmental costs.

The group of carbohydrate sources causes the least environmental costs per person per day over all food groups (except beverages and rest), with 0.17€, 0.30€ and 0.26€/cap/d for LLD, NRD and PHD, respectively. This difference is primarily due to higher amounts of fruits and vegetables recommendations by NRD and PHD than the current consumption under LLD.

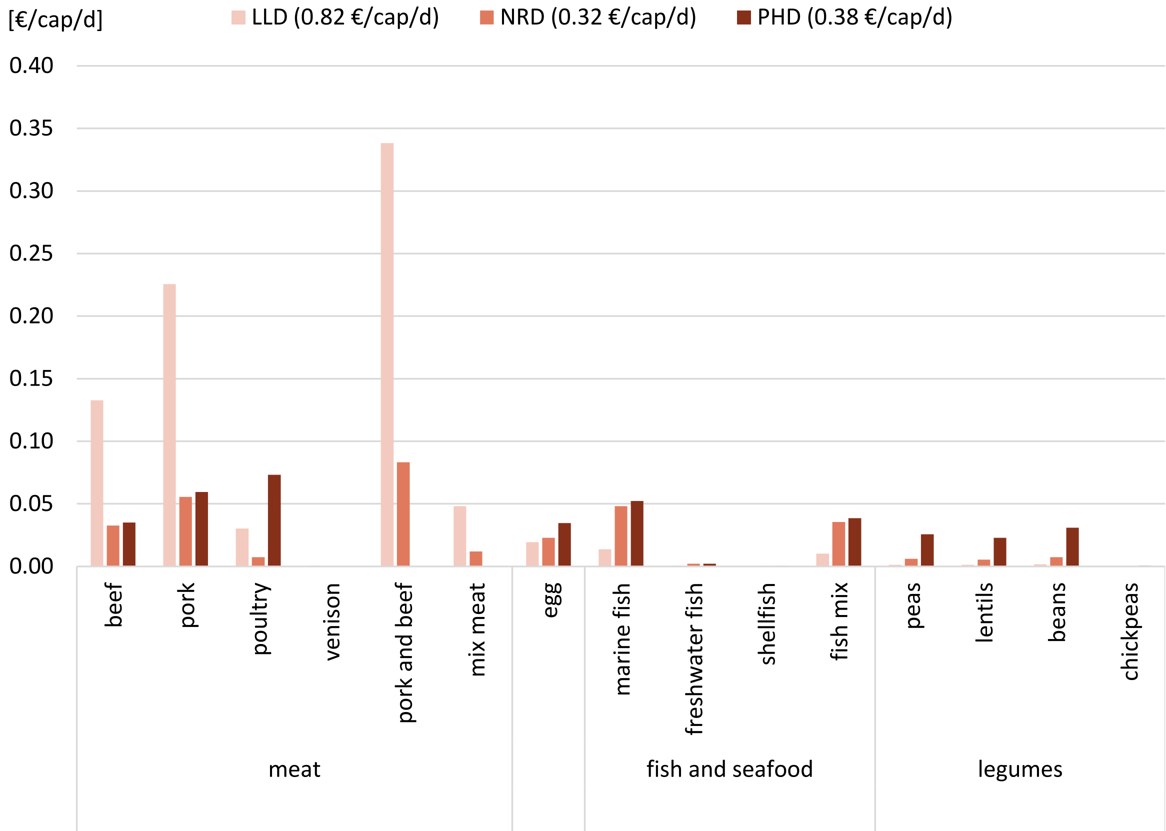

Figure 8: Daily per capita environmental costs of the LLD, NRD and PHD for protein sources in Germany.

Protein sources are the largest cost contributor within the LLD and the second largest cost contributor (after fat sources) within the NRD and PHD. Across all food products, **meat** is one of the largest cost drivers of the German LLD. Particularly pork and mixed meat (like sausages, meat cold cuts, etc.) consumption causes high external costs in comparison with products in the German diet with 0.23€/cap/d and 0.34€/cap/d, respectively. Switching to the recommended NRD or PHD levels for beef, pork and processed meat products would reduce environmental costs compared to current diets (LLD). Across all meat products, the German LLD causes 0.78€/cap/d of environmental costs, whereas the NRD causes only 0.19€/cap/d and the PHD 0.17€/cap/d. The high environmental costs associated with all meat categories are primarily due to the production of fine particulate matter from manure and the substantial land use required for animal feed production.

Plant-based protein sources (here: legumes) contribute minimally to the overall cost of diets. Shifting away from the meat-centric protein intake (LLD) to the NRD or PHD would save 0.59€ or 0.61 €/cap/d, respectively. This means environmental cost savings of 215.35€/cap/a (NRD) or 222.65€/cap/a (PHD) through less meat intake alone.

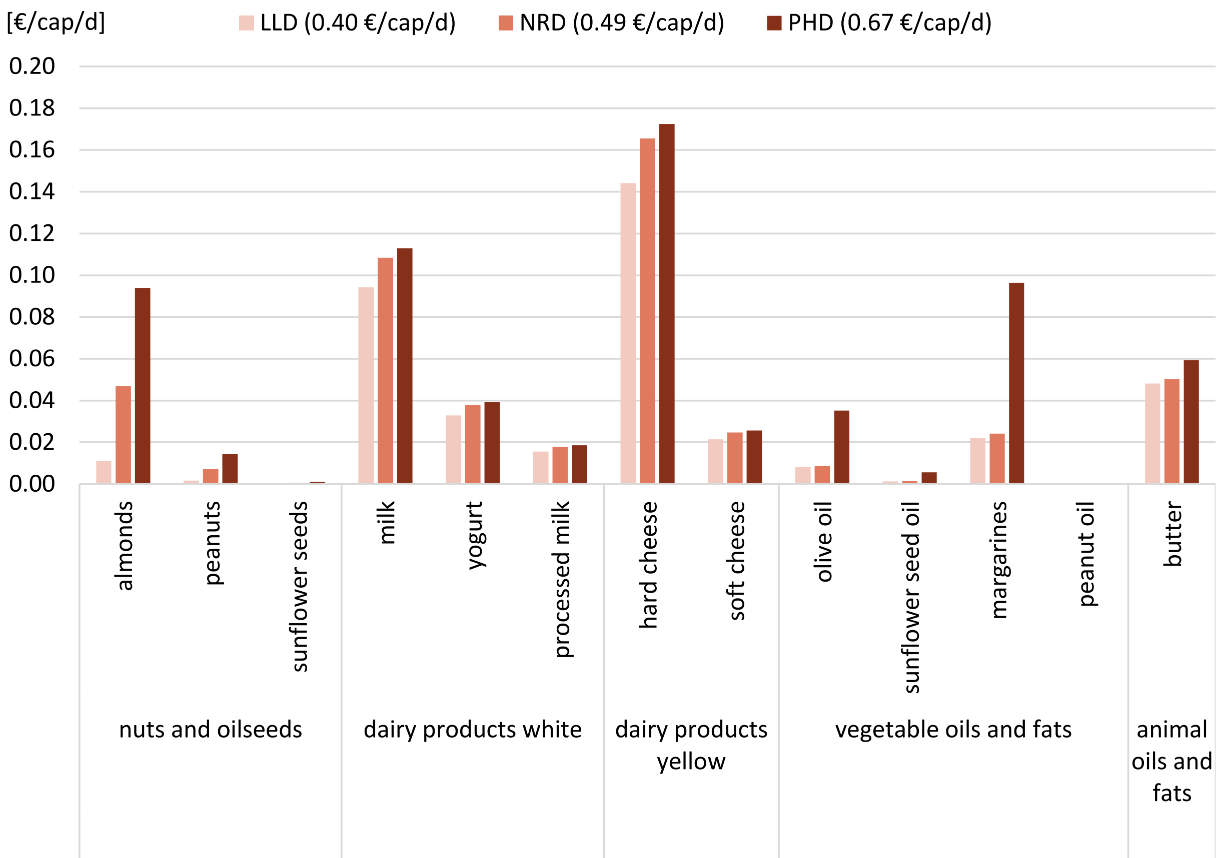

Figure 9: Daily per capita environmental costs of the LLD, NRD and PHD for fat sources in Germany.

Fat sources are the highest cost contributor in the two recommended diets (NRD and PHD). This is due to the higher recommended amounts of nuts (both diets) and vegetable oils (PHD).

Another major cost driver across all diets and products is **dairy products with high milk input (e.g. cheeses)**, which even exceed the costs of some meat products: hard cheese entails environmental costs of 7.18€/kg, whereas pork and poultry cause less environmental costs (5.06€/kg and 2.53€/kg respectively). Hard cheese contributes 0.14€/cap/d, 0.17€/cap/d and 0.17€/cap/d to the total costs of the LLD, NRD and PHD, respectively, making it a hotspot across all three dietary patterns. Hard cheese causes high external costs, since there is large milk input required to yield rather small amounts of cheese (for 1 kg of soft cheese about 5 kg of milk, for 1 kg of hard cheese about 10 kg of milk). As described in section 3.1.1, the recommended dairy intake (both NRD and PHD) exceeds that of the consumed dairy products in LLD, resulting in the higher environmental costs of NRD and PHD compared to LLD.

Within the PHD, the consumption of vegetable oils and fats – due to the distribution of consumption, particularly margarine, which contributes 0.10€/cap/d – accounts for a substantial portion of the PHD's total costs (11%), amounting to 0.14€/cap/d. Especially margarine requires considerable seed input and seed processing, which contributes substantially to the overall cost of the PHD. Another outlier in the PHD is the recommended nut intake, contributing 0.11€/cap/d to overall PHD costs.

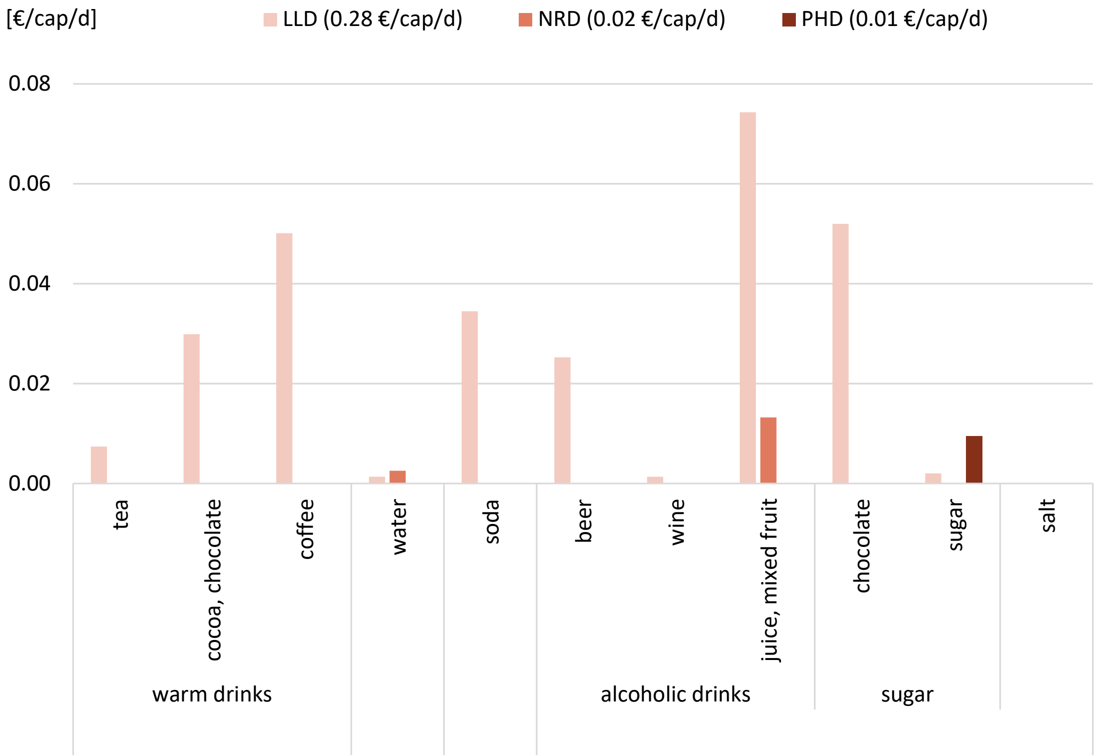

Figure 10: Daily per capita environmental costs of the LLD, NRD and PHD for beverages and other products in Germany.

Within the food group of beverages and other products, fruit juice contributes the highest costs to the LLD of Germany. This cost of 0.07€/cap/d is even higher than the costs of all consumed fruit combined (0.03€/cap/d). This is primarily due to the high consumption level of fruit juice in Germany. Although products derived from exotic fruits and crops (tea, coffee, chocolate) generate high environmental costs per kg of product – for example, one kg of cocoa beans results in 7.52€/kg of environmental costs – their impact on the LLD costs is relatively minor. However, a combined cost of 0.14€/cap/d for tea, coffee and chocolate, still represents a notable expense.

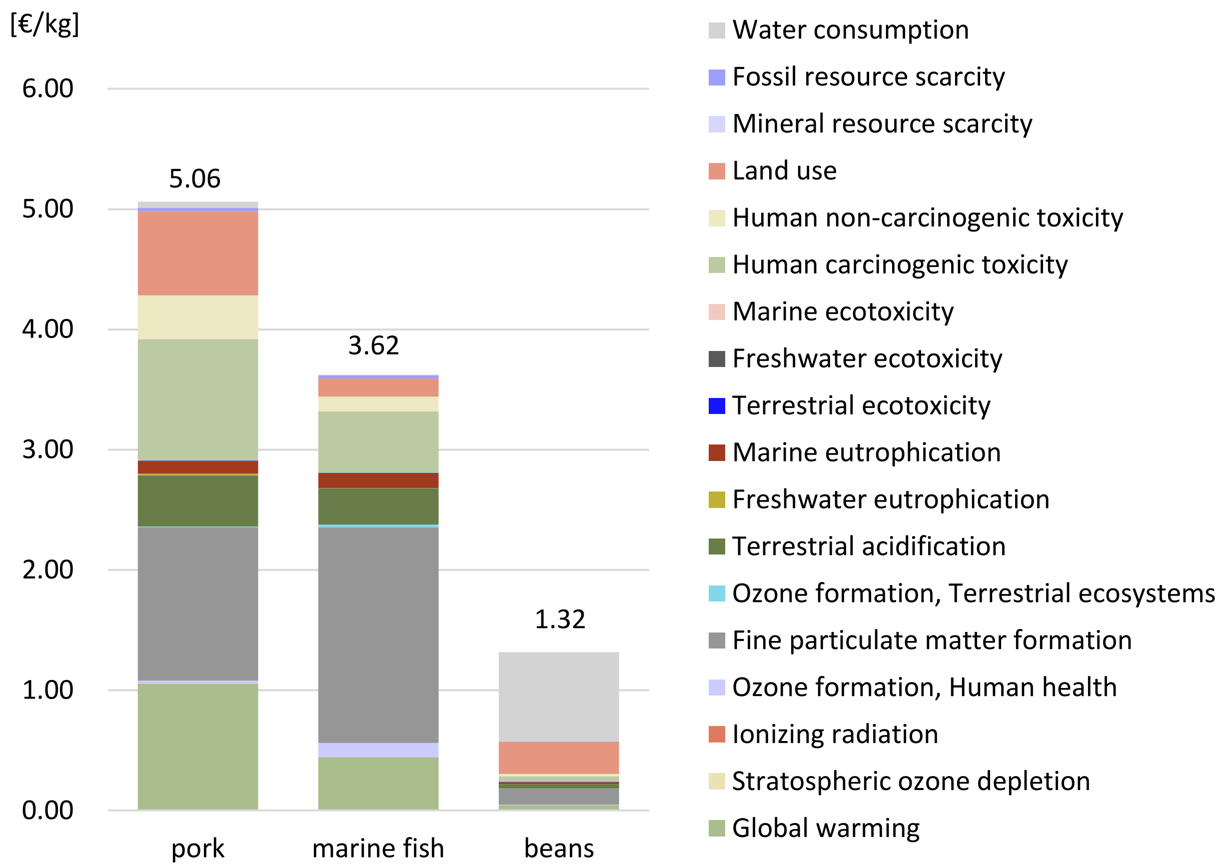

Figure 11: Daily per capita environmental costs according to their underlying impact for pork, marine fish and beans per kg, as consumed in Germany.

The composition of environmental impacts within the total environmental costs depends entirely upon the underlying product, as seen in Figure 11. Here, we compare three different products from different food categories: pork as an example for meat products, marine fish as an example for fish products and beans as an example for legumes. While for beef the cost of global warming is most relevant (4.11€/kg of beef), for pork it is the cost of fine particulate matter formation (1.28€/kg of pork). This is due to the high ammonium amount in pork manure. In the case of marine fish, likewise, the costs of particulate matter are higher than those of global warming (0.18€ and 0.44€/kg of marine fish, respectively). Interestingly, there are land use costs associated with fish production (0.18€/kg of marine fish), which is due to the feed used for fish farming. For Germany, beans are an outlier among plant-based products in general and among legumes in terms of their high agricultural water consumption due to irrigation (more on this in the subsequent paragraphs). Water consumption for the production of beans in some of their countries of origin results in comparatively higher environmental costs among legumes and all products, with costs of 0.74€/kg for water consumption alone (56% of their total environmental costs of 1.32€/kg).

Environmental impacts that primarily increase German environmental external costs over all food groups is **fine particulate matter**, which is caused during on-farm processes that emit ammonia (Wyer et al. 2022). Examples of such processes are manure handling and the use of synthetic fertilizers. Other contributing environmental impacts vary between food groups. **Land use** is particularly relevant to meat, legumes, dairy products and cereals. **Global warming** is a relevant environmental impact stemming from beef and all dairy products, as well as cocoa. In beef and dairy production, the ruminants' emissions from their intestinal enteric fermentation processes are a driving factor in this environmental impact. **Human toxicity** is another driving factor, with carcinogenic toxicity being more relevant, especially in fruits and vegetables. This is driven especially by infrastructure, like greenhouse buildings, or machinery used for on-farm production and transport.

In German diets, environmental hotspots are notably influenced by the country's **reliance on imports** from countries with less environmentally friendly production standards. This reliance can amplify environmental impacts, as seen with the unexpectedly high environmental cost of **beans**.

The substantial water consumption in bean-exporting countries such as Ethiopia, the United States of America, or Kyrgyzstan contributes substantially to these costs. For instance, water consumption alone accounts for 56%[25] of the environmental costs of beans consumption in Germany. The negative environmental impacts of this imported good illustrate how the environmental practices in exporting countries can affect the overall environmental footprint of dietary consumption in Germany. Paying attention to the environmental production standards when sourcing beans (and all products generally), e.g. by preferring local produce, which requires substantially less water, could potentially improve the environmental performance of a diet without having to make changes to the diet itself. Nevertheless, these increases in external costs per kg do not necessarily translate to the three diets: in LLD, consumption levels of legumes are rather low, and even if recommendations are higher for both NRD and PHD, the costs do not substantially influence the overall diets' environmental costs.

Further, these imports also require **transport** from abroad. Germany has a rather high modal share in road travel, which generally contributes especially to global warming costs. Nevertheless, transport does not highly influence the results, as seen with air travel included in exotic fruit production, which only contributes about 1.4% of the overall environmental costs of exotic fruit products.

3.1.3 HEALTH IMPACTS AND COSTS

Table 14: Health costs of all three diets (LLD, NRD, PHD) in Germany per person per day compared to baseline (NRD).

Health costs	Germany [€/cap/d]
LLD	19.30
NRD	-
PHD	-7.31

Health costs of German dietary patterns vary greatly between Planetary Health recommendations and the current consumption levels. While the LLD causes substantial costs per day, the PHD even brings benefits of over 7€/cap/d. (cf. Table 14).

A) DIET COMPARISON

In Germany, the results suggest that adopting the PHD could lead to substantial health cost savings, particularly if consumers follow the recommendations to reduce meat consumption.

Notably, there are some health benefits that the NRD has over the PHD in Germany. The NRD recommends a higher fruit intake than the PHD for addressing dietary risks related to inadequate fruit consumption. In comparison to the French and Irish NRD, Germany's NRD recommends 23 g of red meat per day (Table 12) and is therefore closest to the PHD recommendation of 14 g of red meat per day. This explains in part the very high health costs of LLD in Germany compared to other LL countries as LLD consumption is even further away from the recommended NRD levels (baseline for the health assessment).

However, the PHD offers health benefits in Germany, especially compared to current consumption levels (LLD), due to its higher recommended intake of plant-based foods, such as legumes. Shifting the German LLD to the PHD would result in substantial cost savings, particularly with increased legume intake, leading to potential health benefits of 4.53€/cap/d for this dietary risk factor. This shift also highlights potential reductions in costs associated with low fruit and vegetable intake. Germany's vegetable intake is the lowest among the three countries analysed here, averaging 88 g per person per day (compared to 129 g in Ireland and 140 g in France).

[25] However, this figure is uncertain, as the method we use for water use in exported crops does not provide specific data on whether irrigation is applied directly to beans or to more water-demanding crops like fruits and nuts. Unfortunately, we rely on average irrigation data per country, which is applied uniformly across all crops.

The cost decrease associated with increased vegetable consumption would be 1.13€/cap/d of health costs under the LLD to 0.43€/cap/d of health benefits under the PHD.

B) HOTSPOTS

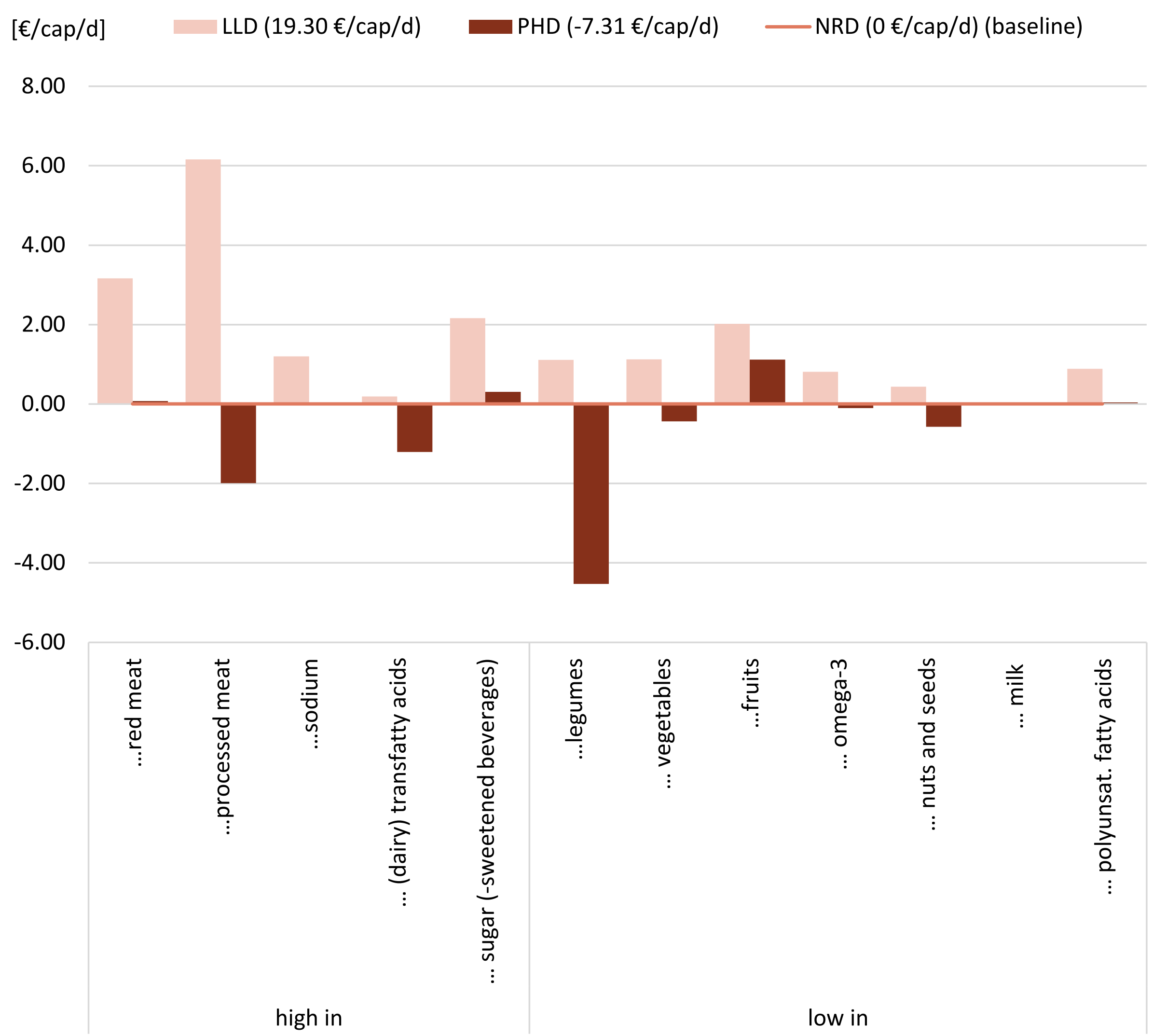

Figure 12: Health costs per person per day for LLD and PHD across all dietary risk factors in Germany. NRD is the healthy benchmark diet and therefore depicted as the zero-line over all dietary risk factors.

In Germany, **meat intake** (both red and processed) is the largest cost driver among all dietary-related health risks. The German NRD advises the lowest intake of red meat among the three LL countries, recommending 13 g per person per day (cf. Table 13) compared to 56 g in Ireland (cf. Table 18) and 41 g in France (cf. Table 24). This lower recommendation for red meat is a major factor in the high health costs associated with the German LLD, which incurs 3.17€/cap/d in costs from red meat and 6.16€/cap/d from processed meat consumption.

An insufficient consumption of **plants** (legumes, fruits, vegetables, nuts and seeds) causes the same costs of heightened meat consumption: in total 4.69 €/cap/d are incurred due to insufficient plant consumption in Germany. Especially fruits, contributing 2.02€ to the health costs of the LLD, should find more emphasis in German diets. As the NRD recommends higher levels of fruit intake than the PHD, this is another category where the PHD incurs costs rather than benefits to the NRD (1.12€/cap/d).

The health costs associated with **salt** and **sugar** consumption (LLD) amount to health costs of 3.36 €/cap/d. This is primarily due to sweetened beverage consumption.

Sugar is also the primary dietary risk causing health costs within the PHD across all LL countries, as the PHD allows for some mindful sugar consumption, whereas all NRDs recommend no sugar consumption for optimal health.

Additionally, Germans consume rather low amounts of **fish**, leading to health costs of 0.81 €/cap/d related to omega-3 deficiency. The average fish intake in Germany is 7 g per day as compared to the recommended amount of 26 g and 28 g per day in the NRD and PHD respectively. This amount is also substantially lower than the 24 g in Ireland and 25 g in France. This is not particularly a hotspot but notable, nonetheless.

3.1.4 SOCIAL RISKS

Table 15: Social risks of all three diets (LLD, NRD, PHD) in Germany in mrheq per person per day.

Social risks	**Germany** [mrheq/cap/d]
LLD	3.59
NRD	2.05
PHD	4.23

Overall, it is important to note that the primary factor contributing to product-specific risks is the sourcing countries. As outlined in section 2.4, we evaluate the top five sourcing countries for each representative product. A detailed list of these countries is provided in electronic Appendix 3.

A) DIET COMPARISON

In Germany, the social risk assessment indicates rather small differences in social risks between the LLD and the two recommended diets NRD and PHD, with NRD performing best. Shifting from the LLD to the NRD would be beneficial in reducing social risks:

- **LLD** shows moderate social risk due to substantial contributions from tea and coffee.
- **NRD** exhibits the lowest risk, with remaining risks primarily driven by beans, rice and hard cheese.
- **PHD** has the highest social risk, mainly caused by beans, rice and nuts.

The LLD exhibits moderate total social risk, largely driven by high-risk contributions from tea, coffee, pork and rice. Specifically, tea contributes substantially to the social risk in Germany with 0.8 mrheq/day (23% of social risks). Coffee also presents a notable risk at 0.71 mrheq/day (20% of social risks). These high-risk contributions underscore the importance of targeted interventions in these categories. Therefore, it benefits the NRD and PHD that tea and coffee are not included in the recommendations. Excluding tea and coffee, the LLD would only bear social risks of 2.04 mrheq/day and would therefore perform better than both recommended diets. While the higher risks in LLD are associated with higher amounts of meat intake, specifically pork, the NRD and PHD recommend a higher intake of beans and nuts, which bear comparatively high social risks.

Adopting the NRD in Germany could lead to a reduction in social risks. The remaining social risks are primarily caused by contributions from beans (0.60 mrheq/day), rice (0.27 mrheq/day), hard cheese (0.14 mrheq/day) and fruiting vegetables (0.13 mrheq/day). Although the NRD imposes the lowest risks, there are still areas for improvement, particularly in reducing reliance on beans sourced from high-risk countries and prioritising options that are more socially sustainable. The PHD shows the highest level of social risks due to the high recommended intake of beans, rice and nuts. The main contributor is beans with 2.54 mrheq/day, which is mostly offset by the overall lower risk across other food categories.

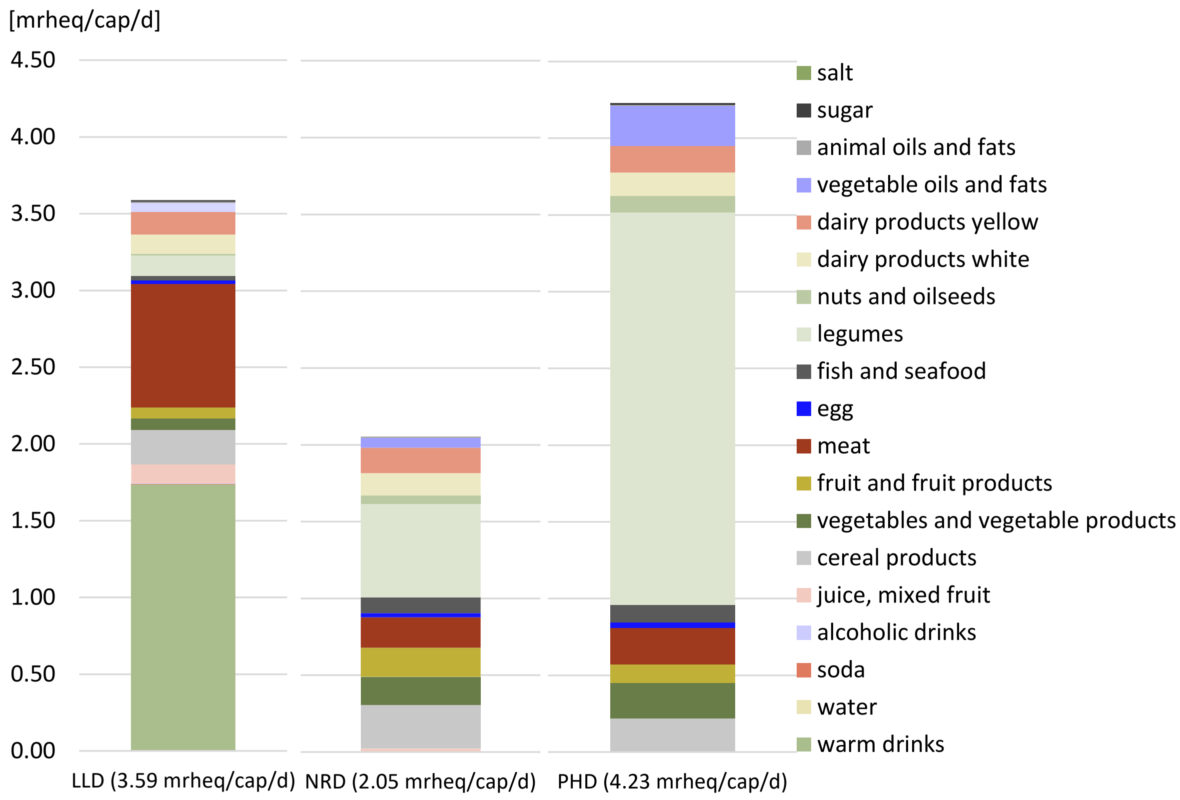

Figure 13: Contribution to social risks of LLD, NRD and PHD per person per day in Germany from different product groups.

Figure 13 shows the diets in comparison to one another with all product categories and their respective risk contribution to the diets. It becomes clear that different categories contribute in varying degrees to social risks. While shifting from the LLD to the NRD or PHD would substantially reduce high-risk contributions from tea and coffee, the NRD and PHD still show potential for risk reduction. The PHD would strongly benefit from reducing reliance on beans sourced from high-risk countries or shifting to a different source of legumes, such as peas, lentils or chickpeas since none of these alternatives is sourced from a high-risk country.

B) HOTSPOTS

In the following, we describe and discuss hotspots within the diets in more detail. We examine social risks for carbohydrate sources (Figure 14), protein sources (Figure 15), fat sources (Figure 16) and beverages and other products (Figure 17).

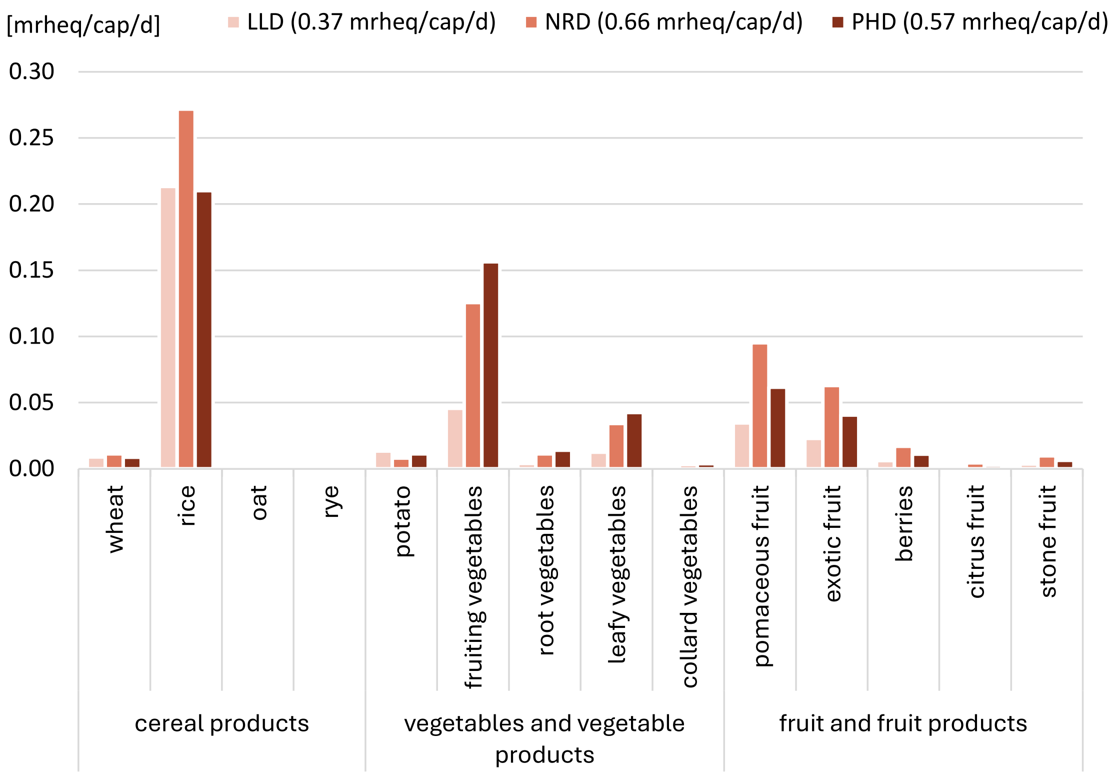

Figure 14: Social risks [medium risk hour equivalents (mrheq) per person per day] of the LLD, NRD and PHD, carbohydrate sources, Germany.

In the category of **cereals,** oats, wheat and rye outperform rice. Particularly, rice sourced from Cambodia and Myanmar poses social challenges, with high contributions from subcategories within Labour Rights as well as Occupational Toxicity and Hazards, State of Environmental Sustainability, Legal System or Access to Hospital Beds, among others. Rice sourced from strong democracies in Europe, such as Spain, France and Italy indicate a low social risk. However, it is unlikely that even the lower recommended intake under the NRD and PHD can be covered by European supply alone. Among **vegetables and fruits,** fruiting vegetables (e.g. tomatoes) and pomaceous fruits (e.g. apples) contribute the most to social risks due to the quantity consumed, while collard vegetables (e.g. cabbage) contribute the least. Given the higher intake of vegetables and fruits under NRD and PHD the social risk is approximately increasing by factor 3 for both diets in the category of fruiting vegetables. Regarding the potential for improvement of Labour Rights for sourcing fruiting vegetables and pomaceous fruits, attention should be directed to the Netherlands, as the poorest performer among German import countries. The Netherlands show comparably high social risks among all risk categories; however, the main risk contribution comes from labour rights.

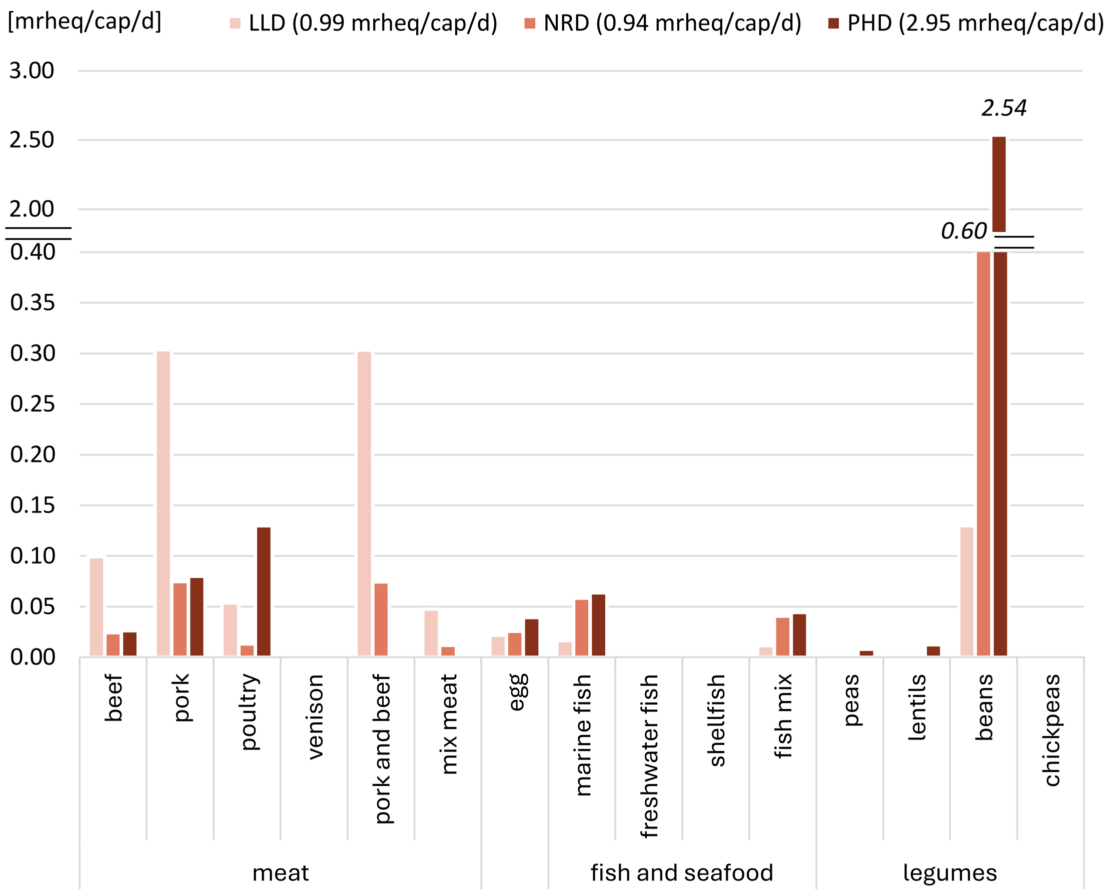

Figure 15: Social risks [medium risk hour equivalents, mrheq per day] of the LLD, NRD and PHD, protein sources, Germany.

Across meat, pork and the pork-beef mix bear high social risks under the LLD, which are considerably reduced under the NRD and even more under the PHD. Beef has the highest social risks per kg followed by the mixed pork-beef, pork and poultry. As 86% of pork comes from domestic production with moderate social risk, the highest risk per kg is associated with pork imports from Belgium. No social risk subcategory shows especially high contributions, but risks are accumulated quite evenly among all subcategories. In the case of fish and seafood, the risk is mainly driven by marine fish and the fish mix. While the social risk associated with fish and seafood is relatively low at current intake levels, it increases considerably for the NRD and PHD. For legumes, beans demonstrate very high social risks, particularly under the high intake levels of the NRD and PHD. For German consumption, this is primarily due to its imports from Ethiopia (24% of total legume consumption is imported from Ethiopia[26]) where Labour and Human Rights as well as Community Infrastructure issues raise the risk score remarkably. Turkish, Canadian and American bean imports entail a fraction of this risk.

[26] Among the top five sourcing countries.

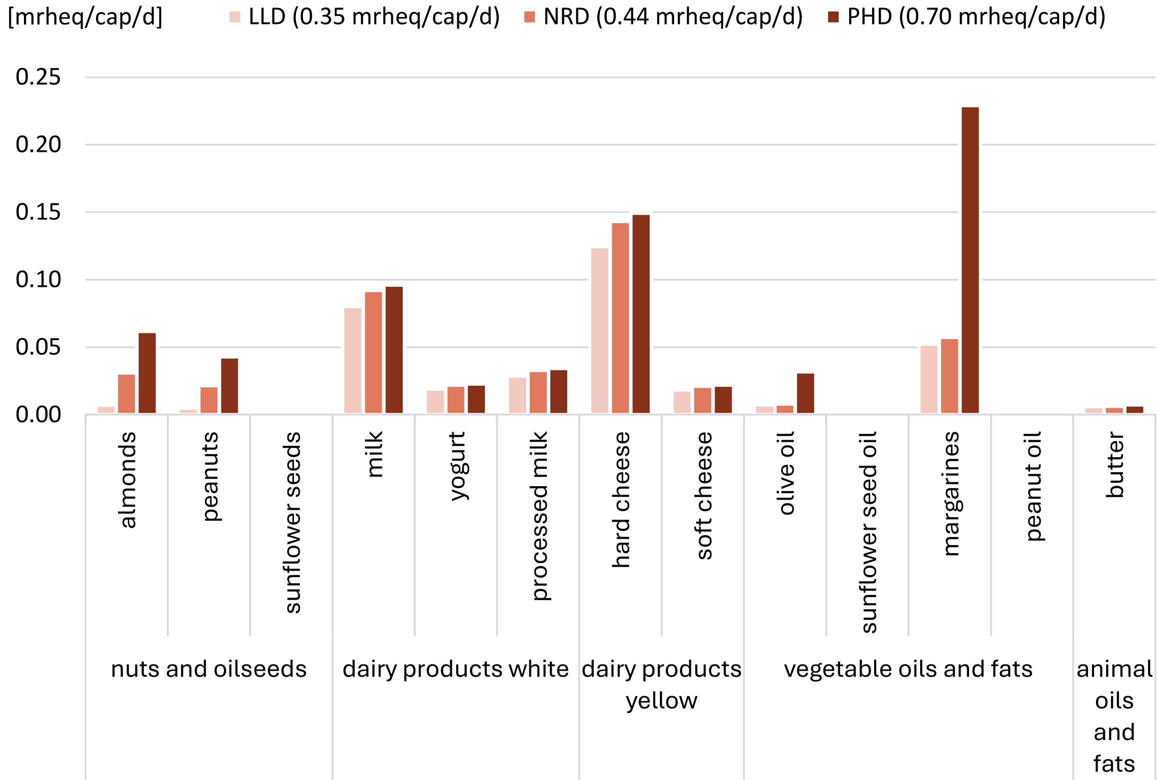

Figure 16: Social risks [medium risk hour equivalents, mrheq per day] of the LLD, NRD and PHD, fat sources, Germany.

Among the German LLD, **nuts and oilseed** only contribute marginally to the social risks. As the social risk increases with the NRD and PHD due to the consumption distribution, informed and responsible sourcing is becoming more relevant for this food category. Hence, almond imports from Morocco as well as peanuts from Nicaragua, indicating high social risk due to Labour Rights and Community Infrastructure should be considered carefully. Across **dairy products,** milk and hard cheese consumption entails the highest risk, and this risk slightly increases for a potential transition to the NRD and the PHD. Per kg, hard cheese demonstrates 10 times greater risk caused by higher milk input per kg. 80% of the milk is sourced nationally and the main risk contributions come from the subcategories of Injuries and Fatalities, Occupational Toxicity and Hazards as well as Child and Forced Labour, among others. The social risk of **oils and fats** is mainly attributable to vegetable oils and especially margarine, where the latter has an elevated risk in the PHD due to higher dietary intake. Main contributions come from the subcategories of Forced Labour, Injuries and Fatalities and Child Labour. Peanut oils come with the highest social risk per kg but are barely consumed.

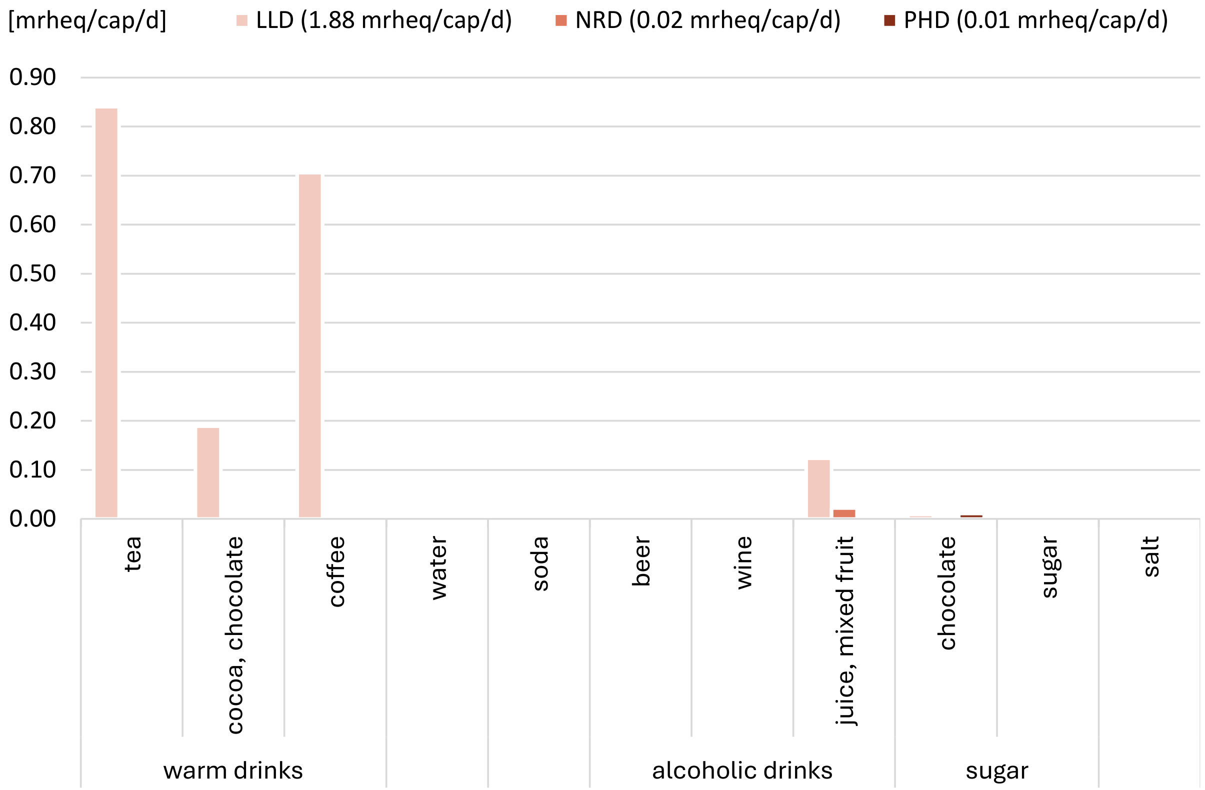

Figure 17: Social risks [medium risk hour equivalents, mrheq per day] of the LLD, NRD and PHD, beverages and other products, Germany.

Tea and coffee demonstrate high social risk, particularly due to Wage Assessment, Workers in Poverty, Child Labour, Forced Labour (mainly for tea), Occupational Toxicity and Hazards, Injuries and Fatalities among others. Concerning tea imports to Germany especially Kenya and Malawi show very high social risk due to poor Labour Rights. India, Sri Lanka, Indonesia and Argentina indicate only a fraction of this social risk per kg. Coffee is imported mainly from Brazil, Peru, Honduras, Indonesia, Columbia and Ethiopia. The latter scores poorly not only in terms of Labour Rights but also regarding Human Rights and Community Infrastructure. For both the NRD and PHD, there is no recommendation on tea and coffee consumption, theoretically leading to no social risk. The same holds for soda and beer consumption, which contribute slightly to social risks within the NRD. Lastly, the juice is connected to increased social risk, majorly led by contributions within Labour Rights as well as the subcategory Injuries and Fatalities.

3.1.5 POTENTIAL FOR GERMAN DIETARY TRANSITION

The German **LLD** shows environmental cost contributions primarily from meat consumption, especially pork and its processed products. Dairy products, particularly hard cheese, also substantially increase costs. Similarly, health costs are considerably driven by red and processed meat consumption and consequential insufficient intake of plant-based foods, especially fruits and vegetables. Social risks however are rather moderate compared to NRD (lowest risks) and PHD (highest risks) yet with high contributions from tea and coffee. Again pork, and also rice, contribute notably to LLDs' social risks. The German **NRD** shows the lowest environmental costs among all three diets. However, dairy products particularly hard cheese remain notable contributors to environmental costs. The NRD's reduction in meat consumption, especially pork, plays a major role in lowering its environmental costs. As the NRD serves as a benchmark for health, no additional costs are incurred here. However, there is potential to further enhance health outcomes by increasing plant intake in its recommendations, particularly legumes and reducing meat recommendations even further. Social risks are lowest in the NRD, but certain foods like beans, rice and hard cheese still pose moderate risks. Despite its environmental focus, the German **PHD** incurs slightly higher environmental costs than the NRD, primarily due to increased consumption of poultry, nuts and vegetable oils. However, it still offers substantial reductions in environmental costs compared to LLD.

It also offers the most substantial health benefits, resulting in cost savings through a high intake of legumes and reduced consumption of red and processed meats. Contrary to this, the PHD shows the highest social risks across the three German diets, due to its recommendations of beans, rice and nuts, all of which carry substantial social risks because of their associated countries of origin. The social risks associated with these foods could potentially offset the benefits of reducing meat consumption. Across all three German diets (LLD, NRD, PHD) and the three impact areas (environment, health, social), the following foods consistently emerge as hotspot foods with negative impacts and high costs: **Pork** and its processed products are a major contributor to environmental costs, particularly in the LLD. High consumption of pork, particularly in processed form, is associated with great health costs particularly due to cardiovascular disease and cancer. It also has notable social risks including issues related to labour conditions. **Cheese** (and other dairy products) has substantial environmental costs, particularly in terms of greenhouse gas emissions and land use. High consumption of cheese (high in saturated fats) contributes to health costs. The dairy industry also poses social risks, including labour exploitation. Derivates from exotic plants, particularly beverages like **tea and coffee**, contribute to environmental costs. Health costs or benefits of tea and coffee could not be evaluated with this methodology, however, high consumption or dependence (on caffeine) can lead to health issues. Social risks associated with tea and coffee are high for multiple reasons (see above).

3.1.6 COMPARISON BETWEEN THREE IMPACT AREAS (ENVIRONMENTAL, HEALTH, SOCIAL)

The environmental and health performance of a product are usually closely aligned highlighting that there are few trade-offs between sustainability and health when it comes to diets. Both areas emphasize the benefits of transitioning to more plant-based diets, which offer advantages for both health and the environment. For example, reducing the consumption of red and processed meat is beneficial to the health of both people and the planet. While the PHD offers substantial environmental benefits, it, like all diets, still incurs some environmental costs due to the increased consumption of certain plant-based foods that require high resource input, like oilseeds for vegetable oils, or nuts.

The social risks often diverge from environmental and health impacts, especially when considering plant-based foods. While nuts and beans generally have lower health and environmental impacts compared to meat, their social risks depend heavily on the source and supply chain, with higher risks potentially arising from imports in certain regions. However, beans grown in Europe, often used as animal feed, could be redirected for human consumption with minimal social risks. Additionally, there are substantial social risks associated with meat production, such as animal welfare and the mental health of slaughterhouse workers, which are not fully captured in this assessment The divergence between social risks and environmental and health impacts is most evident in the PHD diet, where the focus on plant-based foods results in improved health outcomes but highlights social risks connected with current supply chains.

Health costs are particularly critical for the LLD diet. All three impact areas consistently show negative effects of animal-based food and the complexities associated with foods that rely on global supply chains with possibly non-transparent production practices. These issues not only cause social risks but also make accurate environmental assessment difficult.

3.1.7 AFFORDABILITY OF THE GERMAN DIETARY PATTERNS

Results of the cost assessment

Table 16 presents the estimated daily costs of the three dietary patterns in Germany in 2021 PPP EUR prices, per person per day.

Table 16: Daily cost of the three diets for Germany

Country	LLD [2021 PPP €/cap/d]	NRD [2021 PPP €/cap/d]	PHD [2021 €/cap/d]
Germany	1.4	2.2	2.3

The cost analysis reveals that the German LLD is the cheapest diet at 1.4 PPP €/person/day, with the NRD and PHD being 57% and 66% more expensive.

The NRD and PHD are comparable in price, with the PHD being slightly more expensive. This suggests that the transition to the NRD, rather than the PHD, will not only benefit the environment but also personal expenses.

Figure 18 shows the distribution of the costs across the different food groups for each diet. Analysing these results provides insights into how transitioning to more sustainable and healthier diets affects cost allocation across food groups.

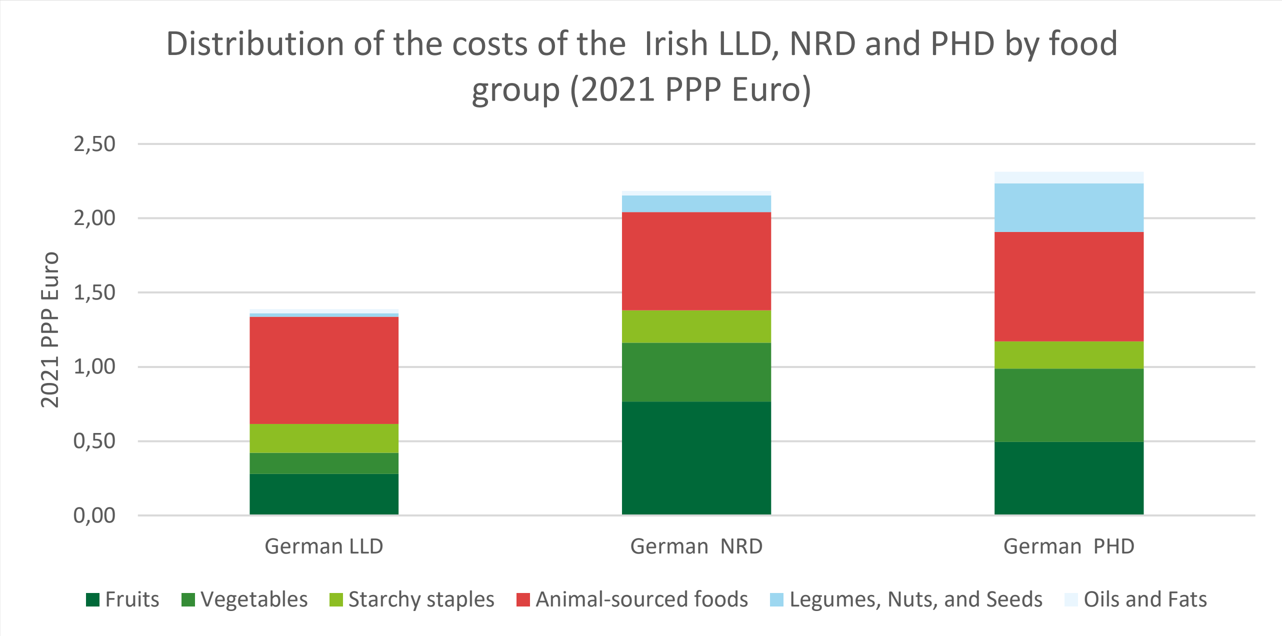

Figure 18: Relative distribution of the cost across the different food groups of the German LLD, NRD and PHD (2021 PPP Euro).

Animal-sourced foods make up the largest share of costs in the LLD (0.72€), reflecting a diet heavily reliant on meat, dairy and other animal products. Notably, meat is also the leading contributor to environmental and health costs, highlighting the potential triple benefits —health, environmental and financial— of reducing its consumption. A substantially lower proportion of costs is allocated to fruits (0.28€) and vegetables (€0.14), suggesting that these food groups are less emphasized in the current dietary practices. The cost allocation for legumes, nuts and seeds is notably low in the LLD (0.03€), which aligns with the diet's focus on animal proteins rather than plant-based alternatives. The cost for starchy staples remains fairly consistent across all diets, with the LLD at 0.19€, NRD at 0.22€ and PHD at 0.18€, indicating that the consumption of these foods is stable across dietary patterns.

The NRD has the highest cost allocation for fruits (0.77€) and a substantial cost for vegetables (0.40€), reflecting its emphasis on fruit and vegetable consumption in line with national dietary guidelines. It shows a slightly lower cost (0.66€) for animal-sourced foods, reflecting the recommended reduction in animal-sourced foods for health reasons.

Surprisingly, the PHD, which is designed to be more sustainable and lower in animal products, has an even higher cost allocation for animal-sourced foods (0.73€).

Affordability assessment

In this section the results regarding the affordability of the diets are presented, taking into account the costs of the diets as well as the national income distribution in Germany.

Table 17 presents Germany's daily and annual median equivalised net income for an adult with dependent children.

Table 17: Daily and annual net income for a single person with dependent children in Germany

Country	Median equivalised net income [€/cap/d]	Median equivalised net income [€/cap /year]
Germany	52.6	19,000

The daily median income for a single person with dependent children in Germany is 52.6€. The costs for the LLD, NRD and PHD diets are 1.4€, 2.2€ and 2.3€, respectively. These costs represent 2.6%, 4.2% and 4.4% of the daily disposable income, all well within the 20-30% affordability threshold. Thus, all three diets are considered highly affordable in Germany.

According to the same source (EU-SILC), the annual disposable income for the first decile of the German population in 2021 was 12,535 €/a or 34.34 €/d. For households in the first decile of income, all three diets LLD, NRD and PHD remain affordable, with the highest percentage of income spent being 6.7% for the PHD. This is substantially below the 20-30% threshold considered affordable in high-income contexts, yet more than twice as high as for households with median income indicating substantially higher financial burdens for households with less disposable income.

The findings from this cost analysis highlight important considerations for dietary affordability in Germany. While the LLD is considerably cheaper (though its costs may be underestimated due to likely underreported expenses for animal-sourced products), the NRD and PHD offer a sustainable dietary pattern at a slightly higher, yet affordable cost.

3.2 Ireland

Second, we present results for the LL country Ireland.

3.2.1 CONSUMED AMOUNTS OF LLD AND RECOMMENDED AMOUNTS OF NRD AND PHD

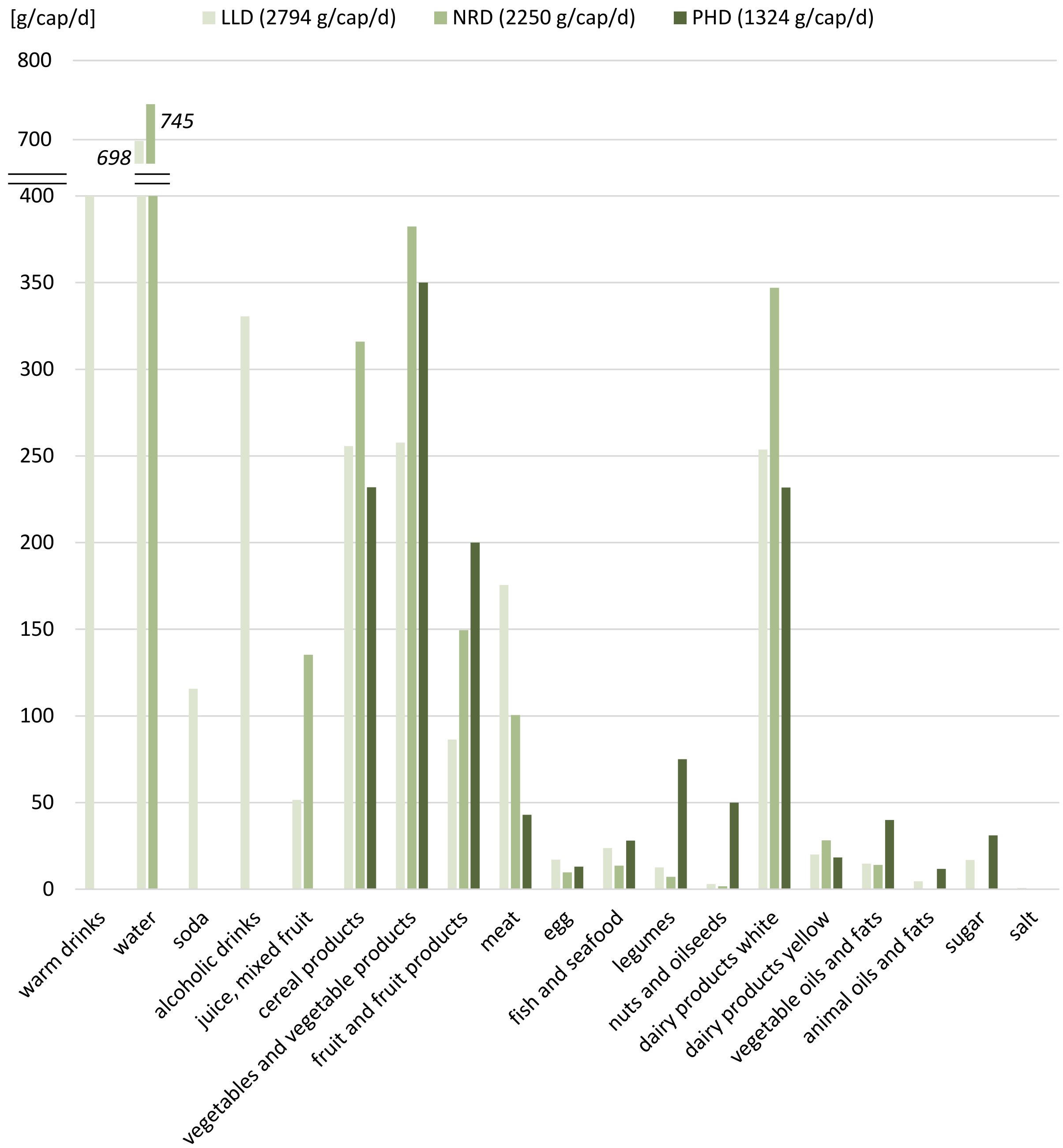

Figure 19: composition of consumption values (LLD) and recommended intake (NRD, PHD) in Ireland per person per day. Some food categories are not recommended within the NRD or PHD and columns therefore missing (e.g. warm drinks).

Table 18: Composition of consumption values (LLD) and recommended intake* (NRD, PHD) in Ireland per person per day. Table cells are grey when there are no values recommended for these respective products.

Category	#	Product**	LLD [g/cap/d]	NRD [g/cap/d]	PHD [g/cap/d]
Beverages	1.1	Warm drinks	456		
	1.2	Water	698	745	
	1.3	Sugary drinks	116		
	1.4	Alcoholic drinks	331		
	1.5	Fruit juices	52	135	
Carbohydrate sources	2.1	Cereal products	256	316	232
	2.2	Starchy vegetables	129	159	50
	2.3	Other vegetables	129	223	300
	2.4	Fruit and fruit products	86	150	200
Protein sources	3.1	Beef	58	33	2
	3.2	Pork	39	22	12
	3.3	Poultry	62	36	29
	3.4	Meat, other***	16	9	
	3.5	Eggs	17	10	13
	3.6	Fish and seafood	24	14	28
	3.7	Legumes	13	7	75
Fat sources	4.1	Nuts and oilseeds	3	2	50
	4.2	Dairy products white	254	375	219
	4.3	Dairy products yellow	20	28	31
	4.4	Vegetable oils and fats	15	14	40
	4.5	Animal oils and fats	5		11.8
Rest	5.1	Sweets	17		31
	5.2	Salt	1		

* Numbers are represented as in the original recommendations.

** Further definitions of product categories are provided in Appendix 1.1, Table 30.

*** 'Meat, other' encompasses venison, beef and pork and mixed meat, more detailed consumption data is provided in the digital Appendix 2.

Ireland's consumption levels show substantial deviations from the recommended diets, particularly for protein sources and certain carbohydrate categories (cf. Figure 19 and Table 18). Consumption of beef, pork and poultry far exceeds the amounts recommended by both the NRD and the PHD. It needs to be noted that the share of beef consumption might be underestimated in the NRD and PHD, as substantial amounts of beef can be assumed to fall under the 'other meat' category and are therefore not accounted for based on the division of meat types by current consumption patterns. The intake of starchy vegetables is also much higher than suggested by the PHD. In contrast, the consumption of vegetables, fruits, legumes and nuts is considerably below the recommended levels by both the NRD and the PHD. Notably, the Irish NRD recommendation for legume intake is even lower than current consumption levels. Consumption of dairy products and cereal products aligns more closely with the PHD but is still lower than the NRD recommendations (disregarding the distinction between whole grain and refined grain).

Warm drinks and sugary drinks are consumed at high levels, although not recommended by either the NRD or the PHD, indicating a potential area for reducing environmental and health impacts. Alcoholic beverage consumption is also notably high, compared to the other two LL countries.

A notable point of divergence between the PHD and the NRD is in the consumption of meat products. The PHD recommends substantially lower meat intakes, particularly for beef and pork, which will likely result in reduced environmental costs compared to the current LLD and potentially the NRD.

3.2.2 ENVIRONMENTAL IMPACTS AND COSTS

Table 19: Environmental costs of all three diets (LLD, NRD, PHD) per person per day in Ireland.

Environmental costs	Ireland [€/cap/d]
LLD	2.26
NRD	1.63
PHD	1.24

A) DIET COMPARISON

In Ireland, the PHD achieves the lowest environmental costs at 1.24€/d (cf. Table 19), primarily due to its recommendation of lower meat intake (e.g. savings in beef at 0.36€/cap/d compared to NRD) and dairy intake (e.g. savings in milk at 0.08€/cap/d compared to NRD).

By transitioning from the LLD to the NRD, there is a potential reduction in environmental costs of 0.63€/cap/d. Switching from LLD to PHD saves 1.03€/cap/d. This means cost savings of 231.49€/cap/a from LLD to NRD and 375.10€ from LLD to PHD. For the country of Ireland, this results in total environmental cost savings of 1.19 billion Euros per year for NRD and 1.92 billion Euros per year for PHD.

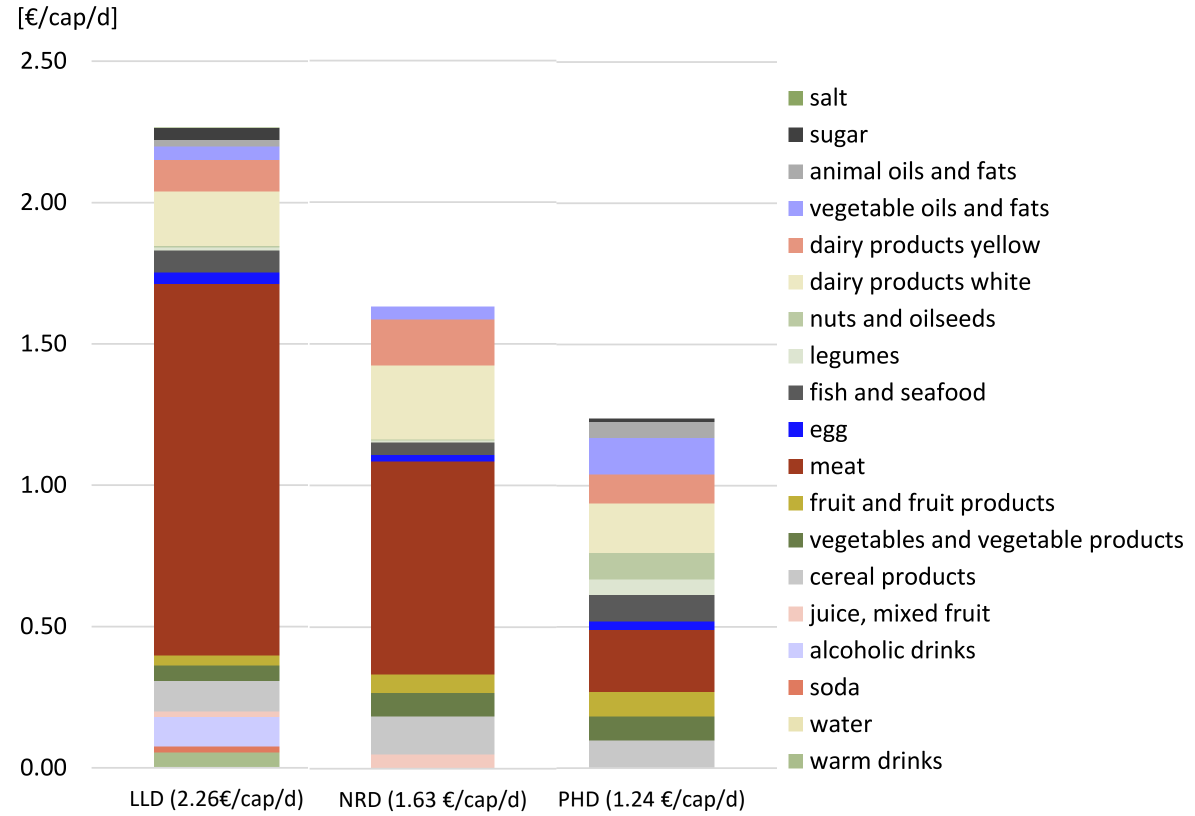

Figure 20: Contribution to environmental costs of LLD, NRD and PHD from product categories in Ireland per person per day.

Figure 20 shows the diets in comparison to one another with all product categories and their respective cost contribution to the diets. It becomes clear that different categories contribute in varying degrees to environmental costs. Within the LLD and NRD, meat consumption is by far the highest cost contributor, whereas costs within the PHD across all product categories seem more balanced.

In the following, we will describe and discuss hotspots within the diets in more detail.

B) HOTSPOTS

In the following, environmental costs for carbohydrate sources (Figure 21), protein sources (Figure 22), fat sources (Figure 23), beverages and other products (Figure 24) are presented and discussed in successive graphs.

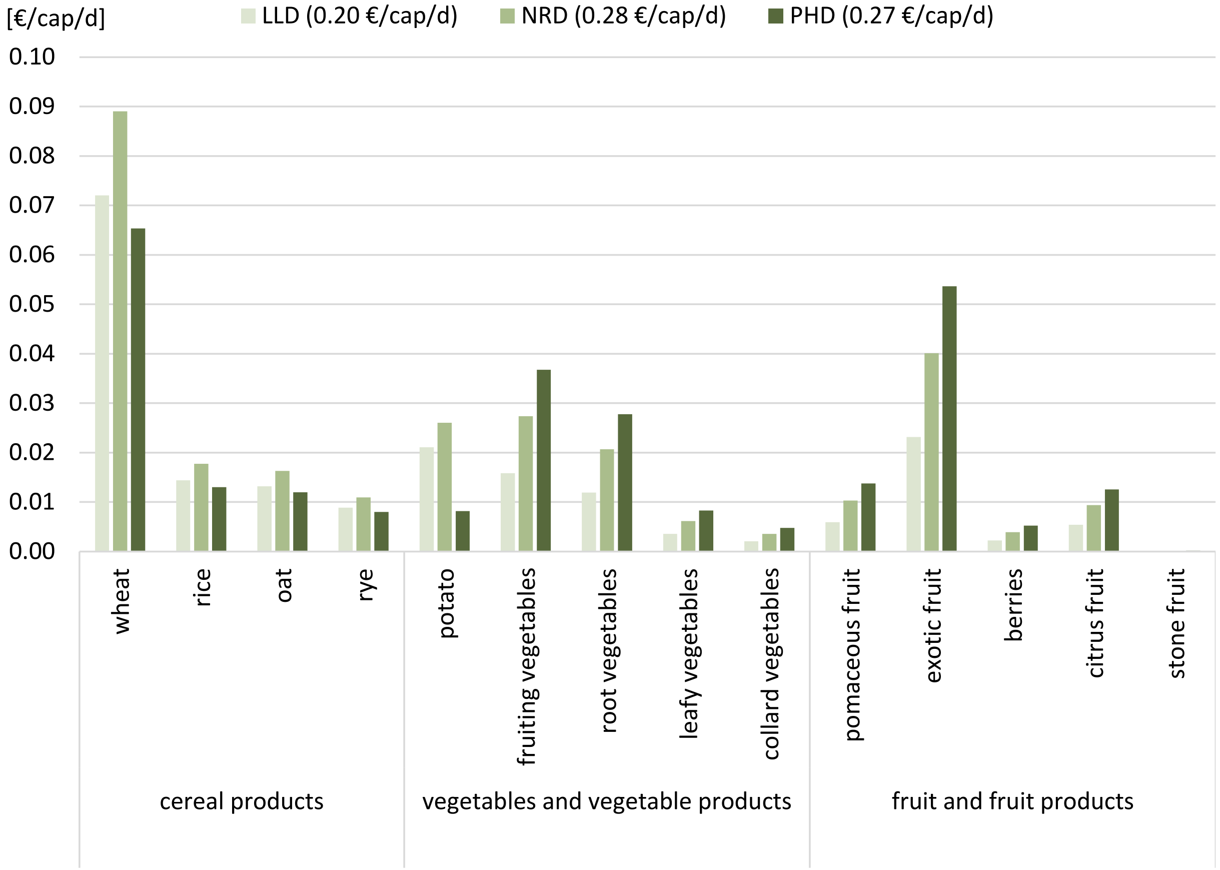

Figure 21: Environmental costs of the LLD, NRD and PHD for carbohydrate sources in Ireland per person per day. Values close to zero can be either, because there are no recommended values within the NRD or PHD, or because the consumption levels are so small that their environmental costs are not evident from this figure.

Within the food group of carbohydrate sources, as in Germany, the highest cost contribution stems from wheat (or wheat products generally), contributing up to 0.09€/d to the NRD and 0.07€/d to both the LLD and the PHD. Again, this is due to the consumption or recommended intakes per day rather than the environmental cost per kg of wheat which along oat is the most cost-efficient option within the cereals category, with environmental costs of 0.37€/kg (while other cereal products range between 0.37€ (oat) to 1.22€/kg (rice)).

Another high-cost factor is exotic fruits, which is particularly apparent in the PHD, as it recommends higher fruit intake than the LLD or the NRD. Exotic fruits in Ireland have higher environmental costs per kg compared to the other fruit products (0.85€/kg, while the other fruits range from 0.02€/kg (stone fruit) to 0.53€/kg (berries)). These higher costs are particularly driven by fine particulate matter emissions.

The NRD and the PHD costs of carbohydrate sources are quite similar (0.28€/cap/d and 0.27€/cap/d, respectively), with a difference of only 0.01€/cap/d, due to high recommendations of cereal intake in the NRD.

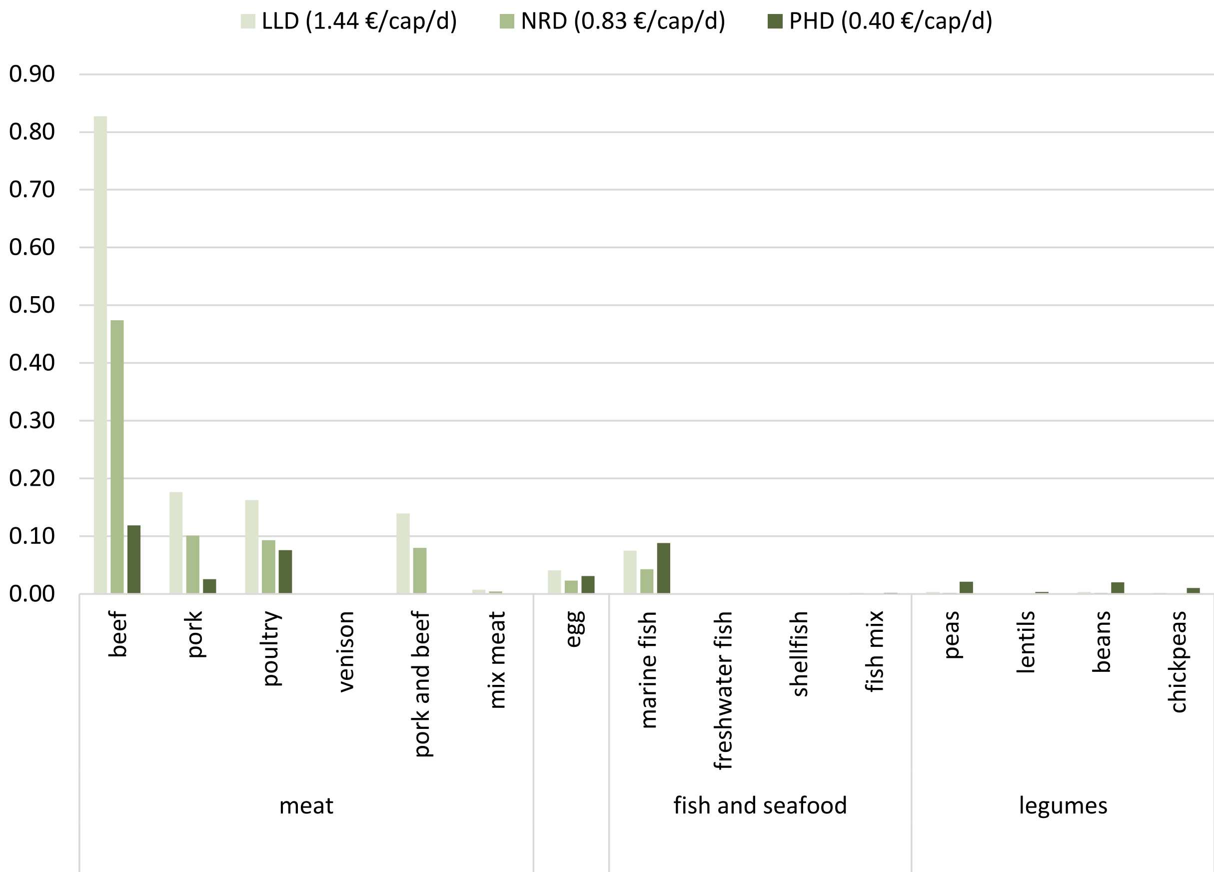

Figure 22: Environmental costs of the LLD, NRD and PHD for protein sources in Ireland per person per day.

For Ireland, protein sources are the largest cost drivers within the LLD and the NRD. Particularly **beef** consumption causes the highest environmental costs among all products in the Irish LLD with 0.83 per person per day, the highest environmental cost in the Irish NRD with 0.47€/cap/d. This contrasts with the PHD recommendation where beef consumption contributes only 0.12€/cap/d. Across all meat products, the Irish LLD generates 1.31€/cap/d of environmental costs, compared to 0.75€/cap/d in the NRD and only 0.22€/cap/d in the PHD. These high environmental costs for all meat categories are mainly due to the production of particulate matter from manure, as well as land use from animal feed intake. In the case of beef, the non-carcinogenic toxicity to humans is also a substantial cost contributor, again primarily from manure.

Contrary to Germany and France, beans consumed in Ireland are not associated with high costs for water consumption. This is due to the importing countries in which beans are produced and associated cost savings, especially in the environmental impact of water consumption.

Across all protein sources, the LLD causes 1.44€/cap/d in environmental costs (cf. Figure 22). A switch to the NRD would result in a 0.61€ cost reduction, whereas a switch to the PHD would reduce costs by 1.04€/cap/d. (cf. electronic Appendix 4).

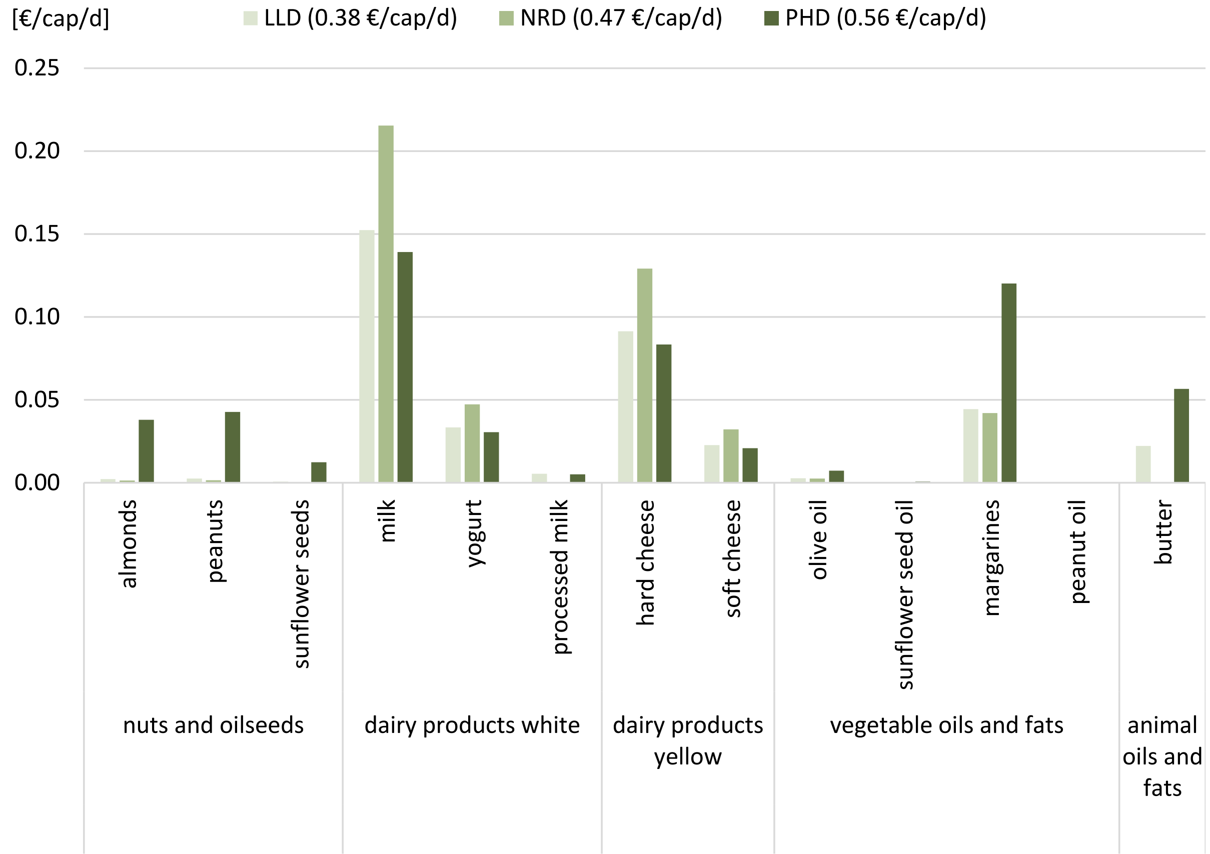

Figure 23: Environmental costs of the LLD, NRD and PHD for fat sources in Ireland per person per day.

Fat sources are the highest cost contributor in the PHD. Within this food group and across all diets, dairy products, particularly milk, are another high-cost driver. In the LLD, milk contributes 0.15€/cap/d in environmental costs, as seen in Figure 23. This cost is even higher in the NRD at 0.22€/cap/d whereas in the PHD milk accounts for 0.14€/cap/d. In Ireland, dairy consumption (LLD) is lower than the recommended intake for dairy under NRD, explaining the total cost difference of 0.12€/cap/d between the LLD and the NRD.

A cost driver for the PHD under fat sources (as in Germany) is **vegetable oils and** – and due to the distribution of consumption, particularly margarine, contributing a total of 0.13€/cap/d to the PHD.

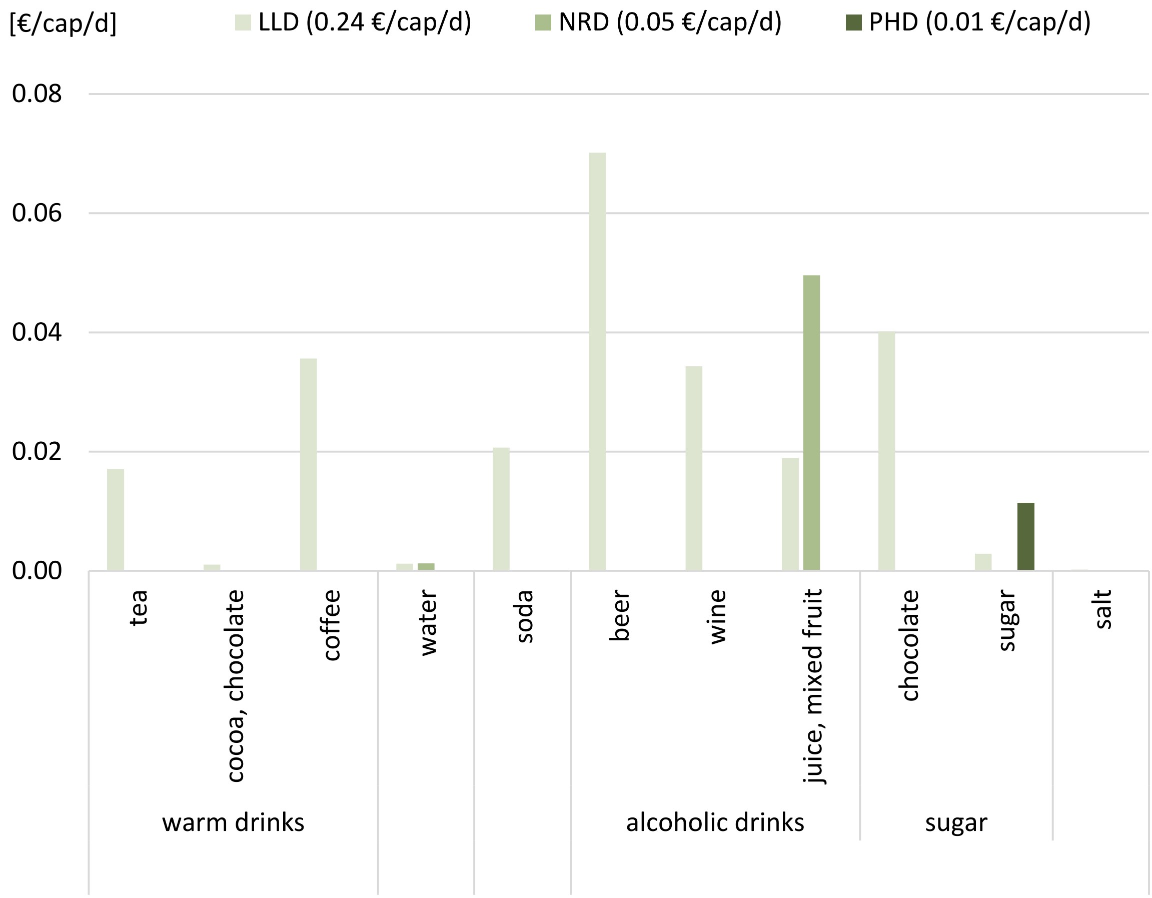

Figure 24: Environmental costs of the LLD, NRD and PHD for beverages and other products in Ireland per person per day.

Within the group of beverages and other products, beer is the largest contributor to the daily environmental costs of Ireland (cf. Figure 24). This is due to the relatively high consumption levels. At 0.07€/cap/d, it accounts for almost a third of all costs within this group.

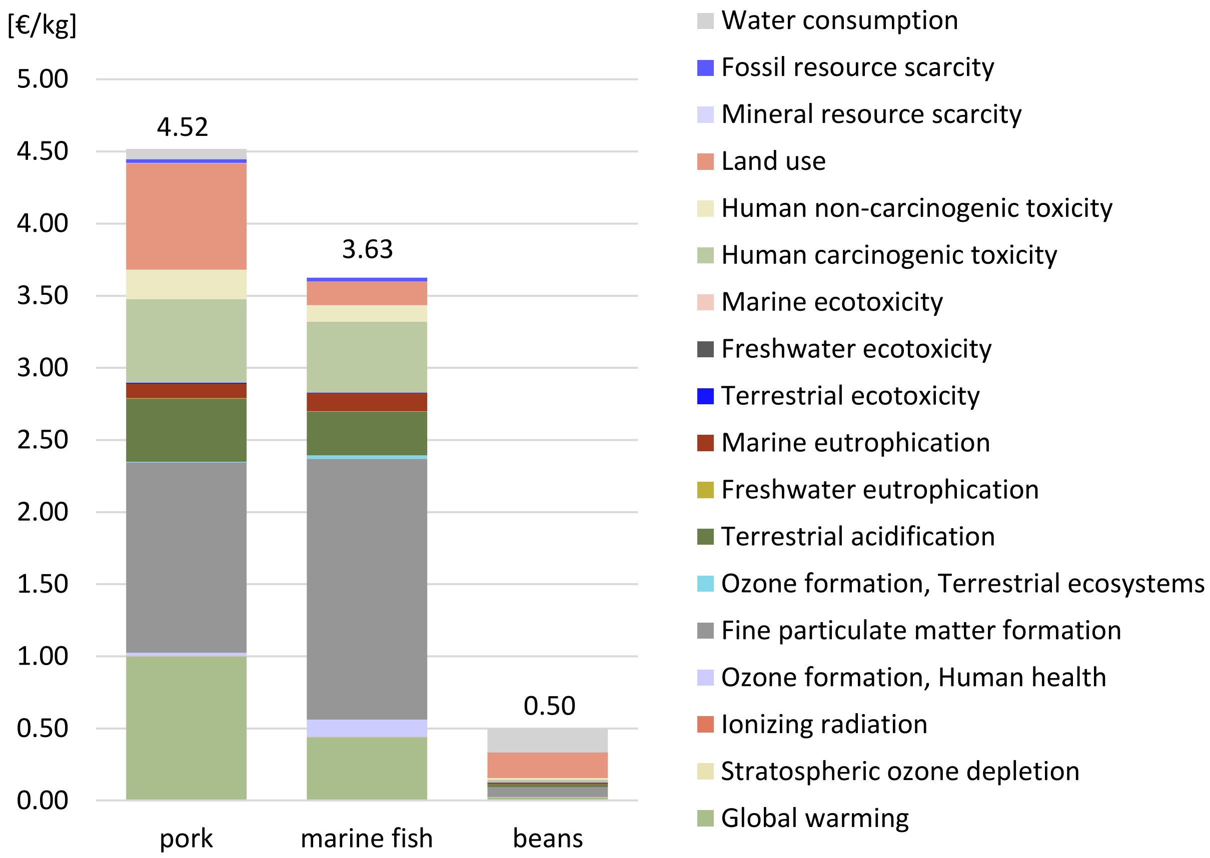

Figure 25: Environmental costs according to their underlying impact for pork, marine fish and beans per kg, as consumed in Ireland.

The example in Figure 25 shows how the environmental costs of different products vary substantially in their composition. Fine particulate matter formation is again very relevant for both animal-based products (1.32€/kg of pork and 1.81€/kg of marine fish), whereas the environmental costs of beans, in this case, consist mainly of costs for water consumption (0.16€/kg of beans) and for land use (0.18€/kg of beans).

Environmental impacts driving Irish environmental costs for all food products are primarily **global warming**, **fine particulate matter** and **land use**. The latter is mostly influenced by the yield within the countries of origin of a product in plant-based cases or the yield of feed for livestock in animal-based cases. Land use is the most relevant cost factor for the entire food categories of legumes, dairy products and vegetable oils as well as other food products scattered among the other categories. As can be seen in Figure 25, fine particulate matter is somewhat less relevant for the plant-based category of legumes, but otherwise always one of the highest cost contributors. The same applies to global warming, particularly relevant for dairy products.

Ireland generally has the highest importing quotas as it is an island relying somewhat more on other systems to achieve the same levels of diversity in food production. Nevertheless, this does not necessarily have a great influence on the total diet costs in Ireland, because environmental costs of food products depend more on the underlying production practice in the country of origin – be it the LL country or elsewhere – than on the distances and means of transport.

3.2.3 HEALTH IMPACTS AND COSTS

Table 20: Health costs of all three diets (LLD, NRD, PHD) in Ireland per person per day compared to baseline (NRD).	
Health costs	**Ireland [€/cap/d]**
LLD	7.80
NRD	-
PHD	-6.49

A) DIET COMPARISON

Health costs of Irish dietary patterns vary greatly between the PHD recommendations and the current consumption levels under the LLD. While the LLD causes costs of 7.80€/cap/d, the PHD yields benefits of 6.49€/cap/d (cf. Table 20).

In Ireland, the PHD incurs substantial health cost savings compared to the LLD and NRD, mainly due to a substantial decrease in meat consumption, also when compared to the Irish NRD. Meat intake is the most pronounced driver of health costs for the Irish LLD. Dairy intakes (both with low and high milk input) in the LLD and recommended intake in the PHD are rather close to recommended levels of the NRD, therefore showing no substantial cost deviations in this area.

B) HOTSPOTS

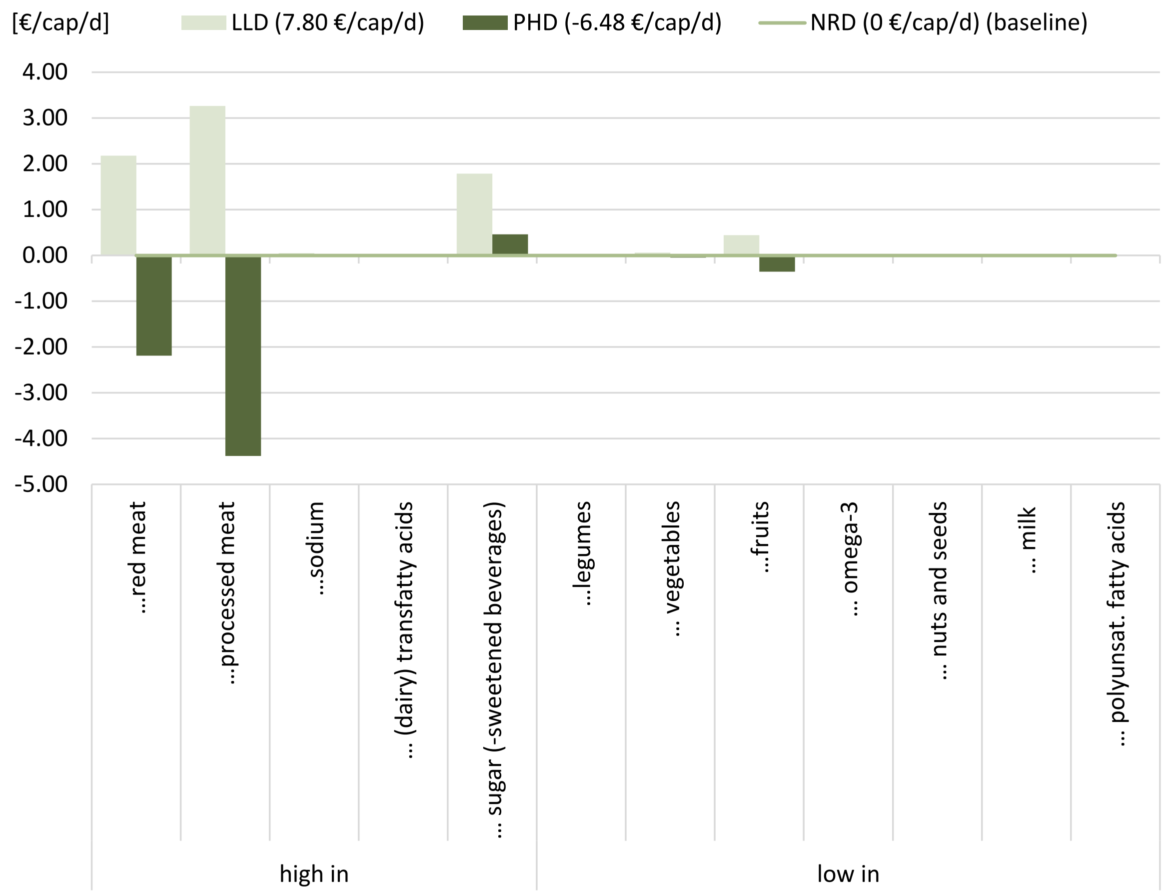

Figure 26: Health costs for LLD and PHD across all dietary risk factors in Ireland per person per day. NRD is the healthful benchmark diet and therefore depicted as the zero-line over all dietary risk factors.

In Ireland, **meat intake** (both red and processed) is the largest cost driver of all dietary risks (cf. Figure 26). The Irish NRD advises a meat intake of 56 g, which is the highest of the three LL countries, amounting to a total of 65 g of red meat and processed meat intake. Together with processed meat, the LLD exceeds this recommendation by almost 50 g per day and hence incurs costs of 5.44€/cap/d due to excessive meat intake.

Inadequate plant intake, i.e. too little fruit and vegetable consumption, adds 0.50€/cap/d to the health costs of the LLD, whereas exceeding the fruit and vegetable consumption benefits the PHD by 0.40€/cap/d. Due to methodological differences, the health costs of legumes and nuts and seeds could not be evaluated (cf. subsection 2.3.1), therefore their benefits are zero here. In both cases, the actual consumption levels (LLD) exceed the recommended levels (NRD), implying health benefits that could not be validated with the corresponding costs of illness for the associated dietary risks.

While salt consumption is not very pronounced in the LLD, excessive **sugar** consumption amounts to 1.79€ of health costs in Ireland. Again, this is primarily due to sweetened beverage consumption. As sugar is also recommended in moderate amounts in the PHD, it costs 0.46€/cap/d, slightly diminishing the remaining health benefits of the Irish PHD.

3.2.4 SOCIAL RISKS

Table 21: Social risks of all three diets (LLD, NRD, PHD) in Ireland per person per day.

Social risks	Ireland [mrheq/cap/d]
LLD	4.88
NRD	1.78
PHD	2.00

Overall, it is important to note that the primary factor contributing to product-specific social risks is the sourcing countries. As outlined in section 2.4, we evaluate the top five sourcing countries for each representative product. A detailed list of these countries is provided in electronic Appendix 3.

A) DIET COMPARISON

In Ireland, the social risk assessment indicates notable differences in the social risks between the LLD and the two recommended diets NRD and PHD (cf. Table 21). The social risks of the NRD and PHD are at the same level, with the NRD performing marginally better. Shifting from the LLD to the NRD or PHD would both be beneficial in reducing social risks:

- **LLD** has the highest social risk due to substantial contributions from tea and coffee.
- **NRD** has the lowest social risk, primarily driven by milk, beef and poultry.
- **PHD** has slightly higher social risk than the NRD, with the remaining risks primarily associated with margarine, milk, beans and nuts.

The LLD exhibits the highest total social risk, dominated by high-risk contributions from tea, coffee, meat (beef, poultry and pork) and milk. Specifically, tea contributes substantially to the social risk in Ireland with 2.69 mrheq/cap/d (55% of social risks). Coffee also presents a notable risk at 0.24 mrheq/cap/d (5% of social risks). These high-risk contributions underscore the importance of targeted interventions in these categories. Since there is no recommended intake of tea and coffee in the NRD and PHD, both recommended diets perform considerably better. Excluding tea and coffee, the LLD would account for 1.93 mrheq/cap/d and would therefore perform almost equally well as the NRD and PHD.

While the LLD includes higher risks due to higher amounts of meat intake in general and specifically beef and poultry, the NRD and PHD recommend a higher intake of beans and nuts, which bear comparatively high social risks.

Adopting the NRD in Ireland could lead to a substantial reduction in social risks. The remaining social risks are primarily caused by contributions of exotic fruits (0.24 mrheq/cap/d), milk (0.22 mrheq/cap/d), beef (0.21 mrheq/cap/d), poultry (0.16 mrheq/cap/d) vegetable oils and fats (and due to the consumption distribution particularly margarine, with 0.12 mrheq/cap/d) and rice (0.12 mrheq/cap/d). Although the NRD does not explicitly recommend the consumption of exotic fruits, the general recommendation of fruit intake is assumed to be distributed across all fruit types as shown by the LLD consumption data. Therefore, even within the NRD, there are substantial risks associated with the consumption of exotic fruits. While the NRD imposes similarly low risks as the PHD, there are still areas for improvement, particularly in reducing the reliance on high-risk foods such as milk and meat.

The PHD also shows a low level of social risk. The main contributors are margarine (0.34 mrheq/cap/d), exotic fruit (0.31 mrheq/cap/d), milk (0.14 mrheq/cap/d), peanuts (0.14 mrheq/cap/d), poultry (0.13 mrheq/cap/d), fruiting vegetables (0.12 mrheq/cap/d) and beans (0.12 mrheq/cap/d). Concerning exotic fruits, the same issue as described under NRD applies to the PHD.

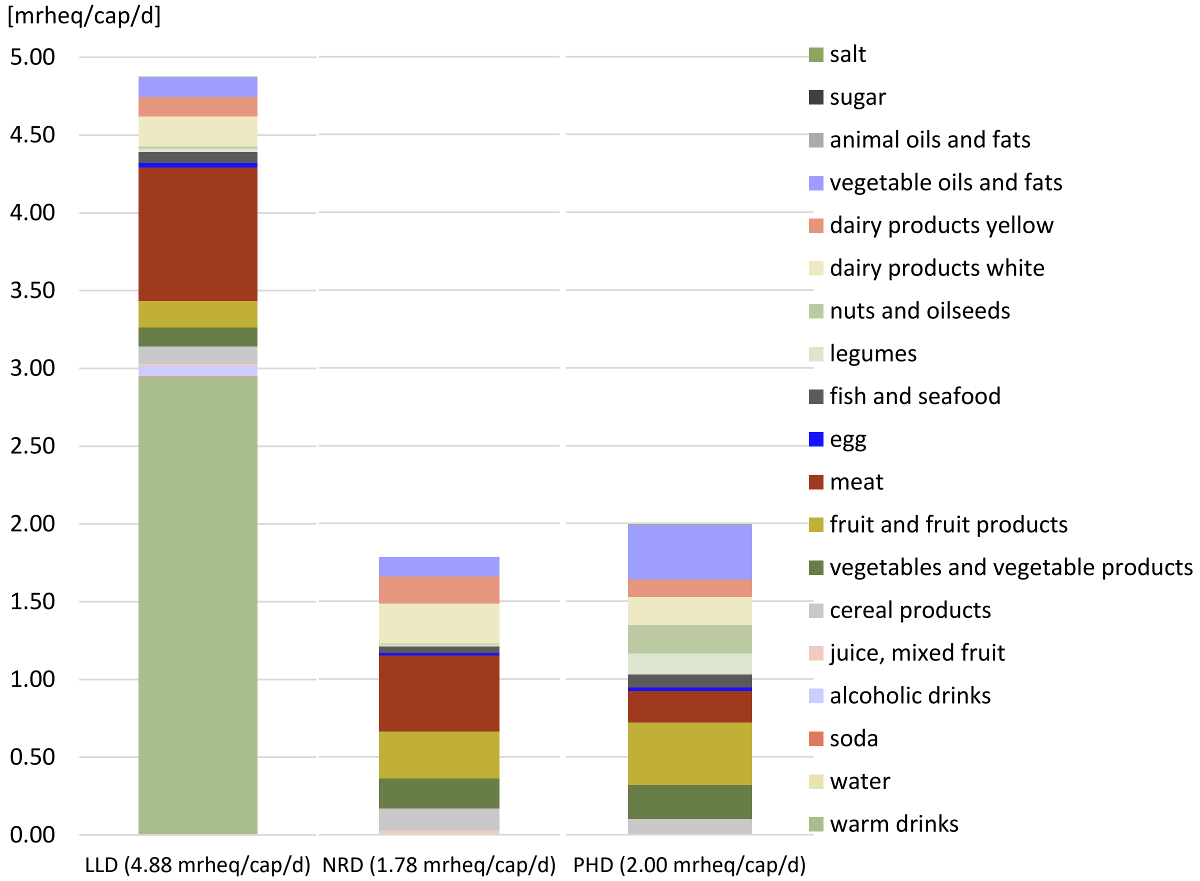

Figure 27: Contribution to social risks of LLD, NRD and PHD from product groups, Ireland.

Figure 27 shows the diets in comparison to one another with all product categories and their respective risk contribution to the diets. It becomes clear that different categories contribute in varying degrees to social risks. While the LLD has the highest social risk in Ireland, primarily due to tea and coffee, shifting towards the NRD and PHD can substantially mitigate these risks. The NRD presents the lowest risks, which could still be reduced by intervening in high-risk categories like milk, meat and margarine. Adopting the PHD also results in substantial social risk reductions, which could be even more reduced if the PHD further decreases margarine and dairy intake. In the following, we will describe and discuss hotspots within the diets in more detail.

B) HOTSPOTS

In the following, social risks for carbohydrate sources (Figure 28) protein sources (Figure 29) fat sources (Figure 30) and beverages and other products (Figure 31) are shown and described.

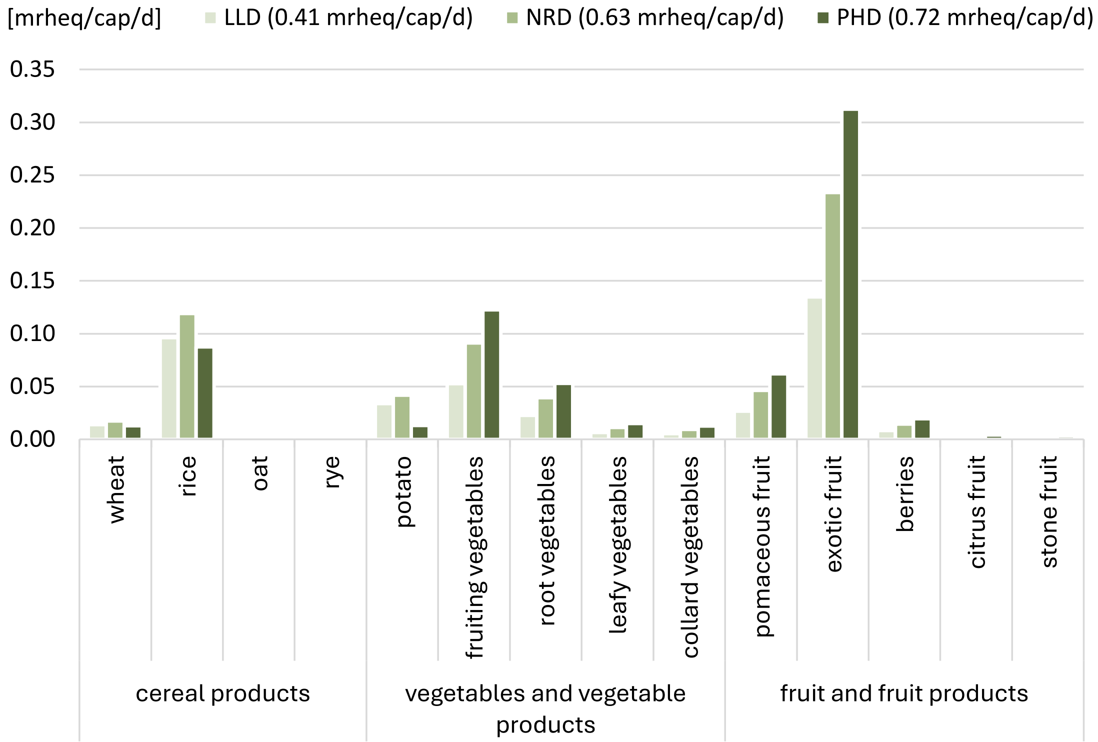

Figure 28: Social risks [medium risk hour equivalents, mrheq per day] of the LLD, NRD and PHD, carbohydrate sources, Ireland.

For **cereals,** rice entails the highest risk, amplified by imports from Cambodia, where Labour Rights and Human Rights issues persist, as well as high contributions within Governance and Community Infrastructure. Despite the low proportion of rice imported into Ireland from Cambodia, the high-risk contributions impact the overall social risk. Best performing cereals are oats and rye, with very low-risk contributions among all three diets. Exotic fruits contribute most to the risk profile of **vegetables and fruits**. Imports from Cote d'Ivoire and Cameroon in particular increase the risk of violations of Labour Rights, Human Rights and Community Infrastructure. Fruiting vegetables and pomaceous fruits also contribute to the social risks, with the highest risk coming from fruiting vegetables sourced from the Netherlands. The social risks, especially concerning Labour Rights as well as Health and Safety, are most pronounced in the Netherlands and the UK.

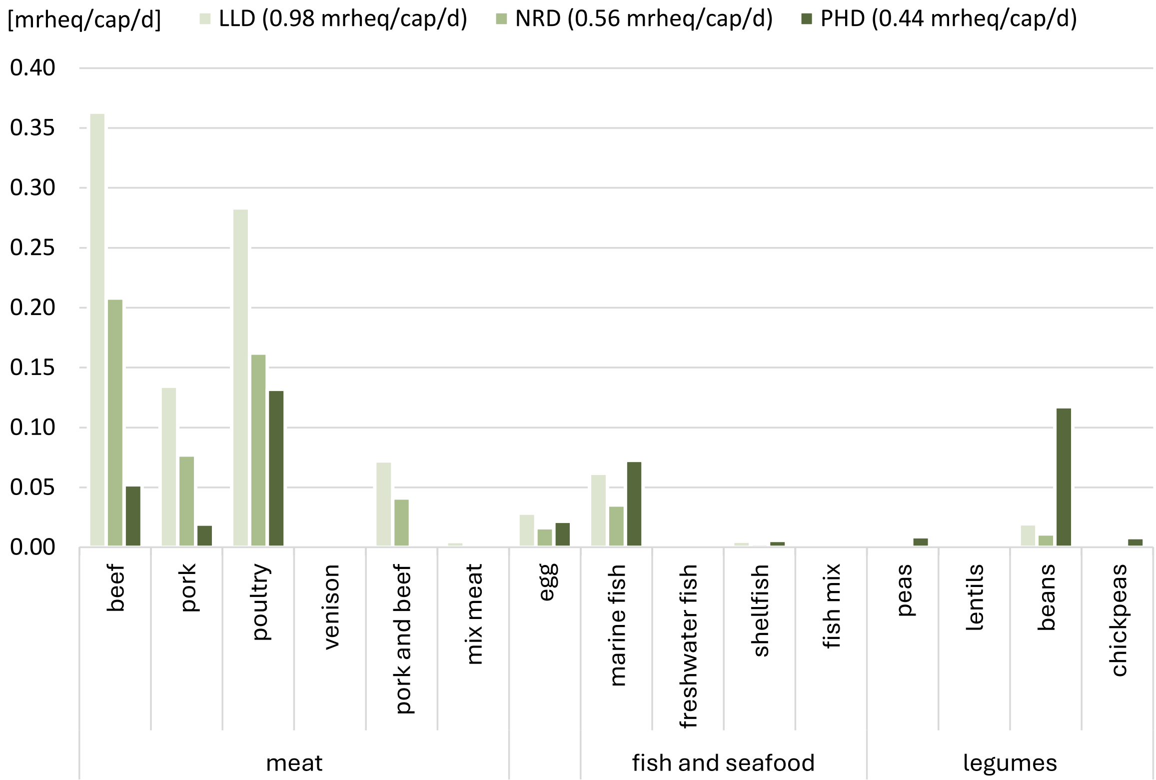

Figure 29. Social risks [medium risk hour equivalents, mrheq per day] of the LLD, NRD and PHD, protein sources, Ireland.

Among **meat**, beef and poultry entail the highest risks at current Irish consumption levels, which could be gradually reduced by a transition to the NRD or PHD. Most beef (96%) is sourced nationally, however, Belgium, the UK and the Netherlands present elevated social risk per kg, with the UK, in particular, contributing to the total risk-weighted by production shares. There is no social risk subcategory with a particularly high contribution, but risks are accumulated quite evenly across all subcategories. Regarding **fish and seafood,** marine fish comes with the highest social risk, which, however, is at a relatively low level. Among **legumes,** beans are often critical concerning the social risk under PHD's (e.g. Germany, France). In contrast, the risk for their consumption remains moderate in Ireland, while it is noteworthy that the social risk regarding beans rises by a factor of five when transitioning from the current LLD to the PHD. Further, Ethiopia entails a very high social risk per kg of beans due to Labour and Human Rights as well as Community Infrastructure. As a result, despite its relatively low production share, Ethiopia by far accounts for the largest contribution to the social risk of beans weighted by production share for Ireland.

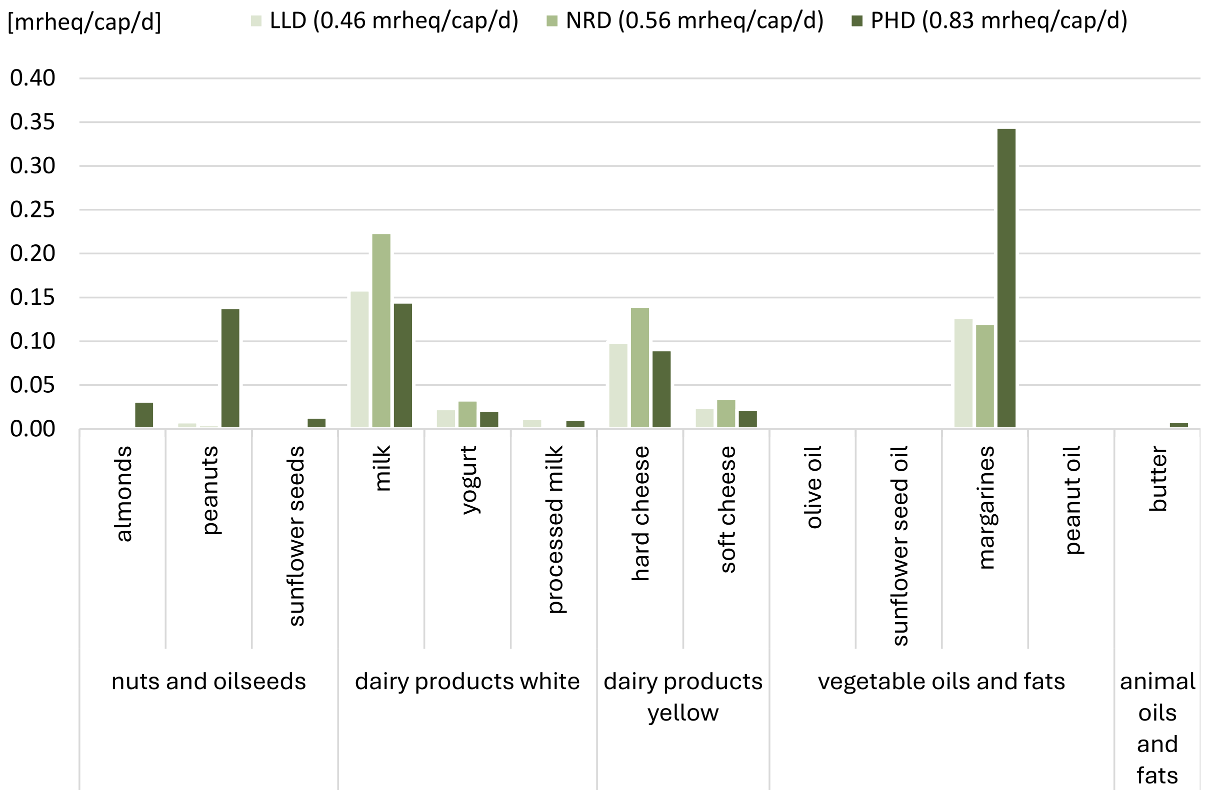

Figure 30. Environmental costs of the LLD, NRD and PHD for fat sources, Ireland.

The social risk related to **nuts and oilseeds** plays a minor role in Ireland for the LLD but considerably increases for the PHD. Specifically, peanuts from Nicaragua come with an elevated risk due to Labour Rights and Governance issues, the latter being mainly caused by Corruption, the Legal System and social issues related to Democracy & Freedom of Speech. Imports of peanuts from Brazil and the USA have a low social risk per kg. Milk and hard cheese carry the highest social risk among **dairy products,** in both cases mainly due to contributions to Labour Rights, Community Infrastructure and Human Rights. For milk, the predominant total risk contributor is the UK due to high risks within the categories of Labour Rights and Health & Safety, despite the high national sourcing percentage of Ireland. The NRD shows the highest risk contributions due to the highest recommended intake of these products. Across **oils and fats,** animal oils and fats are of minor importance, whereas the social risk of vegetable oils and fats, especially margarine, becomes increasingly relevant for the PHD. This is due to the high recommended intake of vegetable oils and fats in all countries, including Ireland.

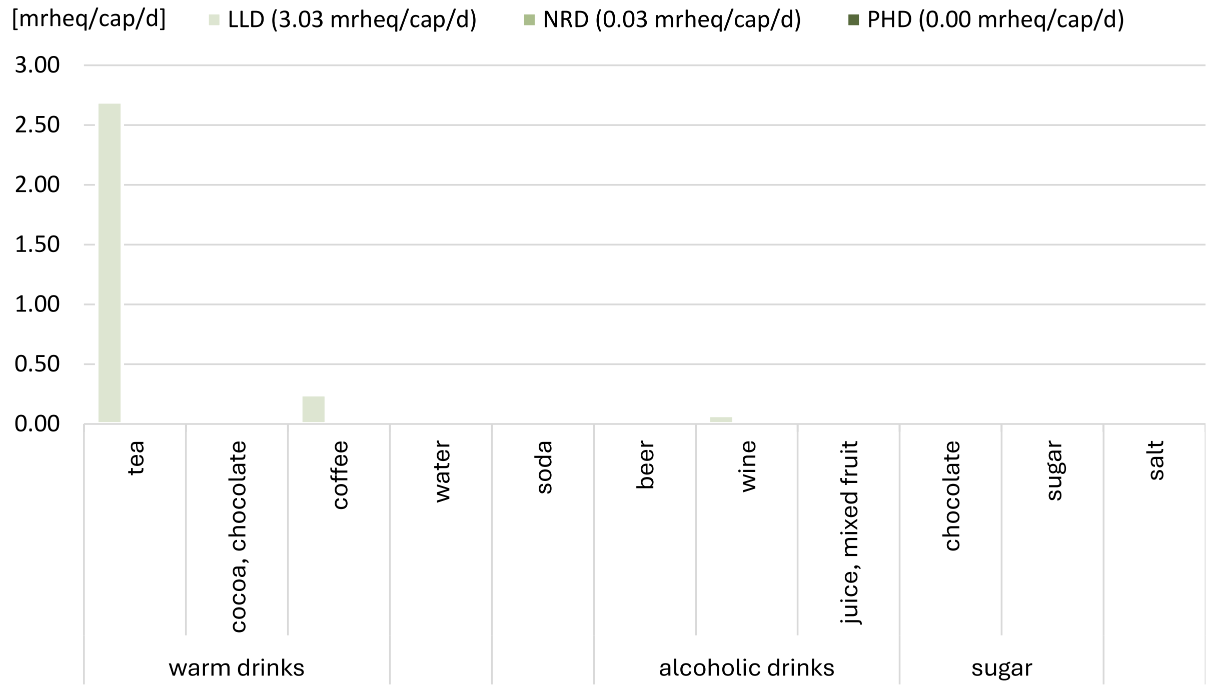

Figure 31: Social risks [medium risk hour equivalents, mrheq per day] of the LLD, NRD and PHD, beverages and other products, Ireland.

Tea has a very high social risk, which is mainly due to tea imports from Kenya and Malawi, where contributions within Labour Rights as well as equally high-risk scores for all other subcategories drive up the social risk per kg of tea. In Ireland, Kenya is particularly noteworthy, as it drives the risk-weighted by production share, due to its high production share (50%) combined with a high risk per kg of tea. Sri Lanka is an option for tea imports with lower social risk. Concerning coffee imports from Ethiopia, Labour and Human Rights as well as Community Infrastructure are equally leading to a very high social risk. Better alternatives in terms of social risk assessment are Brazil and Colombia. The analysis only covers the LLD, as neither the NRD nor the PHD of Ireland recommends tea or coffee consumption.

3.2.5 POTENTIAL FOR IRISH DIETARY TRANSITION (HOTSPOTS)

The Irish **LLD** has the highest environmental costs among the three diets. The main contributors are high meat consumption, especially beef and high dairy consumption. Beef is the largest environmental cost driver, contributing substantially to global warming and land use impacts. Likewise, the main drivers of the health costs in the Irish LLD are the intake of red and processed meats, followed by sugar and sugary beverages. The LLD also has the highest social risk over the three Irish diets, with key contributors of tea, coffee and, yet again, meat products.

The **NRD** reduces environmental costs in Ireland, primarily due to lower recommended meat and dairy intake. However, beef and dairy intake remains a large cost contributor, with dairy costs even exceeding those of the LLD. While the health benefits compared to the LLD remain notable, the NRD should focus even more on plant-based intakes to provide more health cost savings with increased vegetable and legume intake (as seen in the PHD) and even lower meat and dairy consumption. The latter is likewise a factor for the social risks of the NRD. Despite reduced meat consumption in the NRD, products like milk, beef and poultry still pose notable social risks.

The Irish **PHD** achieves the lowest environmental costs, due to its environmental focus. The main factors are lower consumption of meat and dairy. This also is the primary factor for the health benefits of the Irish PHD, mainly driven by reduced meat consumption. The PHD shows similarly low social risk as the NRD, however, the main contributors here are vegetable oils and fats, milk, beans and nuts. While these items carry social risks due to current importing patterns, they are generally lower than those associated with the LLD and could further be reduced by sourcing socially certified produce.

Across the three Irish diets (LLD, NRD, PHD) and the three impact areas (environmental, social, health), the following foods consistently emerge as hotspots with negative impacts across all areas:

Meat, especially beef, is a substantial contributor to environmental costs, particularly for the LLD and NRD. Environmental cost contributions include greenhouse gas emissions from enteric fermentation, land use for feed production and grazing and water consumption. Red and processed meat consumption is likewise linked to adverse health costs, due to risks of cardiovascular diseases and cancer, influencing both health costs of the LLD and even the PHD compared to the NRD. The production of meat, especially beef and poultry in the Irish case, is again associated with social risks, including poor labour conditions and other social equity issues along the supply chains.

Dairy products contribute substantially to Ireland's environmental impacts in both the LLD and NRD, but to some extent, also in the PHD. While dairy can be part of a balanced diet, excessive consumption, especially of high-fat dairy products, is linked to negative health costs due to risks of cardiovascular health. The dairy industry is associated with social risks similar to those in the meat industry.

Although not as impactful as meat and dairy, the consumption of **beverages like tea, coffee and sugary beverages**, are also linked with environmental and health costs, as well as social risks. Health costs are incurred with Irish consumption of sugary beverages and would likely be for tea and coffee if they could be assessed using the methodology presented/applied here. Social impacts associated with global supply chains are also notable, in the Irish case particularly those of tea.

3.2.6 COMPARISON BETWEEN THREE IMPACT AREAS (ENVIRONMENTAL, HEALTH, SOCIAL)

Some foods, such as certain plant-based foods (e.g. nuts and legumes), may have moderate social risks and environmental costs but be highly beneficial from a health perspective, as seen especially in the Irish PHD diet. This shows a divergence where what is environmentally or socially challenging might still offer health benefits.

Conversely, sugary beverages have a pronounced health impact yet a lower environmental impact, indicating that even if a dietary shift away from sugary beverages would not necessarily lead to better environmental performance, the health benefits could still be large.

Similarly, beverages like tea have higher social risks without substantially contributing to environmental or health costs. This highlights how social impacts can sometimes be isolated to specific foods and beverages or industries, rather than being a cross-cutting issue.

Overall, the environmental and health costs associated with meat and dairy are the most pronounced and intertwined. In Ireland, the social risks associated with the production of, especially beef and poultry align with high health and environmental costs and underscore beef as a primary target.

As in Germany, the health costs per day are higher compared to the environmental costs. Nevertheless, environmental damage should not be underestimated due to the broader ecosystem effects, some of which cannot be fully monetized. Furthermore, synergies between health, social and environmental concerns (particularly for beef and dairy consumption) will yield benefits in all impact categories if addressed through recommendations and consumption.

3.2.7 AFFORDABILITY OF THE IRISH DIETARY PATTERNS

Results of the cost assessment

Table 22: Daily costs of the three diets for Ireland.

Country	LLD [2021 PPP €/cap/d]	NRD [2021 PPP €/cap/d]	PHD [2021 PPP €/cap/d]
Ireland	1.34	1.64	1.66

The Irish dietary cost analysis indicates that the LLD is the cheapest of the three diets at 1.34 PPP €/person/day, with the NRD and PHD costing 1.64 PPP €/person/day and 1.66 PPP €/person/day, respectively (Table 22).

The small difference between the NRD and PHD costs in Ireland suggests that transitioning to a more sustainable diet may not require substantial additional financial resources, making both the NRD and PHD a feasible option for promoting both health and sustainability.

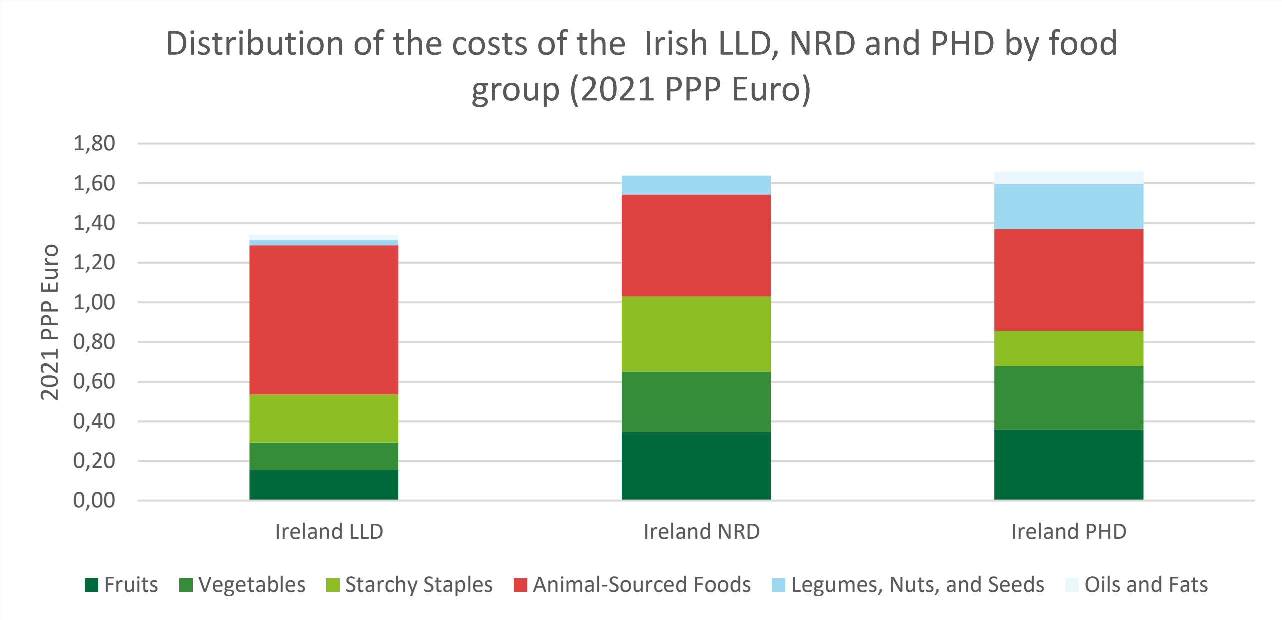

Figure 32: Relative distribution of the costs across the different food groups for the three Irish diets

As presented in Figure 32 the Irish LLD shows a strong emphasis on animal-sourced foods, with a cost of 0.75€ representing over half of the diet's total costs. Starchy staples and fruits account for a substantial portion of the costs as well, 18.1% and 11.6% respectively.

In the Irish NRD, there is a noticeable decrease down to 0.51€ (31.4% of the total cost) in the expenditure on animal-sourced foods compared to the LLD, reflecting a shift towards a more balanced diet with reduced reliance on animal products. In the NRD the costs associated with fruits and vegetables are substantially higher than in the LLD, now constituting a substantial portion of the diet cost (almost 40%).

The PHD further reduces the expenditure on animal-sourced foods to 30.8% of total costs, aligning with its plant-based focus. The expenditure on legumes, nuts and seeds is notably higher in the PHD compared to both the LLD and NRD, reflecting the diet's increased focus on plant-based protein sources.

Transitioning from the LLD to a more sustainable and healthier NRD and PHD increases the expenditure on plant-based foods (fruits, vegetables, legumes, nuts and seeds) while reducing the cost associated with animal-sourced foods. This shift reflects both higher nutritional quality and environmental sustainability of the diets.

Affordability assessment

Table 23 presents Ireland's daily and annual median equivalised net income per adult with dependent children.

Table 23: Daily and annual net income for a single person with dependent children in Ireland.

Country	Median equivalised net income [€/cap/d]	Median equivalised net income [€/cap /year]
Ireland	56.54	20,638

Ireland shows the highest median income among the three countries at 56.54€/d. The LLD, NRD and PHD costs are 1.34€, 1.64€ and 1.66€, respectively. These costs account for just 2.4%, 2.9% and 2.9% of the daily income, falling far below the 20-30% threshold and making all three diets very affordable.

The affordability in Ireland is notable, with even the most expensive diet (PHD) costing less than 3% of daily income. The annual disposable income for the first decile of the Irish population in 2021 was 16,013€ or 43.87€/d. All three diets remain affordable for households in the first decile of the population, with the highest percentage of income spent being PHD with 3.8%.

3.3 France

Third, we present results for the LL country France.

3.3.1 CONSUMED AMOUNTS OF LLD AND RECOMMENDED AMOUNTS OF NRD AND PHD

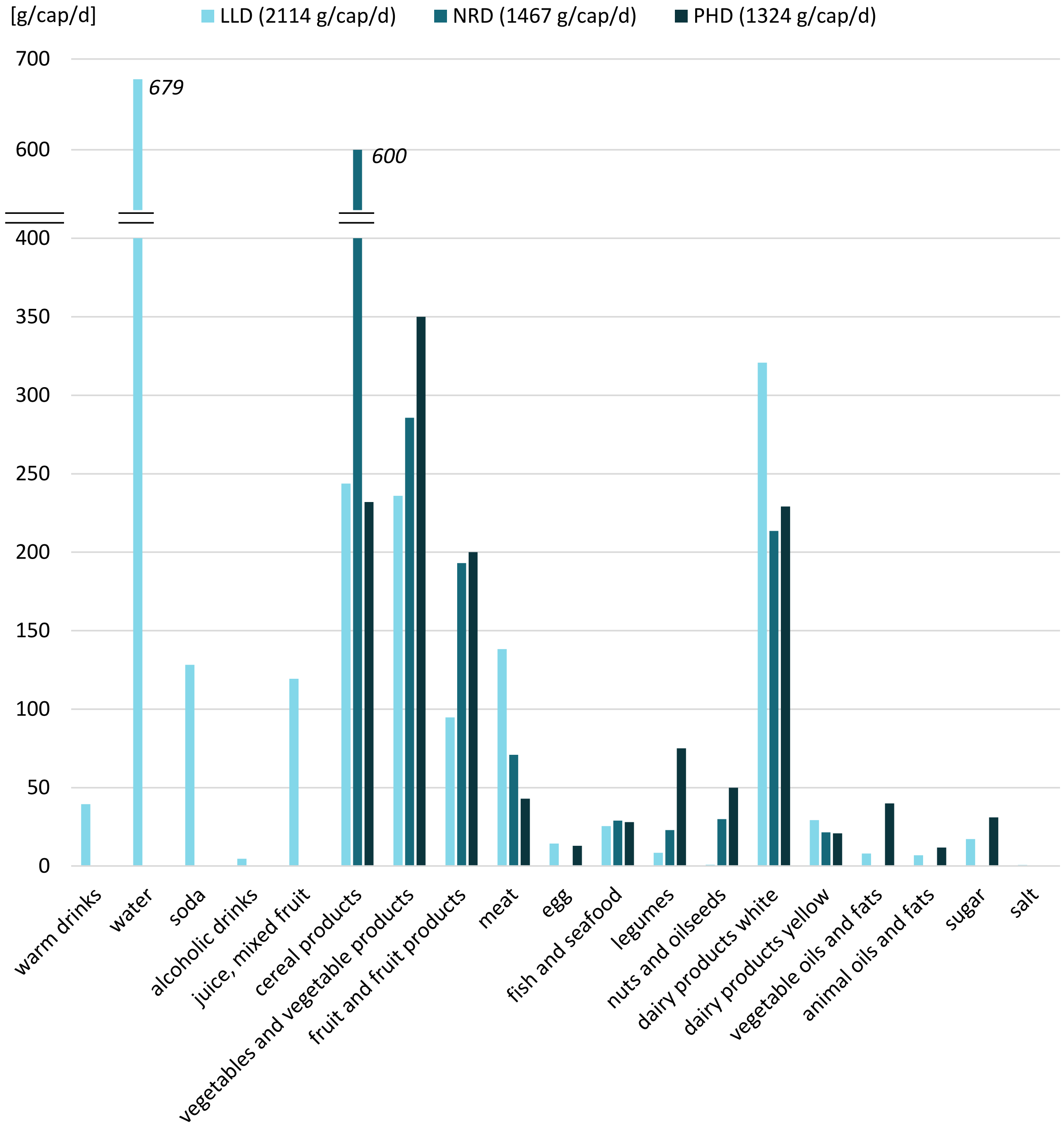

Figure 33: Composition of consumption values (LLD) and recommended intake (NRD, PHD) in France per person per day. Some food categories are not recommended within the NRD or PHD and columns therefore missing (e.g. warm drinks).

Table 24: Composition of consumption values (LLD) and recommended intake* (NRD, PHD) in France. Table cells are grey when there are no values recommended for these respective products.

Category	#	Product**	LLD [g/cap/d]	NRD[g/cap/d]	PHD[g/cap/d]
Beverages	1.1	Warm drinks	40		
	1.2	Water	678		
	1.3	Sugary drinks	128		
	1.4	Alcoholic drinks	5		
	1.5	Fruit juices	119		
Carbohydrate sources	2.1	Cereal products	244	431	232
	2.2	Starchy vegetables	96	[27]169	50
	2.3	Other vegetables	140	286	300
	2.4	Fruit and fruit products	95	193	200
Protein sources	3.1	Beef	47	22	2
	3.2	Pork	32	15	12
	3.3	Poultry	44	21	29
	3.4	Meat, other***	14	7	
	3.5	Eggs	14	[28]7	13
	3.6	Fish and seafood	25	29	28
	3.7	Legumes	9	23	75
Fat sources	4.1	Nuts and oilseeds	1	30	50
	4.2	Dairy products white	321	214	219
	4.3	Dairy products yellow	29	22	31
	4.4	Vegetable oils and fats	8		40
	4.5	Animal oils and fats	7		11.8
Rest	5.1	Sweets	17		31
	5.2	Salt	1		

* Numbers are represented as in the original recommendations.

** Further definitions of product categories are provided in Appendix 1.1, Table 30.

*** 'Meat, other' encompasses venison, beef and pork and mixed meat, more detailed consumption data is provided in the digital Appendix 2.

France's consumption patterns also show notable differences from the recommended diets, especially in the consumption of meat products. The intake of beef, pork and poultry is much higher than the recommended amounts under both NRD and PHD.

[27] In the French National Dietary Recommendation, potatoes and cereals are subsumed under the same group as 'starchy foods'. 3 serving sizes per day at 200 g are recommended, which brings the total amount between cereal products and starchy vegetables to 600 g per day. We allocated according to the actual consumption levels (cf. 2.1.2)

[28] In the French national dietary recommendation, eggs are included under the meat category. In total, 500 g per week are recommended, which we allocated according to the consumption levels (cf. 2.1.2)

It needs to be noted that the share of beef consumption might be underestimated in the NRD and PHD, as substantial amounts of beef can be assumed to fall under the 'other meat' category and are therefore not accounted for based on the division of meat types by current consumption patterns. Additionally, the consumption of sugary drinks and fruit juices is much higher than what is suggested in the recommendations. Further, white dairy consumption is particularly high compared to the recommendations. Contrary to this higher intake, the consumption of vegetables, fruits, legumes and nuts under LLD is substantially lower than both NRD and PHD recommended levels.

Warm drinks and alcoholic beverages are consumed at low levels (resulting from the LLs age group of adolescence), which aligns more closely with NRD and PHD, indicating a smaller area of concern in these categories. Similarly, the intake of fish and seafood in the current diet is relatively close to both recommendations, though still slightly lower.

The intake of cereal products (disregarding the distinction between whole grain and refined grain) and starchy vegetables in the LLD, as well as the nationally recommended amount under NRD, is substantially higher than the PHD recommendation. Another point of comparison between PHD and NRD is in the reduction of meat intake. The PHD advocates for much lower consumption of meat products than consumed and recommended levels in France, which could lead to reduced environmental costs and improved health outcomes compared to the current LLD and potentially NRD as well.

3.3.2 ENVIRONMENTAL IMPACTS AND COSTS

Table 25: Environmental costs of all three diets (LLD, NRD, PHD) per person per day in France.

Environmental costs	France [€/cap/d]
LLD	2.02
NRD	1.35
PHD	1.35

A) DIET COMPARISON

Similar to Germany, despite the PHD being designed to enhance environmental sustainability, the NRD achieves the same environmental costs compared to PHD, primarily due to the PHD's recommendation of more nuts (0.06€/cap/d more compared to NRD) and vegetable oil consumption (0.16€/cap/d more compared to NRD). Contrary to that, NRD recommends higher amounts of meat, particularly beef (0.29€/cap/d more compared to PHD).

By transitioning from the LLD to the NRD and PHD, there is a potential reduction of 0.67€/cap/d in environmental costs in France. This means potential environmental cost savings per person per year of 243.85€ by transitioning to either of the recommended diets. For the country of France, this would result in total environmental cost savings of over 16.57 billion Euros per year over the whole population.

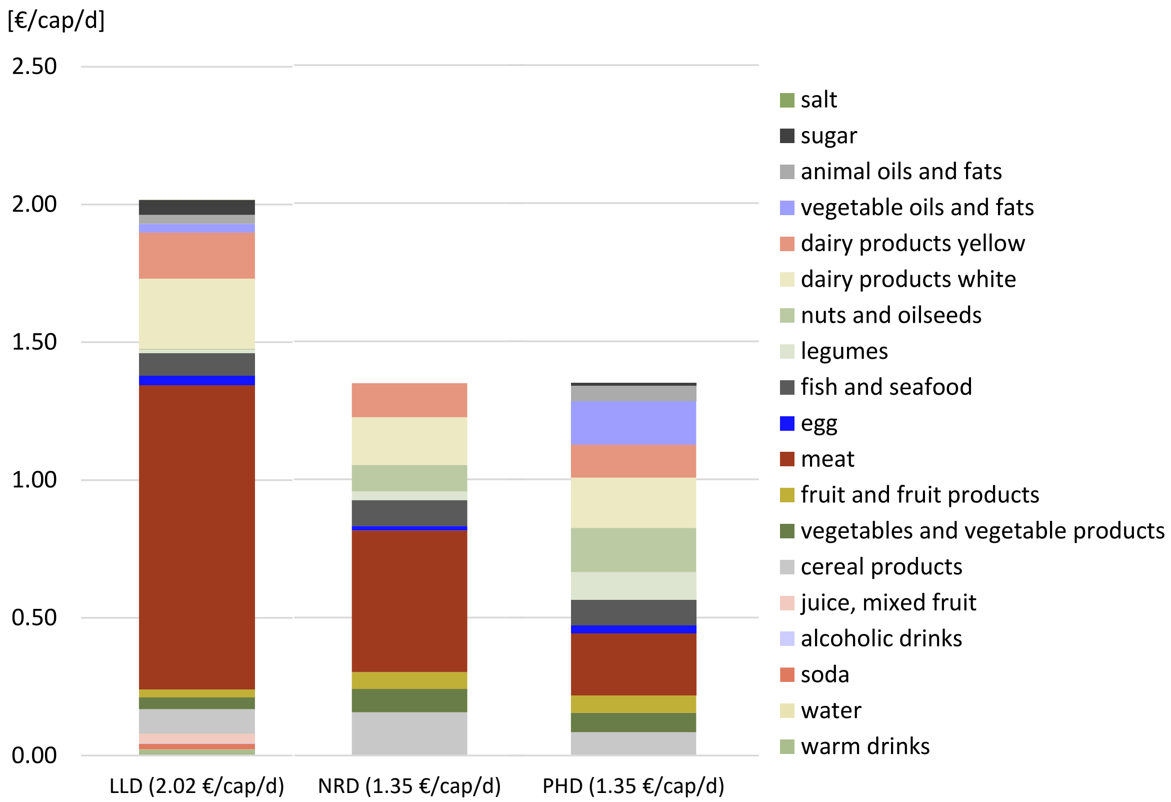

Figure 34: Contribution to environmental costs of LLD, NRD and PHD from product categories in France.

Figure 34 shows the diets in comparison to one another with all product categories and their respective cost contribution to the diets. Whilst in the LLD meat consumption by far exceeds costs of all other products with 1.22€/cap/d (61% of the total environmental LLD costs per person per day) and similar tendencies are observed in the NRD (0.62€/cap/d, 46% of the total environmental NRD costs per person per day), the PHD displays a more balanced distribution over all products.

In the following, we describe and discuss hotspots within the diets in more detail.

A) HOTSPOTS

In the following, environmental costs for carbohydrate sources (Figure 35), protein sources (Figure 36), fat sources (Figure 37), beverages and other products (Figure 38) are presented and discussed in successive graphs.

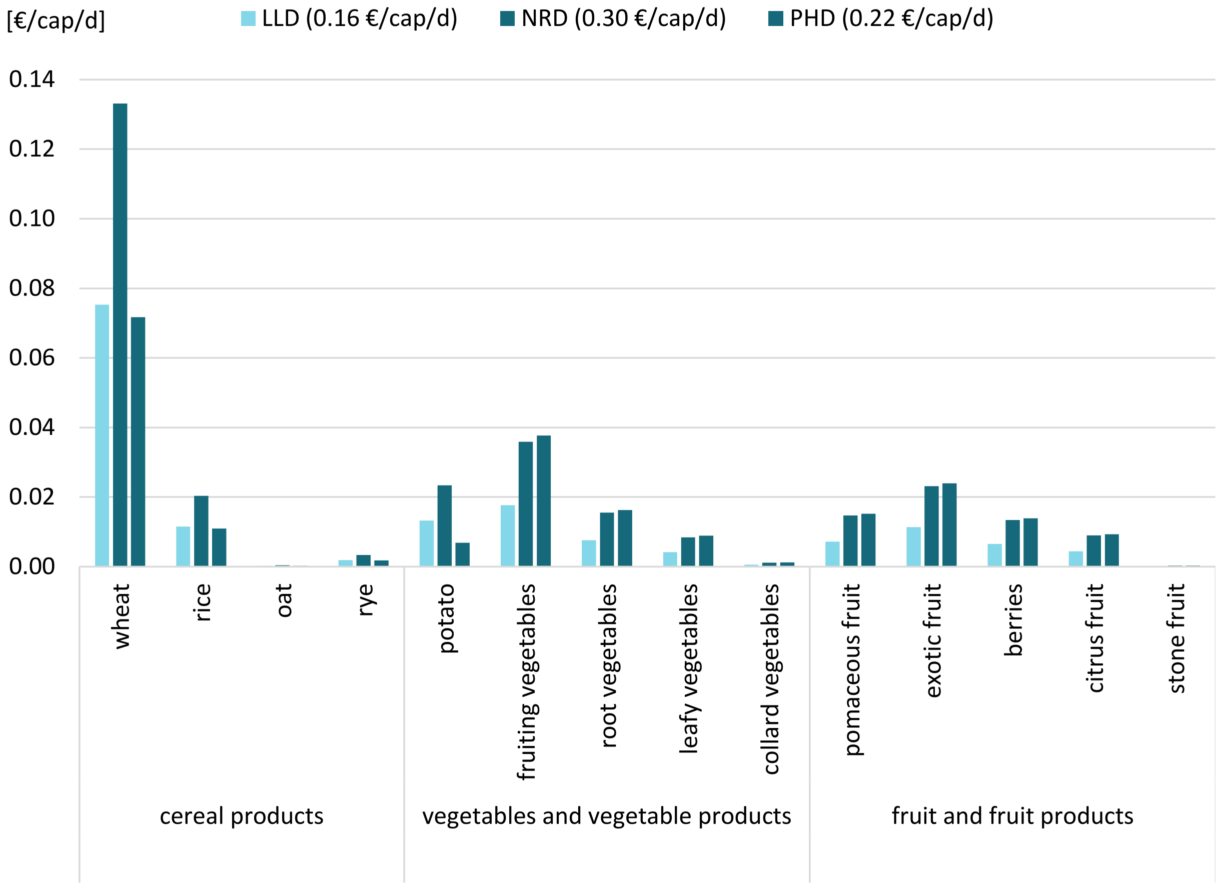

Figure 35: Environmental costs of the LLD, NRD and PHD for carbohydrate sources in France per person per day. Values close to zero can be either, because there are no recommended values within the NRD or PHD, or because the consumption levels are so small that their environmental costs are not evident from this figure.

Similar to the other two LL countries, within the food group of carbohydrate sources the highest cost contribution stems from wheat (or wheat products generally), contributing up to 0.13€/cap/d to the NRD, 0.08€ to the LLD and 0.07€/cap/d to the French PHD (cf. Figure 35). This is due to the consumption or recommendation levels of intake per day rather than the environmental costs caused by wheat (0.33€/kg), with wheat being the most cost-efficient cereal product consumed in France (the rest of cereal costs vary between 0.56€/kg for oat and 0.82€/kg for rice). The primary driver of environmental costs for wheat is land use (0.14€/kg wheat), which is greatly influenced by the yield of wheat in the countries of origin. This is also the case for oat (0.27€/kg) and rye (0.28€/kg); for rice, however, fine particulate matter is the primary cost driver (0.33€/kg), which stems from the burning of rice straw as well as nitrous oxide emission due to intermittent field flooding for rice production.

As fruiting vegetables are the most consumed vegetable products and are likely to be grown partly in a greenhouse (e.g. tomatoes, cucumber, bell pepper), comparing crops grown partially under greenhouses is worth mentioning. The type of greenhouse and its infrastructure greatly influences the environmental costs. For instance, in French tomato production, tomatoes grown in open fields have an external environmental cost of 0.04€/kg. This cost increases fivefold to 0.20€/kg for tomatoes grown in non-heated greenhouses and it increases further to 0.65€/kg in heated greenhouses. The largest share of the costs in heated greenhouses is from gas for heating the greenhouse and the infrastructure's (greenhouse, machinery to operate it) material, like steel and aluminium. Thus, the greater the reliance on greenhouse production for tomatoes (and other products partially grown in a greenhouse, like berries or leafy vegetables), the higher the associated environmental costs.

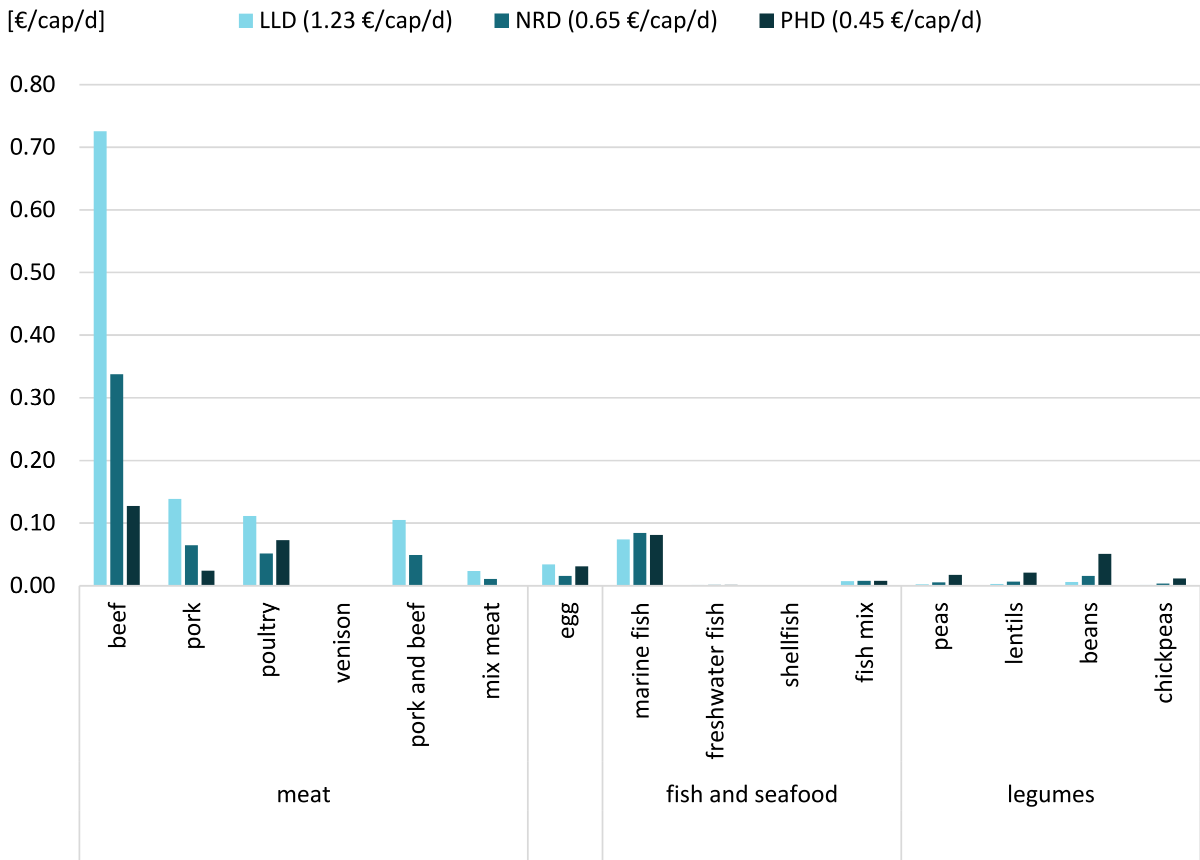

Figure 36: Environmental costs of the LLD, NRD and PHD for protein sources in France.

Protein sources are the largest cost contributor in the LLD and NRD and the second largest, after fat sources, in the PHD. Among all food products, meat substantially drives up costs in the French LLD, with beef bearing the highest environmental costs, adding up to 0.73€/cap/d (cf. Figure 36). A shift toward the recommended NRD or PHD could reduce these environmental costs for the French diet, especially in terms of meat consumption. The French LLD incurs 1.10€/cap/d in environmental costs from meat, while the NRD and PHD incur 0.51€/cap/d and 0.22€/cap/d, respectively. These high environmental costs across all meat categories are primarily due to the production of fine particulate matter from animal manure and the extensive land use required for animal feed.

Plant-based protein sources (here: legumes) do not contribute large cost additions to the overall diets.

Shifting from a predominantly animal-based protein intake (1.23€/cap/d under LLD) towards a lower meat consumption would save 0.59€/cap/d or 0.78€/cap/d with NRD and PHD recommendations, respectively.

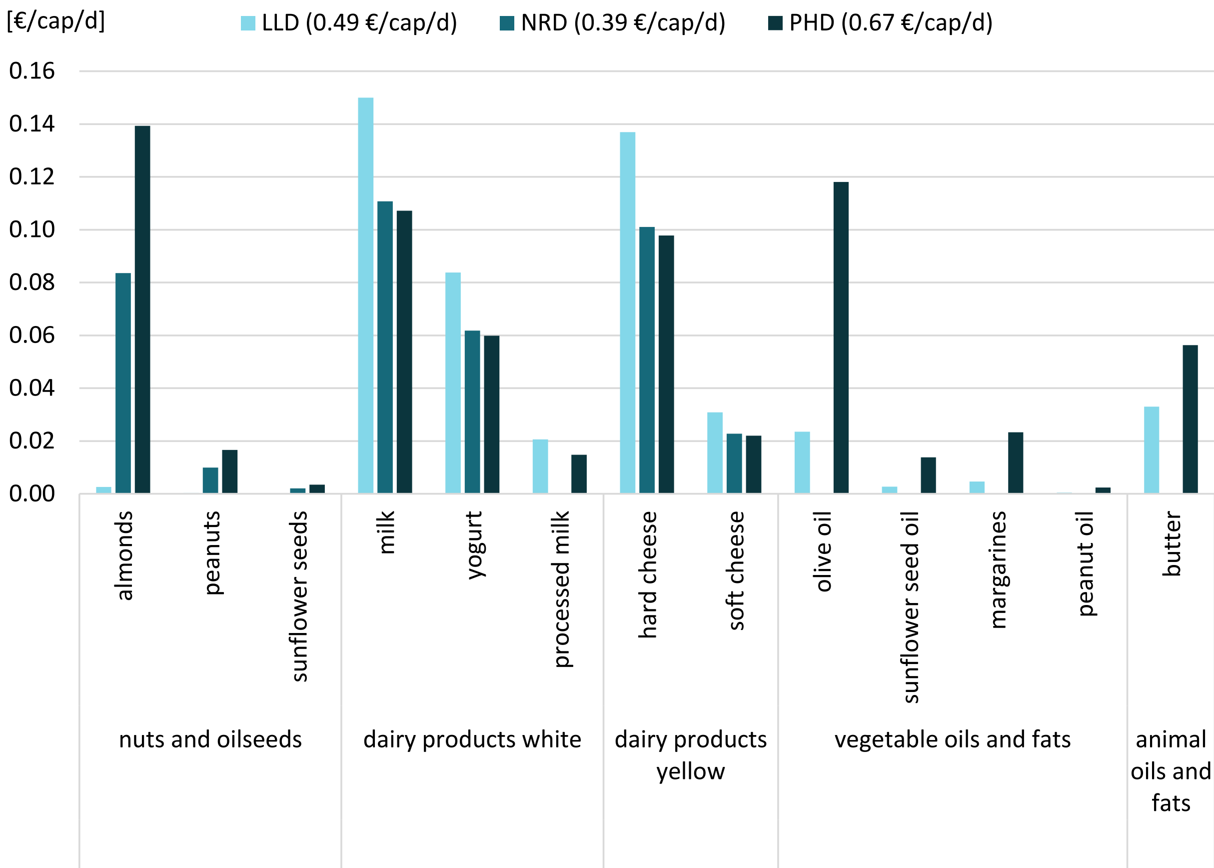

Figure 37: Environmental costs of the LLD, NRD and PHD for fat sources in France.

Fat sources are the highest cost contributor to the recommended PHD. This is primarily due to the high recommendations of **nut** intake, adding environmental costs of 0.16€/cap/d (cf. Figure 37). These costs are mainly associated with fine particulate matter emissions and land use. **Vegetable oils** also add another 0.16€/cap/d to the environmental costs of the PHD.

Within the food group of fat sources, another cost driver is **dairy** products. This cost contributor is not as pronounced as in the other LL countries. Nevertheless, dairy intake in the LLD amounts to 0.46€/cap/d and 0.30€/cap/d and 0.36€/cap/d under NRD and PHD, respectively. Relevant environmental impacts to this category are, besides the frequently mentioned fine particulate matter emissions and land use, greenhouse gas emissions and human non-carcinogenic toxicity. The latter is attributable to silage processes, whereas the former results primarily from enteric fermentation processes in the dairy cows' intestinal system.

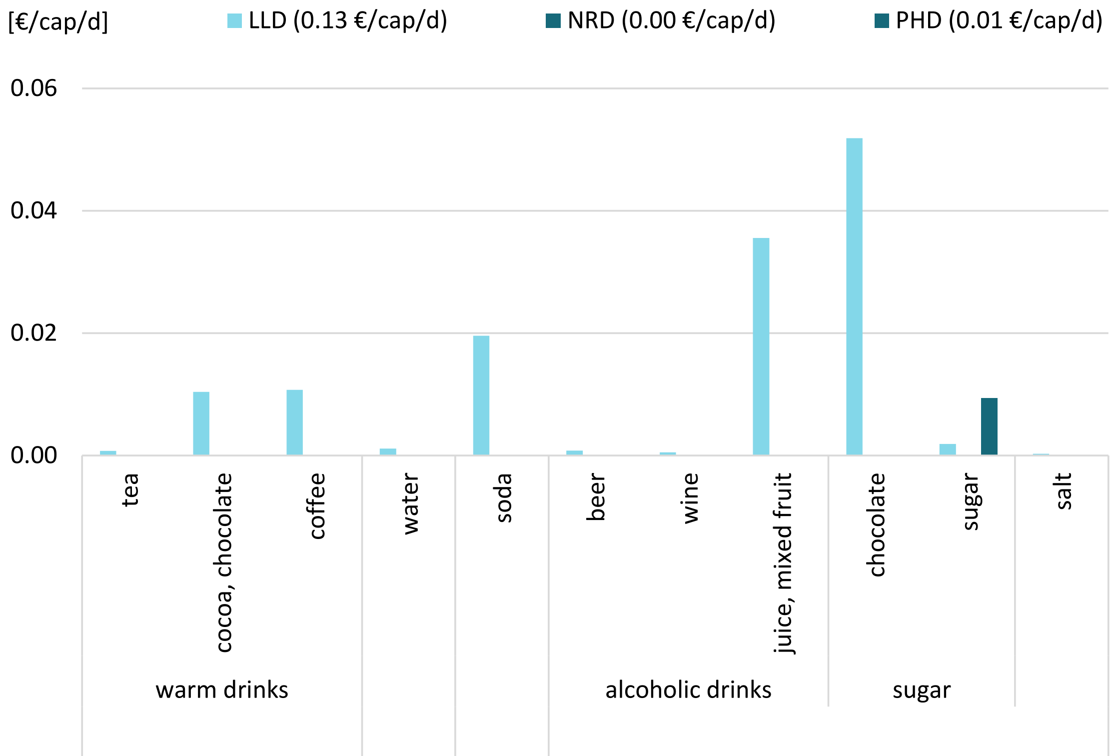

Figure 38: Environmental costs of the LLD, NRD and PHD for beverages and other products in France.

Within the food group of beverages and other products, chocolate contributes the highest costs to the LLD amounting to 0.05€/cap/d (cf. Figure 38). However, this cost does not greatly add to the overall environmental costs of the LLD. Across all products, this is not a major cost contribution. Also 'luxury' drinks, like tea, cocoa or coffee do not add significant costs to the overall environmental costs (0.02€/cap/d).

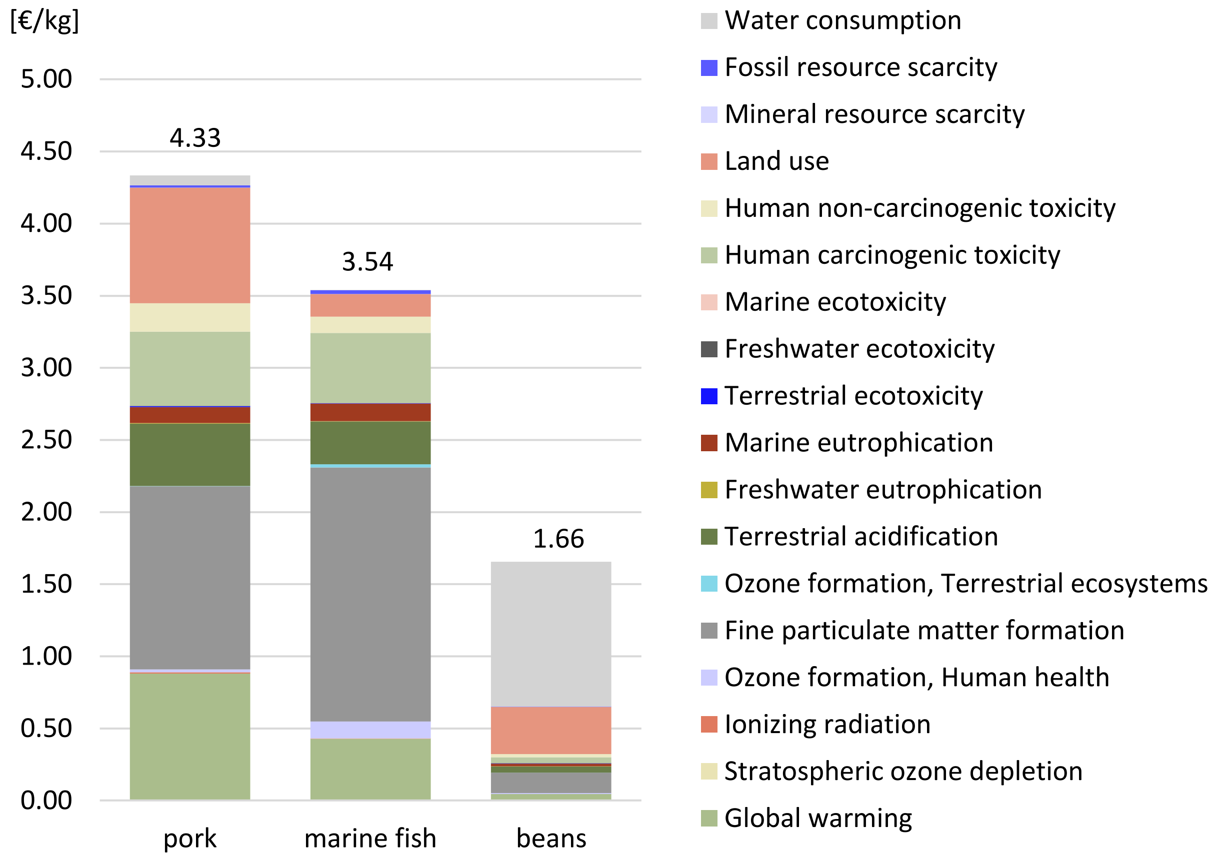

Figure 39: Environmental costs according to their underlying impact for pork, marine fish and beans per kg, as consumed in France.

The example in Figure 39 demonstrates the varying composition in environmental costs of different products. Fine particulate matter formation is again the most relevant to animal-based products (1.27€/kg of pork and 1.76€/kg of marine fish). Contrary to this, the environmental costs of beans in the French case consist mainly of costs for water consumption (1.00€/kg of beans). This is highly dependent on the production practices in the countries of origin of French beans.

With this said, in some cases, single importing countries and their production practices substantially impact an LL country's environmental costs, as seen with French chickpeas, mostly imported from India (55%). The high irrigation levels and its associated electricity use in India drive up costs associated with water consumption, fine particulate matter and human carcinogenic toxicity due to the particular electricity mix in India. Similarly, France imports more almonds from Spain, where low yield rates increase environmental costs due to inefficient land use. Consequently, the environmental cost of almonds is the highest in France at 3.62€/kg, compared to 1.87€ in Ireland and 2.28€ in Germany.

Environmental impacts driving French environmental costs over all food products are again especially **fine particulate matter** and **land use**. Like in the German and Irish diets, there are some products, for which costs are primarily driven by water consumption (e.g. freshwater fish, beans, berries), or global warming emissions (e.g. dairy products, beef, chocolate). Human toxicity is also generally an important environmental impact factor.

3.3.3 HEALTH IMPACTS AND COSTS

Table 26: Health costs of all three diets (LLD, NRD, PHD) in France per person per day compared to baseline (NRD).	
Health costs	**France [€/cap/d]**
LLD	7.75
NRD	-
PHD	-4.22

Health costs of French dietary patterns show great differences between LLD and PHD. Whilst LLD causes substantial health costs per day, the PHD has the potential for health benefits compared to the NRD benchmark.

A) DIET COMPARISON

Results show possible health cost savings if consumers adopt the PHD, particularly concerning meat consumption. In comparison to the other LL countries, the French PHD achieves the lowest benefits compared to NRD by just under one Euro short of the German PHD benefit. Particularly the plant-based recommendations under PHD are rather close to those of the NRD, diminishing its benefits in these food groups.

With 7.75€ health costs per person per day, a shift towards the NRD even poses great potential for health cost relief for France (cf. Table 26). This is also mostly driven by meat consumption. In the French dietary comparison, the costs and benefits associated with plant-based consumption are less pronounced than in the other LL countries.

B) HOTSPOTS

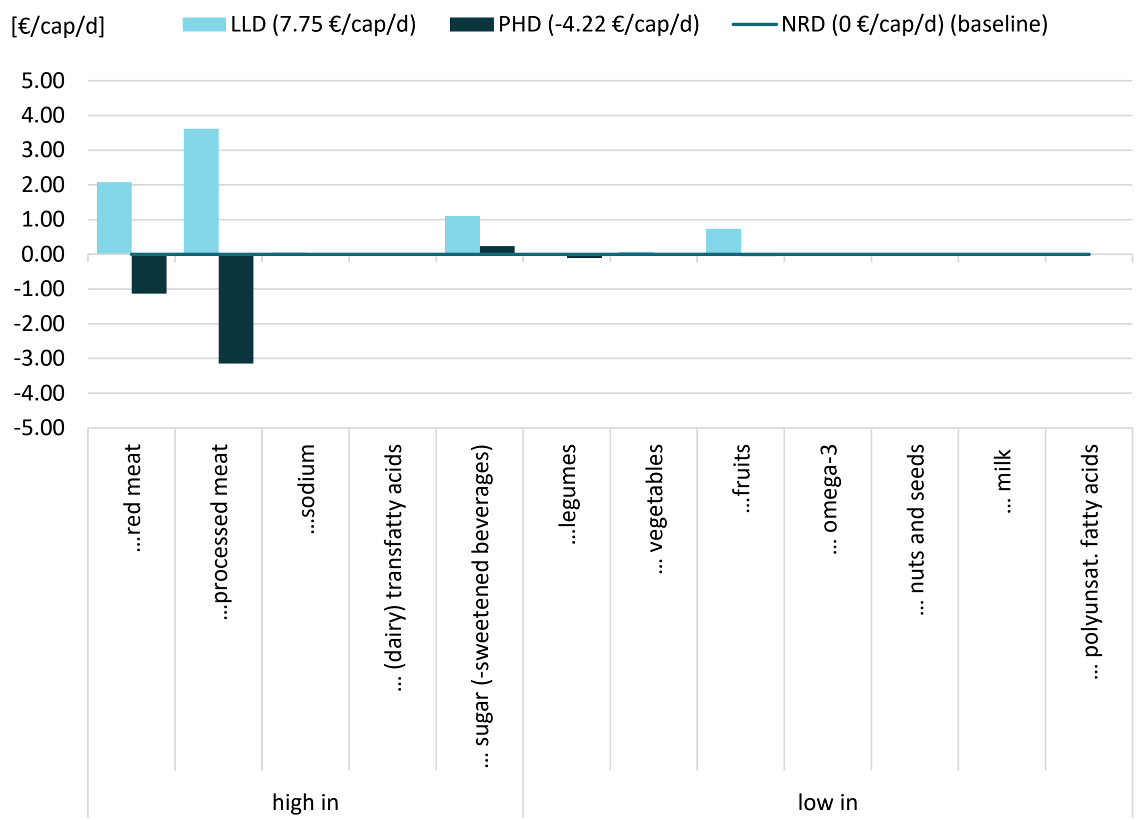

Figure 40: Health costs in France of all three diets (LLD, NRD, PHD) per person per day.

Like in both other LL countries, **meat** intake is the highest health cost and benefit driver in France (cf. Figure 40). Compared to the NRD benchmark, red and processed meat consumption causes 5.70€/cap/d for the LLD, whereas reduced consumption provides health benefits of -4.27€/cap/d for the PHD. This stipulates 75% of all health-related costs for the French LLD.

Contrary to that, the inadequate consumption of **plant-based products** (legumes, vegetables, fruits, nuts and seeds) leads only to health costs of 0.87€/cap/d for the LLD and benefits of -0.19€/cap/d for the PHD. Nevertheless, with transitioning from health-cost-intensive meat consumption to plant-based protein sources like legumes, an even higher health savings in health costs is possible here.

Due to the methodology (as explained in subsection 2.3.2), the health costs of milk and polyunsaturated fats consumption could not be evaluated, therefore their benefits are zero here. In both these cases, the actual consumption levels (LLD) exceed the recommended values (NRD), implying health benefits that could not be validated according to COI for the associated dietary risks.

Although lower than in Germany and Ireland, another cost driver is the consumption of **sugar and sugary beverages**, amounting to 1.11€/cap/d under the LLD.

3.3.4 SOCIAL RISKS

Table 27: Social risks of all three diets (LLD, NRD, PHD) in France

Social risks	France [mrheq/cap/d]
LLD	6.43
NRD	3.61
PHD	8.81

Overall, it is important to note that the primary factor contributing to product-specific risks is the sourcing countries. As outlined in section 2.4, we evaluate the top five sourcing countries for each representative product. A detailed list of these countries is provided in electronic Appendix 3.

A) DIET COMPARISON

In France, the social risk assessment indicates notable differences in social risks between the LLD and the two recommended diets NRD and PHD, with NRD performing the best. Shifting from the LLD to the NRD would be beneficial in reducing social risks:

- **LLD** has moderate social risk due to substantial contributions from tea and coffee.
- **NRD** exhibits the lowest social risk, remaining risks are primarily driven by beans, rice and milk.
- **PHD** shows the highest social risk mainly associated with beans, rice and nuts.

As shown in Table 27, the LLD exhibits moderate total social risk, largely driven by high-risk contributions from tea, coffee, beans and beef. Specifically, tea contributes substantially to the social risk in France with 1.75 mrheq/cap/d (27% of social risks). Coffee also presents a notable risk at 0.58 mrheq/cap/d (9% of social risks). These high-risk contributions underscore the importance of targeted interventions in these categories. Since there is no recommended intake of tea and coffee in the NRD and PHD, both recommended diets show benefits regarding beverage consumption. Excluding tea and coffee, the LLD would account for 4.10 mrheq/cap/d and would therefore perform better than the NRD and PHD. While the LLD includes higher risks due to higher amounts of meat intake in general and specifically beef and poultry, the NRD and PHD recommend a higher intake of beans and nuts, which bear comparatively high social risks.

Adopting the NRD in France could lead to a substantial reduction in social risks. The remaining social risks are primarily caused by contributions from beans (0.58 mrheq/cap/d), rice (0.51 mrheq/cap/d), milk (0.45 mrheq/cap/d) exotic fruits (0.40 mrheq/cap/d) and beef (0.35 mrheq/cap/d). Although the NRD does not explicitly recommend the consumption of exotic fruits, the general recommendation of fruit intake is assumed to be distributed among all fruit types as shown by the LLD consumption data.

Therefore, also considerable risks from exotic fruit consumption arise within the NRD. While the NRD imposes the lowest risks, there are still areas for improvement, particularly in reducing the reliance on high-risk foods such as beans and rice.

The PHD shows a high level of social risks due to the high recommended intake of beans, fruit, rice and nuts. The main contributor is beans with 6.10 mrheq/cap/d, which is mostly offset by the overall lower risk across other food categories. Concerning exotic fruits, the same issue as described under NRD is valid for the PHD.

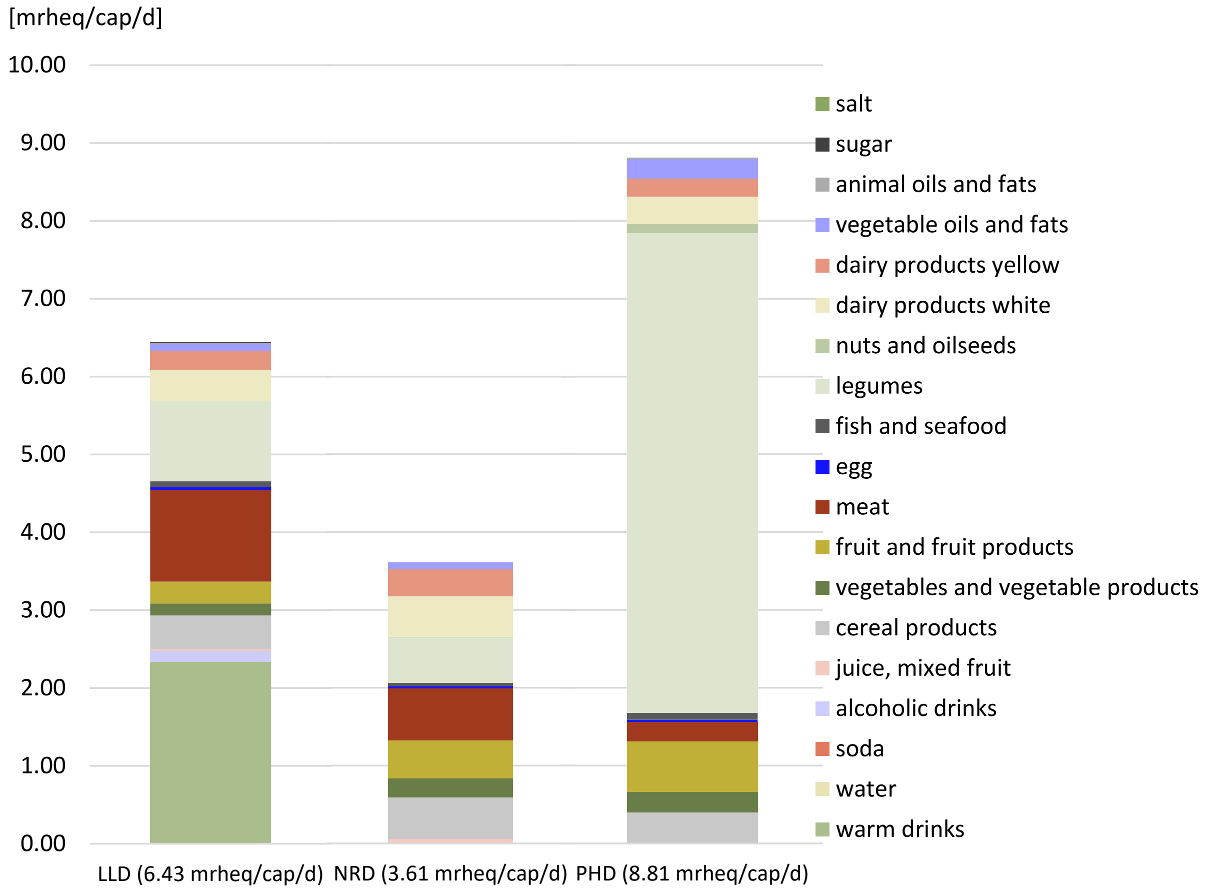

Figure 41: Contribution to social risks of LLD, NRD and PHD from product groups, France.

Figure 41 shows the diets in comparison to one another with all product categories and their respective risk contribution to the diets. It becomes clear that different product categories contribute in varying degrees to social risks. While the LLD has moderate social risk in France, primarily due to tea and coffee, shifting towards the NRD can substantially mitigate these risks. The NRD presents the lowest risks, which could still be reduced by intervening in high-risk categories like beans and rice. In the following, we describe and discuss hotspots within the diets in more detail.

A) HOTSPOTS

In the following, social risks for carbohydrate sources (Figure 42), protein sources (Figure 43), fat sources (Figure 44) and beverages and other products (Figure 45) are shown and described.

Among **cereals**, oats perform the best, sourced mainly from France, Germany, the UK, Finland, Spain and Chile. These countries have strong democracies and institutions, leading to better social outcomes. Similar notions are observable for other locally growable crops like rye or sunflower seeds. As recommended cereal intake is higher than current consumption levels, their associated risks rise with the NRD, especially influencing the performance of rice. Again, rice is mostly cultivated and imported from countries with weaker democracies and less institutional strength leading to high risks within the subcategories of Forced Labour, Migrant Labour, Indigenous Rights, Access to Hospital Beds or Property Rights, among others. Across **vegetables and fruits**, collard vegetables contribute comparatively less to social risks, especially for categories of Governance and Health and Safety.

Generally, basic and cheap products, are easy to grow in local communities, reducing the risk of outsourcing social exploitation to countries with weaker democratic institutions. Among fruits, exotic fruits (represented as bananas) bear the highest social risks. Mainly imports from Cote d'Ivoire and Cameroon increase the risk of violations of Labour Rights, Human Rights and Community Infrastructure.

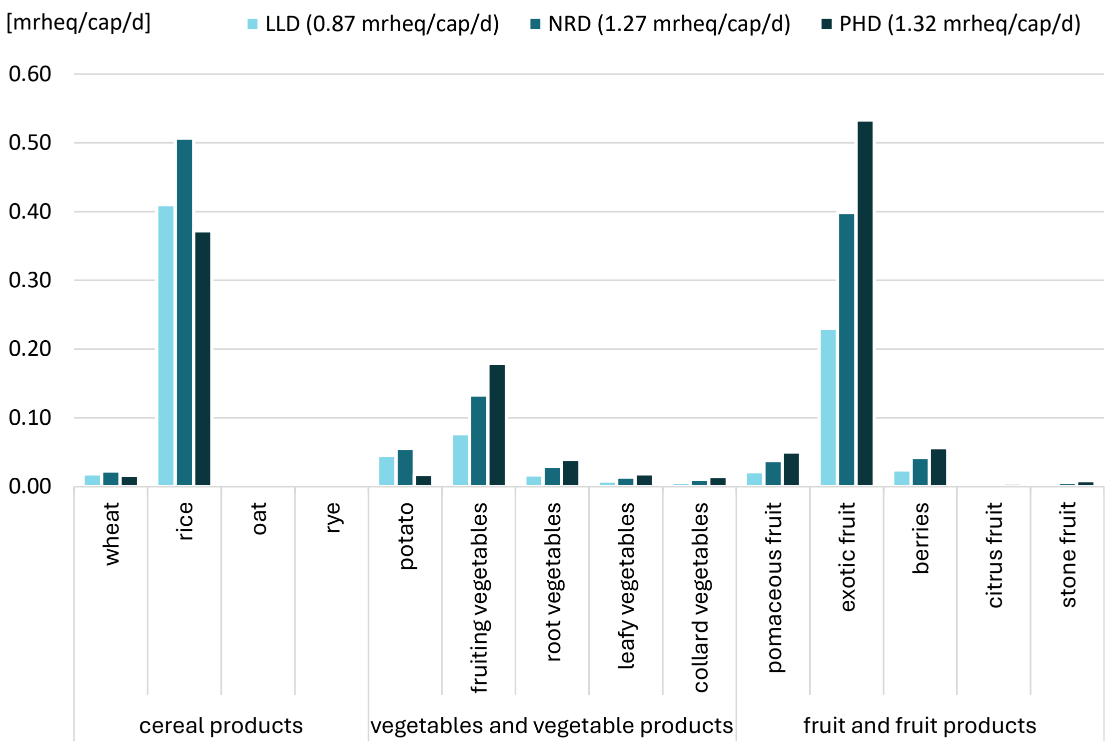

Figure 42: Social risks [medium risk hour equivalents, mrheq per day] of the LLD, NRD and PHD, carbohydrate sources, France.

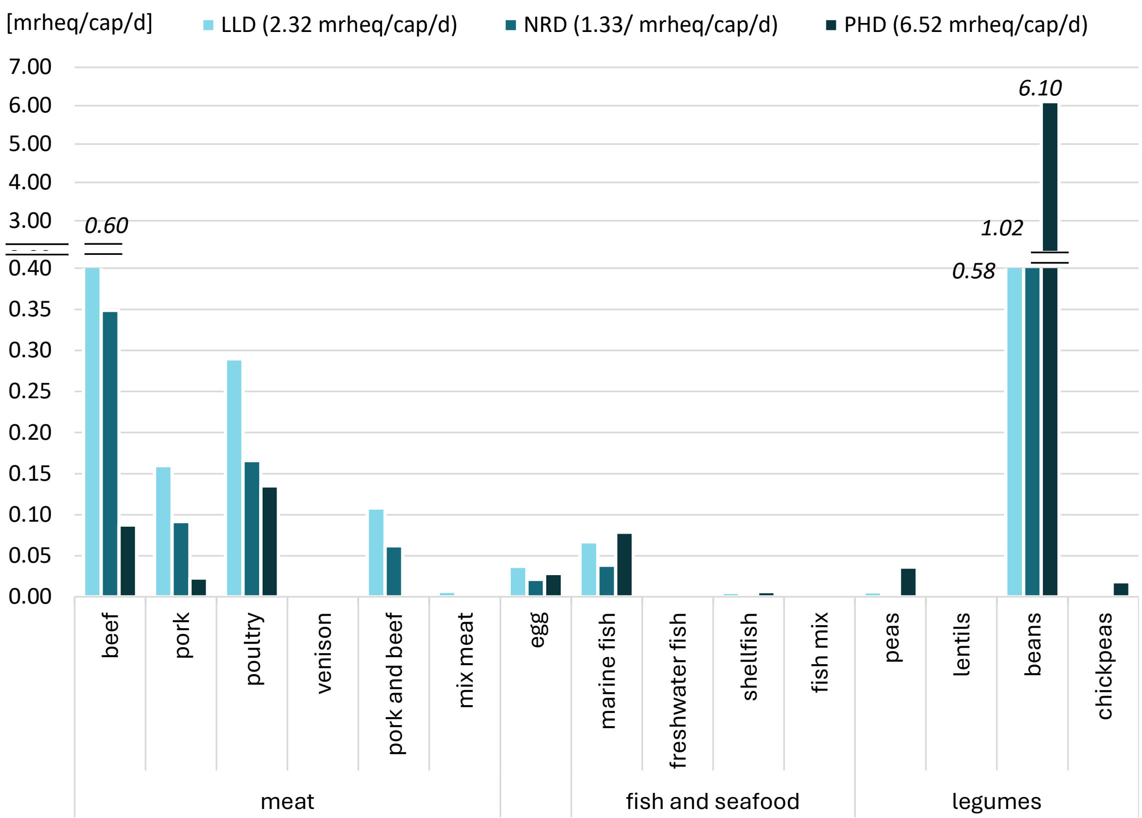

Figure 43: Social risks [medium risk hour equivalents, mrheq per day] of the LLD, NRD and PHD, protein sources, France.

Contrary to the assessment of environmental and health impacts, animal-based products do not result in drastically higher social risks than plant-based products. Across all types of **meat**, beef scores highest in social risks (per kg as well as weighted with the respective consumption within all three diets). The main contributing countries are Belgium and the Netherlands, with social risks spread fairly evenly across all subcategories, rather than any one subcategory showing particularly high contributions. High risks are mainly attributable to the complex production chain of beef, which spans across the globe with feed often produced in the global south and bad feed conversion (a lot of feed needed for beef), both accumulate social risks along the chain. Regarding **fish and seafood,** marine fish entails the greatest social risks, however, it remains moderate compared to beef and poultry in the meat category. For products of **legumes**, beans show much higher total social risk factors compared to other legumes, again pointing towards France's sourcing countries, with Madagascar contributing largely to these social risks. Hotspots lie within Labour Rights, Community Infrastructure and Human Rights. Since legume intake is encouraged in NRD and PHD, the consumption of beans also increases, likewise increasing associated social risks.

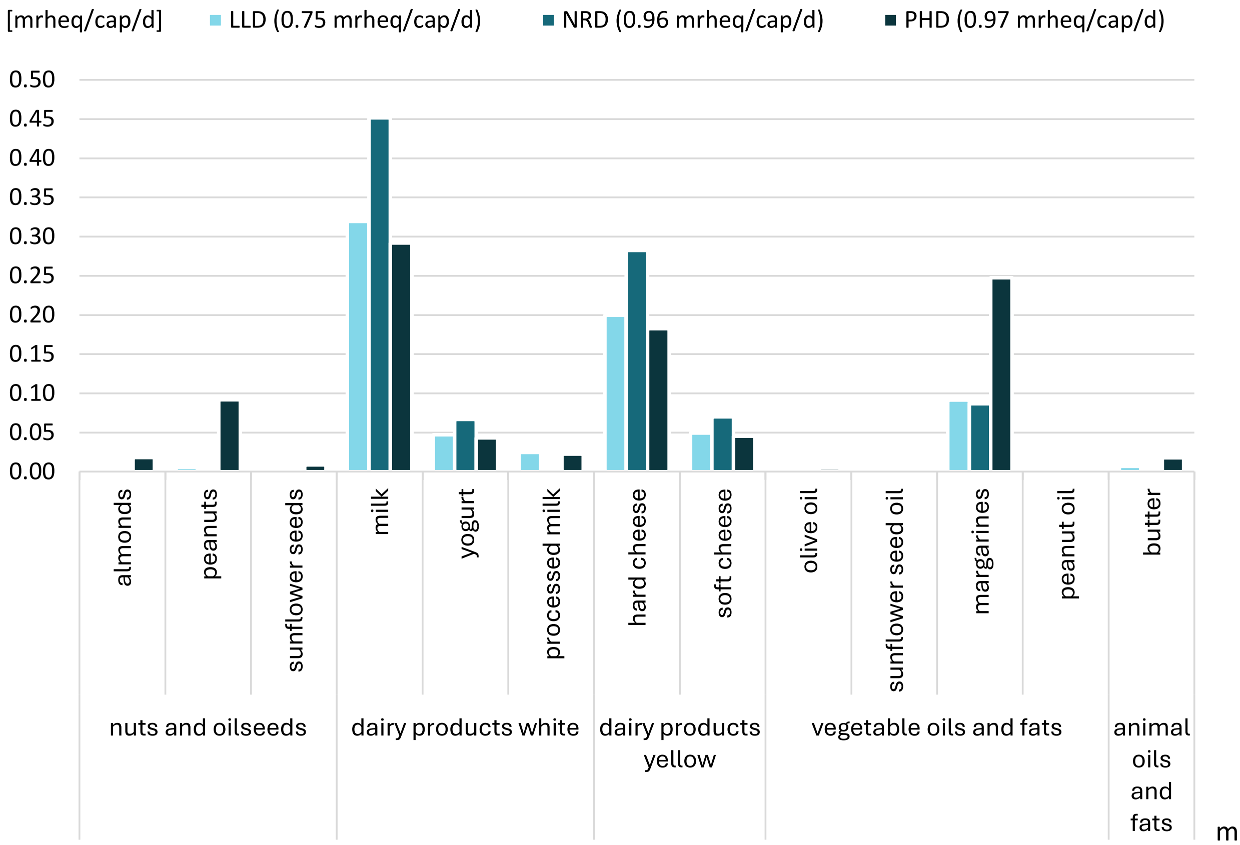

Figure 44: Social risks [medium risk hour equivalents, mrheq per day] of the LLD, NRD and PHD, fat sources, France.

With relatively low intake in the LLD, **nuts and oilseeds** contribute only minimally to social risks. Since the recommended intake in the NRD and PHD is substantially higher, their impact increases. Locally grown almonds do not show advantages compared to imported ones from, e.g. USA or Australia. In the case of peanuts, import from the USA or Brazil comes with low social risk compared to Nicaragua, Egypt or Argentina. For **dairy products,** the consumption of milk and hard cheese show the highest social risks, in both cases mainly due to contributions within Labour Rights as well as Community Infrastructure and Human Rights. Per kg of product, hard cheese causes about 10 times higher risks than milk due to higher milk input per kg of product. While locally produced milk is beneficial for employability and the reduction of transport-related greenhouse gas emissions, the social risk for milk from Ireland and Germany is lower. Under the French NRD social risk for dairy products increases, whereas it is strongly reduced under the PHD, given the limited recommended consumption of dairy products. Among **oils and fats**, vegetable oils and fats, especially margarine due to the consumption distribution, bear the highest social risks.

Main contributions come from the subcategories Forced Labour, Injuries and Fatalities, Wage Assessment and Child Labour. Peanut oils come with the highest social risk per kg but are barely consumed.

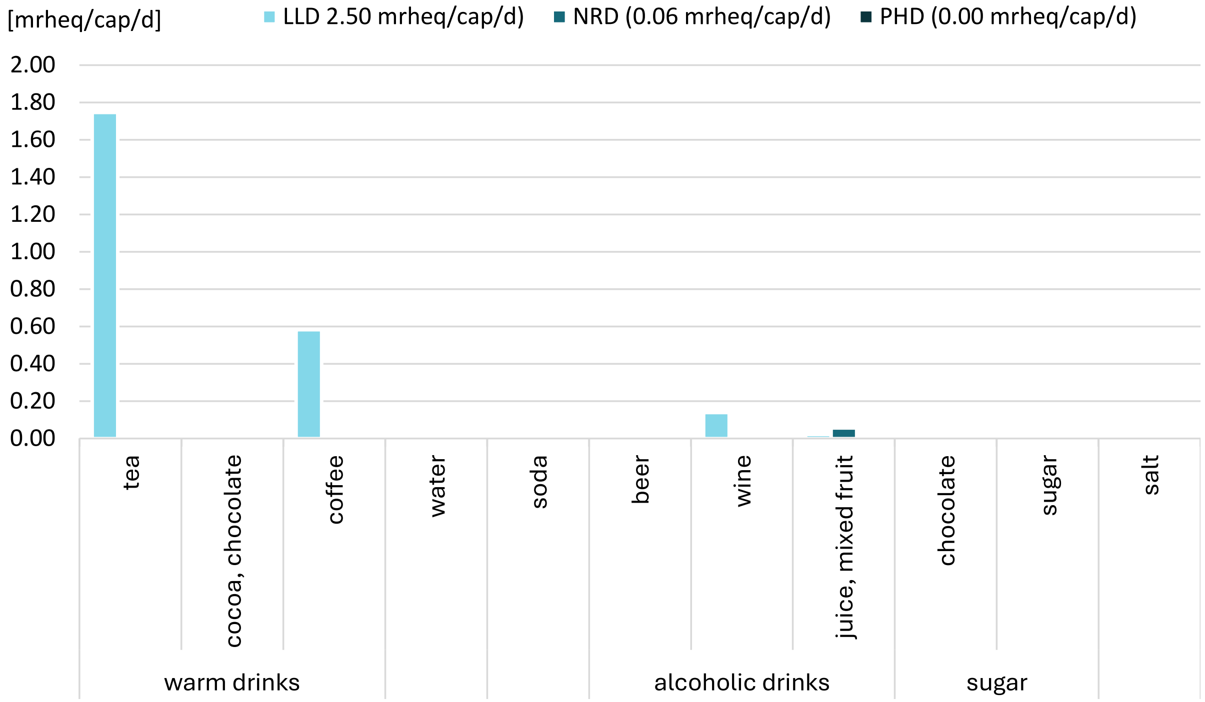

Figure 45: Social risks [medium risk hour equivalents, mrheq per day] of the LLD, NRD and PHD, beverages and other products, France.

In the category of **warm drinks**, tea performs worst per kg in multiple criteria, such as Workers in Poverty, Child Labour, Forced Labour, Discrimination, Occupational Toxicity and Hazards, Injuries and Fatalities, Property Rights, Access to Drinking water, or Access to Sanitation. The main sources of tea for France are Sri Lanka, Kenya, India, Indonesia, Malawi, of which mainly Kenya and Malawi contribute to poor social performance, especially concerning Labour Rights.

Coffee also fares poorly, for various criteria, including Workers in Poverty, Child Labour, Unemployment, Occupational Toxicity and Hazards, Injuries and Fatalities and Access to Essential Services, with Ethiopia as a main driver for social risks, whilst cocoa performs relatively better per kg. The primary sources of cocoa are Côte d'Ivoire, Cameroon, Ghana, Nigeria and Indonesia. For both the NRD and PHD, no tea and coffee consumption is recommended, leading to no social risk. The same holds for soda and beer consumption, which contribute slightly to social risks within the NRD. Lastly, juice is connected to small social risks, majorly led by Labour Rights as well as Injuries and Fatalities.

3.3.5 POTENTIAL FOR FRENCH DIETARY TRANSITION (HOTSPOTS)

In the French **LLD**, the environmental costs are primarily driven by meat consumption, especially beef. This is substantially driven by fine particulate matter formation and land use. Similarly, the consumption of red and processed meats is a major health cost contributor, as well as contributing to social risks. Tied to this, especially considering missed opportunities for health benefits, is the consumption (LLD) of too few plant-based foods. Whilst dairy products add substantial costs to the environmental assessment through greenhouse gas emissions and land use, it is not as relevant to both the health cost and social risk assessment.

High environmental cost contributions in the French **NRD** are also from meat, especially beef. It is by far the largest environmental cost factor across all products. Reducing this could generate further health cost benefits of the NRD in France, but replacement with plant-based alternatives should always consider possible trade-offs: with current NRD recommendations, beans and rice are primary drivers of social risks, mainly due to their origin countries. Addressing social risks by improving sourcing practices for beans, rice and dairy products could make NRD a more balanced diet across all impact areas.

The French **PHD**, while aimed at sustainability, incurs environmental costs particularly in the categories of nuts (especially almonds) and vegetable oils due to its recommendations for high intake and the sometimes resource-intensive producing practices.

Similarly, although legumes offer particularly high health benefits, the production of some, in the French case chickpeas or beans, incurs environmental costs due to the yield and water consumption in the countries of origin. This also ties in with the associated social risks of the importing countries, likewise as in products like nuts or rice. Therefore, whilst the plant-based focus of the PHD brings health benefits in France, the associated social risks particularly should be addressed e.g. by sourcing socially certified produce.

Across the three diets (LLD, NRD and PHD) and all three impact areas (environmental, social and health), the following products and processes emerge as hotspots with negative impacts across all areas:

High greenhouse gas emissions, substantial land use and fine particulate matter emissions make **beef** a major environmental burden. It is consistently one of the largest contributors to environmental costs across all diets, contributes largely to negative health costs and holds great potential environmental and health benefits when its consumption is reduced. Further, beef supply chains often involve labour issues such as poor working conditions, low wages and worker exploitation, including unsafe practices and inadequate labour rights along the supply chain.

The **sourcing of products** can substantially influence the results of certain products. Whilst more plant-based intake is beneficial to health costs of each diet, it is important to source products from countries where production practices are environmentally transparent and efficient, as well as social risks are minimal along the supply chain.

3.3.6 COMPARISON BETWEEN THREE IMPACT AREAS (ENVIRONMENTAL, HEALTH, SOCIAL)

Both health and environmental costs are heavily impacted by the consumption of red and processed meats, particularly beef. The more plant-focused diet, the PHD shows aligned benefits for both health and the environment, as it reduces reliance on resource-intensive animal products and promotes consumption of nutrient-dense plant foods. However, this does not always correlate with the social risks of these foods. Nuts and legumes can still pose a social risk if sourced from vulnerable regions.

Although environmental costs show hotspots (particularly in NRD and LLD) within meat consumption, the costs are still distributed across the different products and moderate to high costs are seen in several food groups. French health costs and benefits, however, are more directly tied to specific food groups and products, such as high meat intake.

As social risks are more so dependent on the geographical and political context of food production rather than the volume consumed, even a smaller consumption of socially risky foods can result in substantial social impact. Contrary to this, health and environmental costs are more consumption-dependent. Therefore, social risks present a distinct but equally important challenge, especially when opting for cost mitigation in health costs through dietary shifts towards more plant-based foods.

3.3.7 AFFORDABILITY OF THE FRENCH DIETARY PATTERNS

Results of the cost assessment

The estimated daily costs of the three diets for France are presented in Table 28.

Table 28: Daily costs per capita of the three diets for France.

Country	LLD [2021 PPP €/cap/d]	NRD [2021 PPP €/cap/d]	PHD [2021 PPP €/cap/d]
France	1.76	2.13	2.21

The French LLD, NRD and PHD, have costs at 1.76 PPP EUR, 2.13 PPP EUR and 2.21 PPP EUR per person per day, respectively.

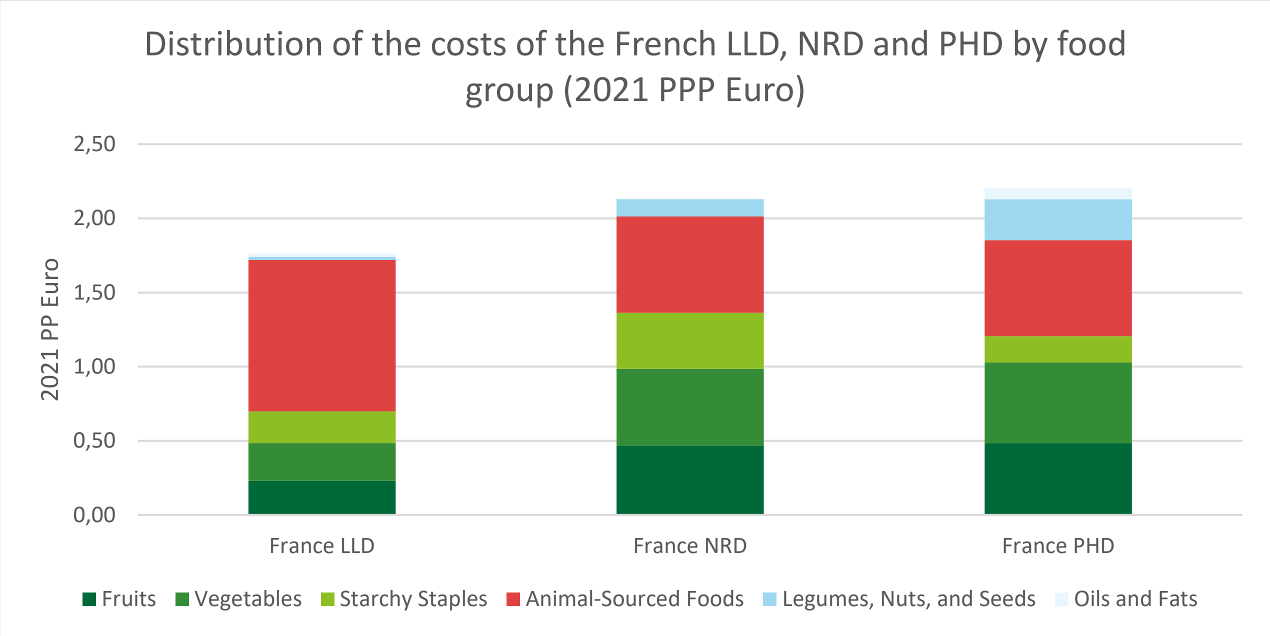

Figure 46: Relative distribution of the costs across the different food groups for the three French diets.

The French LLD has a high expenditure of 1.02€ on animal-sourced foods (57.9% of total cost), reflecting a diet with substantial meat and dairy consumption. This category constitutes most of the total cost, emphasizing the reliance on animal-sourced products. Fruits and vegetables together make up 27.2% of the total cost, indicating a moderate but secondary focus on plant-based foods.

The French NRD reduces the proportion of spending on animal-sourced foods to 0.65€ or 30.5% of total costs, reflecting a shift towards a more balanced diet with reduced meat and dairy consumption. The cost for fruits and vegetables rises substantially, together making up 46.5% of the total cost, indicating an increased emphasis on plant-based foods. The expenditure on starchy staples increases to 17.8%, suggesting a greater inclusion of carbohydrate sources to complement the diet.

The French PHD further reduces expenditure on animal-sourced foods, reflecting a diet that is both more sustainable and health-oriented. Animal products make up 29.5% of the total cost, though in monetary terms the actual cost remains unchanged at 0.65€. The spending on fruits and vegetables is the highest among the three diets, accounting for a combined 46.8% of the total cost, reflecting the diet's strong focus on plant-based foods. The expenditure on legumes, nuts and seeds increases substantially to 12.7%, highlighting the diet's emphasis on plant-based protein sources.

In summary, the increase in cost from the LLD to the NRD and PHD is largely driven by the increased spending on fruits and vegetables and a medium increase in legumes, nuts and seeds.

Affordability analysis

Table 29 presents France’s daily and annual median equivalised net income per adult with dependent children.

Table 29: Daily and annual net income for a single person with dependent children in France.

Country	Median equivalised net income [€/cap/d]	Median equivalised net income [€/cap /year]
France	42.08	15,361

In France, with a daily median income of 42.08€, the LLD, NRD and PHD diets cost 1.76€, 2.13€ and 2.21€, respectively. These costs correspond to 4.2%, 5.1% and 5.2% of the daily income. Although these percentages are (slightly) higher than in Germany and Ireland, they still fall well within the 20-30% threshold.

In France, the annual disposable income for the first decile of the population in 2021 was 12.287€/a or 33.66€/d. The affordability of the diets for this population group – considering the highest percentage of income spent being 6.6% for the PHD – is still well below the 20% threshold. The data suggests that the transformation to healthier and more sustainable diets creates a larger burden for lowest income households, but even then, healthy and sustainable diets can still be well considered affordable.

4. Recommendations for dietary improvements by country

In the following, we present recommendations for improving the different diets examined in this study for the LL countries Germany, Ireland and France. We recommend changes to the currently observed dietary patterns (LLD) relevant to the average consumer, consumer advice centres, nutritionists and health professionals, health insurers and national governments. We also provide recommendations for national authorities on how to improve their national dietary guidelines (NRD) for better health and sustainability performance. Finally, we offer suggestions for refinements and reflections on the EAT-Lancet Commission's PHD based on our models developed for Germany, Ireland and France. The recommendations are drawn from the findings of this study.

4.1 Germany

4.1.1 LLD

To address the environmental, health and social risks associated with pork and processed meat, reducing consumption of these products is recommended. Shifting to minimally processed protein alternatives, like legumes, can serve as a more sustainable and health-conscious substitution.

Additionally, legumes and other minimally processed protein sources can replace animal-derived products, such as cheese and dairy, offering protein and fats with lower health and environmental impacts. Due to the extensive processing chain and associated risks, moderate consumption of cheese, especially hard cheese, is advised.

To minimize social and environmental impacts from imported products (e.g. beans, nuts, rice, tea and coffee), it is advisable to reduce exotic food intake and prioritize items produced under fair conditions. Reputable certifications like Fairtrade and The Rainforest Alliance can help guide consumers toward more sustainable food choices.

In Germany, the health costs of inadequate fruit and vegetable consumption are substantial, highlighting the need for increased intake, with a focus on seasonal and locally sourced produce to reduce environmental and social risks.

4.1.2 NRD

The DGE recommends daily consumption of milk and dairy products for their protein, calcium, vitamin B2 and iodine. However, due to the health costs associated with trans-fatty acids in dairy products and the high environmental costs – especially for hard cheese at 6.7€/kg (environmental costs), – limiting dairy intake is advisable. Nutrient-rich, plant-based alternatives include tofu, broccoli, kale and dairy substitutes for calcium (NIH, 2023), certain mushrooms and spinach for vitamin B2 (Harvard T.H. Chan, 2020), iodised salt for iodine and seaweed (Smyth, 2021).

In terms of fruit and vegetables, root vegetables and cabbage show particularly good environmental and social performance. Within their principles of eating at least five portions of a wide variety of fresh fruit and vegetables every day, the German Nutrition Society (DGE) should emphasise these vegetables as beneficial examples.

4.1.3 PHD

Our study provides insights that can also help health authorities in considering and applying PHD recommendations for Germany. The social risk assessment suggests that social risks are highly dependent on the country of origin and supply chain, with higher risks often potentially arising from imports from certain regions.

In Germany, beans are frequently imported from countries with high social risks. To address this, greater emphasis should be placed on sourcing socially certified products (e.g. Fairtrade) from countries with robust labour standards. This will reduce the increasing dependence on imports of environmentally sustainable and healthy products from countries with high social risks and poor working conditions. It should be taken into account to avoid increased social risks under the PHD potentially undermining the environmental benefits of reduced meat consumption from a holistic point of view.

Although the PHD in Germany yields environmental advantages, our study paradoxically indicates slightly higher environmental costs for the PHD than the NRD (1.3€/cap/d compared to 1.0€/cap/d). The potential for reducing the environmental cost of the German PHD, which is mainly due to the high consumption of poultry, nuts and vegetable oils, is twofold. Firstly, environmental costs should be lowered by moderating poultry consumption and incorporating responsibly sourced, minimally processed protein sources such as legumes. Secondly, it is recommended to promote the procurement of nuts and vegetable oils from regions and practices that minimise environmental damage, with a preference for local and regional products. For palm oil, which is found in almost all margarine products (Kälble, 2023), the Roundtable on Sustainable Palm Oil (RSPO) label, indicating sustainable production, is a good example.

Under the German PHD, fruiting vegetables such as tomatoes, which are often imported from the Netherlands cause additional environmental costs and social risks. Recommendations could be made to fruiting vegetable farmers in the EU to significantly reduce their environmental impact through holistic sustainable energy concepts and responsible use of potable water used for irrigation by collecting rain and condensation water. In addition, organic practices such as the use of 'natural helpers' to control pests and the composting of waste to promote the natural nutrient cycle should be adopted to provide low environmental impact plant foods.

4.2 Ireland

4.2.1 LLD

Given the high environmental and health costs associated with high meat and dairy consumption in Ireland, reducing the intake of these products is advisable. Switching to alternative protein sources, such as legumes, which have lower environmental costs, is particularly recommended. Given the high consumption of beef, poultry and dairy products in the Irish diet, a reduction in consumption can lead to environmental cost savings of up to 0.72€/cap/d when switching from LLD to PHD.

In addition, excessive sugar consumption – particularly in the form of sweetened beverages – imposes a high health cost in Ireland amounting to 1.79€/cap/d. It is therefore strongly recommended that the Irish population reduce their intake of sugary drinks such as soft drinks and opt for water and unsweetened tea instead.

Consumers are also encouraged to prioritize locally grown fruit and vegetables, especially root vegetables and cabbage. Choosing these products over imported products, such as exotic fruit and vegetables, can help to reduce the social risks associated with labour rights abuses in countries from which Ireland imports these products.

4.2.2 NRD

In Ireland, meat consumption is the largest cost driver of all dietary impacts (environmental, social and health-related). Therefore, the Irish Department of Health should consider lowering its current recommendations for dairy product consumption and red meat and poultry intake. The revision of the recommendation is justified not only by the high environmental cost, especially concerning global warming and land use impacts but also by the risks of cardiovascular diseases linked to meat and high-fat dairy products.

To guarantee sufficient nutrient supply, Irish citizens should be educated that certain plant-based foods such as legumes, nuts and root and leafy vegetables not only perform well in both health and environmental terms but also are great substitutes for the intake of key nutrients traditionally derived from dairy products, e.g. calcium (tofu, almonds) and vitamin B2 (mushrooms, spinach).

Further, health authorities should also address the high consumption of sugar in Ireland, particularly in sweetened beverages, which have significant health costs. Reducing sugar intake, especially sweetened drinks such as soft drinks should be further emphasized.

4.2.3 PHD

The results showed that the Irish PHD is already delivering significant environmental and health benefits, particularly through reduced meat and dairy consumption compared to the Irish NRD and LLD.

One way in which the PHD could be improved for Ireland is to encourage a wider variety of plant-based foods. This would help spread the environmental impacts across different crops and avoid the high environmental costs associated with focusing on a single product. For example, nuts are currently emphasised in the PHD for plant-based fat intake, but they can have significant environmental costs, as shown in the case of almonds and peanuts. By recommending other plant-based sources of healthy fats, such as local seeds (e.g. sunflower seeds) and plant oils like olive or sunflower seed oil, the PHD could further reduce its environmental impact while maintaining the health benefits for consumers.

In general, the results show that the PHD has a lower social risk compared to the Irish NRD. In seeking ways to further reduce this risk, attention should be given to the social risk hotspots of vegetable oils and fats, milk, beans and nuts. Ideally, health authorities make further recommendations on how consumers can source these products responsibly and with lower social risk.

4.3 France

4.3.1 LLD

Similarly to the recommendations for Germany and Ireland, French consumers are advised to significantly reduce their consumption of red and processed meat, due to their substantial negative environmental and health costs and replace it with less processed plant proteins such as lentils, chickpeas and other legumes.

Due to the environmental impact of dairy products, especially hard cheeses, French consumers should consider reducing their dairy intake. Where dairy is consumed for protein intake, it can be replaced by legumes, while locally sourced seeds and nuts can serve as alternatives for fat intake. Plant-based milk alternatives can substitute for reduced consumption of cow's milk.

4.3.2 NRD

The results of this study show that the high consumption of red and processed meats is a significant driver of health and environmental costs in France, mainly due to their association with cardiovascular disease and certain cancers. The main health authority, Santé Publique France, should revise its dietary guidelines to reduce the recommended intakes of beef, pork, poultry and processed meats, for example towards the recommended levels of PHD.

In addition, the recommendation for daily dairy consumption should be adjusted, shifting towards lower intakes and emphasising plant-based alternatives such as legumes, which have fewer associated environmental impacts.

4.3.3 PHD

Adopting a PHD in France would yield significant health benefits and environmental cost reductions compared to the LLD and the NRD. However, there is potential for further refinement in the design of the PHD tailored to France, which could lead to additional reductions in environmental costs. For example, our study found that while the French PHD effectively lowers health costs, certain foods – such as poultry, marine fish and almonds – still contribute to environmental costs. It is suggested to adapt the French PHD to include more diverse recommendations for plant-based foods, such as local ancient grains like buckwheat.

It is also recommended to recognise the possibility of increased social risk of the proposed French PHD compared to the LLD and NRD due to imported products such as nuts and certain legumes. In particular, for products imported from countries with high social risks, such as beans and exotic produce, greater emphasis should be placed on sourcing socially certified products (e.g. Fairtrade) from countries with high labour standards.

5. Conclusions

This study aimed to assess the environmental and health costs and social risks of different dietary patterns – LLD, NRD, PHD – across the three LL countries Germany, Ireland and France. By employing methods such as LCA, COI and TCA, the research aimed to provide a comprehensive understanding of the costs and risks associated with various diets.

Key findings are:

- **Environmental costs**: The PHD offers the lowest environmental costs in Ireland and France, while in Germany the NRD shows the best environmental performance. Environmental cost savings stem primarily from reduced land use, reduced particulate matter formation and reduced global warming impact.
- **Health costs**: Transitioning from LLD to the PHD substantially reduced the health costs linked to excessive consumption of red meat and dairy in all three countries.
- **Social risks**: All diets in all three countries raise concerns over social risks in the production of some recommended plant-based foods, which can be mitigated by sourcing socially certified products from countries with high labour standards. This is particularly relevant for the PHD as recommended intake levels of these products are higher compared to NRD and LLD.
- **Affordability**: All diets in all three countries remain within the affordable income threshold of 20-30%, though lower-income households face greater challenges in adopting the PHD.
- **High-impact foods**: Animal products, especially red and processed meats and dairy products, are the highest contributors to health and environmental costs. Tea, coffee and beans often carry high social risks due to poor working conditions in their countries of production.
- **Dietary shifts**: A shift towards plant-based diets, including legumes and diverse fruits and vegetables, benefits both health and environmental sustainability.

This study demonstrates that shifting to healthier, more environmentally sustainable diets not only provides health and environmental benefits and saves external costs but is also economically feasible for most consumers. By highlighting the social risks associated with the sourcing of food it adds a critical dimension to the discourse on sustainable food systems. The integration of TCA into dietary analysis provides a more holistic view, capturing hidden costs that are traditionally overlooked in conventional assessments.

Although it is obvious from the literature of recent years what steps need to be taken for more sustainable food systems (e.g. reducing animal production and consumption), and the research on the effects on health and environmental sustainability and external costs is quite clear, some areas of research need to be addressed in the future. The understanding of social risks associated with the global production of foods as well as the impact of food processing should be deepened. More studies should further explore the feasibility and affordability of sustainable diets for low-income populations to ensure equitable access to healthy and sustainable food.

While there is a strong consensus on what must be achieved, efforts now need to focus on enhancing the 'how' of implementation. For example, this study did not address several practical barriers to adopting plant-based diets, such as varying levels of cooking skills, meal-planning abilities, knowledge of food storage and available time, which are particularly challenging for individuals from lower socioeconomic backgrounds. These factors, which significantly influence the feasibility of dietary shifts, should be considered in future research and by policymakers aiming to promote sustainable dietary transitions.

Lastly, as the EAT-Lancet regional PHD recommendations are forthcoming, future work should assess how these adapted guidelines will further impact true costs and sustainability in specific regions to assess progress toward achieving sustainability.

Finally, the findings of this study provide critical insights for transforming European food systems towards sustainability. By aligning health, environmental and social performance through integrated policies and consumer support, a balanced, sustainable future for food systems is achievable with the necessary will and action of policymakers and all other stakeholders.

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Appendix 1

Appendix 1.1: Decisions for diet mapping

Table 30: Decisions taken for mapping products from the EFSA (2011) data to the diets modelled in this study for each product group.

Type	Category	Representative Products	Notes
1. Beverages	1.1 Warm drinks	1.1.1 Tea 1.1.2 Cocoa 1.1.3 Coffee (Arabica)	All products within this category are classifiable as one of these three products.
	1.2 Water	1.2.1 Tap water	
	1.3 Sugary drinks	1.3.1 Soda (cola)	Cola is the most consumed soda in all three LL countries.
	1.4 Alcoholic drinks	1.4.1 Beer 1.4.2 Wine	Remaining products are matched to representative products based on their main input ingredients (fruit based alcohol, like cider, is sorted into wine; grain-based alcohol, like whiskey, is sorted into beer). If no further information is available (for example 'cocktail drink'), the product is classified as the most consumed representative product in this group, which is beer.
	1.5 Fruit juices	1.5.1 Juice (mixed fruit)	We model the fruit input into this product according to the volume-weighted average of fruits from category 2.4 in each country.
2. Carbohydrate sources	2.1 Cereal products	2.1.1 Wheat 2.1.2 Rice 2.1.3 Oat 2.1.4 Rye	All wheat-based products comprise about 90% of all cereal products. The rest of the cereal-based products differ across the LL countries: in Ireland, oat is most prevalent, whereas in Germany it is rye and in France it is rice. If no information on the main ingredient (e.g. wheat semolina = wheat) of the product is available (for example 'buns', the product is classified as the most consumed representative product in this group, which is wheat.
	2.2 Starchy vegetables	2.2.1 Potatoes	This product category also includes cassava roots and sweet potatoes, but compared to ordinary potatoes the values are negligibly small. Hence, we classify all consumed products as potatoes, since production processes are similar as well.
	2.3 Other vegetables and vegetable products	2.3 1 Fruiting vegetables (tomatoes)	We decided to group this product category according to its botanical properties, as this makes the most difference within the production cycle and hence LCA modelling. For each botanical category,

		2.3.2 Root vegetables (carrot) 2.3.3 Leafy vegetables (salad) 2.3.4 Collard vegetables (white cabbage)	we picked one sensible product that is well-represented in all countries. All remaining products are sorted into the representative product according to their botanical properties.
	2.4 Fruit and fruit products	2.4.1 Pomaceous fruit (apple) 2.4.2 Exotic fruit (banana) 2.4.3 Berries (strawberries) 2.4.4 Citrus fruit (oranges) 2.4.5 Stone fruit (peaches)	We grouped this category according to its botanical properties. The representative products within botanical groups are picked according to what is most consumed in all countries. All remaining products are sorted into the representative product that shares their botanical properties.
3. Protein sources	3.1 Beef	3.1.1 Beef	All beef-based meat products are modelled as beef. Under this category, we also included lamb, goat, sheep or all 'farmed' ruminant products. This is because it is firstly considered 'red meat' (→ health implications), and secondly they, too, are ruminants and therefore have large climate impacts (→ environmental implications).
	3.2 Pork	3.2.1 Pork	All pork-based meat products are modelled as pork.
	3.3 Poultry	3.3.1 Poultry	This includes all products derived from farmed poultry breeds, like chicken, or goose and also bred game poultry, like duck or guinea fowl.
	3.4 Meat, other	3.4.1 Venison 3.4.2 Beef and pork 3.4.3 Mix meat	There is some venison consumed within the LL countries, which is mostly non-bred (like deer or boar) (Wikipedia 2024) and therefore is its own category as free-roaming animals have largely different environmental impacts (e.g. no synthetic fertilizer or farmed feed is necessary) and no social impacts compared to farmed animals. We give venison the same impacts as poultry, as in Agribalyse this is modelled as avian products mostly (e.g. pheasant). The 'beef and pork' or 'mixed meat' is used for meat products consisting of two (beef and pork) or more (mixed meat) meat ingredients. Here we average the meat ingredients beef, pork and poultry for modelling over all categories of 3.3.
	3.5 Eggs	3.5.1 Eggs (chicken)	This encompasses all direct egg derivates (e.g. hard-boiled egg or fried egg).

	3.6 Fish and Seafood	3.6.1 Marine fish (salmon) 3.6.2 Freshwater fish (trout) 3.6.3 Shellfish (mussels) 3.6.4 Fish mix	We differentiate these products according to their habitat and species. This is due to their production chains and the following quantity of environmental and social impact. All remaining products are sorted into the representative product according to their habitual and species properties. The production difference of 'farmed' or 'free capture' fish is not given in EFSA data, which is why we will use national averages to model this accordingly if possible. The 'fish mix' category is used if there are no details given on the specific fish used within this product (e.g. 'fish (meat)'). Here we average the fish ingredients for modelling over the rest categories of 3.6.
	3.7 Legumes	3.7.1 Peas (garden peas) 3.7.2 Lentils (brown) 3.7.3 Beans (common beans) 3.7.4 Chickpeas (chickpeas)	We differentiate legumes according to their botanical differences and model one representative product for each type of legume. All remaining products are sorted into the representative product according to their botanical properties.
4. Fat sources	4.1 Nuts and oilseeds	4.1.1 Almonds 4.1.2 Peanuts 4.1.3 Sunflower seeds	Peanuts are botanically considered a legume, however, consumed as a seed or nut in European diets. This is why we sorted it into 4.1. Almonds are the most-consumed nut in Europe, followed by walnuts (which botanically speaking are drupes) and hazelnuts (source), so we chose almonds as the representative nut product. We choose sunflower seeds as representative of oilseeds. Both the nuts and seeds consumption shares are not consistent within the LL countries (besides peanuts, which is most consumed 'nut' in every country), with Germany, for example, consuming more pumpkin seeds. However, these are a by-product of pumpkin production and hence a stringent modelling of sunflower seeds is more sensible. France, for example, consumes more chestnut rather than almonds., which is not prevalent in any of the other countries. Therefore, we chose to go with overall representative products of nuts and seeds.
	4.2 Dairy products white (i.e. low milk input)	4.2.1 Milk 4.2.2 Yogurt 4.2.3 Processed milk	We disaggregated dairy products with low and high milk input, since the amount of milk used in dairy products is what drives the external costs (cf. Michalke et al. 2024). Within the 'milk' category are all products that are direct derivates of milk, like fermented milk, condensed milk, etc. Yogurt encompasses all slightly processed milk products, like quark or crème fraiche. Processed milk includes all 'highly' processed products like ice cream, puddings, etc.

	4.3 Dairy products yellow (i.e. high milk input)	4.3.1 Hard cheese 4.3.2 Soft cheese	We model two cheeses: soft cheese with low milk input of about 5 l of milk per kg of cheese and hard cheese with high milk input of about 10 l of milk per kg of cheese. Depending on the production practice and quality of the milk (protein and fat content, etc.), this milk input varies even for the same sort of cheese, which is why these two general assumptions suffice for our modelling.
	4.4 Vegetable oils and fats	4.4.1 Olive oil 4.4.2 Sunflower oil 4.4.3 Margarine 4.4.4 Peanut oil	Again, we differentiate vegetable oil according to the botanical properties of their underlying main ingredient. Remaining products are sorted accordingly. Processes of sunflower, olive and peanut oil rely on the production chain of their main ingredient. Margarine is a blend of different plant oils (we will use sunflower, peanut and olive for it).
	4.5 Animal oils and fats	4.5.1 Butter 4.5.2 Animal fat	Animal fat is a by-product of animal meat production. We used these process chains to model it.
6. Rest	6.1 Sweets	6.1.1 Chocolate 6.1.2 Sugar (beet sugar)	The great majority of sweets are produced with either primarily sugar or chocolate or a mix of both. We sort products into these categories according to their main ingredients.
	6.2 Salt	6.2.1 Salt	All salt products (e.g. sea salt, rock salt) are included in this.
Other	Other	NA.	These are all products which we exclude from our assessment, either because we do not know what ingredients they entail (e.g. ready-to-eat meals for children), or they are not sortable into any of the dietary recommendations (e.g. food colours). They amount to less than 2% of the overall products consumed and are therefore negligible.

Appendix 1.2: Decisions for LCI modelling

Tea, cocoa, coffee

Table 31: Conversion factors from tea, cocoa and coffee base product to the beverage.

	g of the base product	**per g of beverage**
Tea	2	200
Cocoa	30	200
Coffee	10	150

For tea, we use models of Kenya and Sri Lanka (available in Agribalyse) and adjust them for the yield in 2022. We use the Agribalyse model of RoW (Rest of World) to model the rest countries of origin. We model transport for all countries of origin, however.

We use the model of Ghana for Nigerian cocoa production.

Oat

Agribalyse was using an eco-invent process for the consumption mix of oat. To stay consistent, we therefore use the 'Oat grain, animal feed' process for our modelling, which is modelled according to the Agribalyse setup.

Rye

Agribalyse is using an eco-invent process for their consumption mix of rye. There is also no other process describing the production of rye as an Agribalyse process (e.g. like for oat, the feed process). We therefore decide to use the barley process instead. This is sensible so far, as that barley and rye production are similar in the way that they are both quite climate resistance and have comparably high yields (also in comparison to other cereals like wheat) (Auffenberg 2021).

We used all relevant rye data, however, to remodel this process. Especially for yield, we used data on rye.

Banana

There is no import share available for Ireland, only a 'Rest of World'-import. We have used half and half of France and Germanys input to approximate this for Ireland.

Tomato

There was no open field process for tomatoes in Agribalyse or ecoinvent, which we could have used to remodel all countries. Therefore, we used the WFLDB process.

Lentils and Chickpeas

Agribalyse uses the 'winter pea' process for their lentil and chickpea processes. We adopt this modelling choice.

Freshwater fish

There is no data on self-sufficiency and countries of origin for fish in the IR2. Therefore, we assume all production/wild catch to happen in the LL countries and only model countries of origin for the feedstock used for fish farming. The same holds for marine fish.

We differentiate between large trout and 'portion trout' or small trout.

The FEAP publishes shares of production volumes for both species in EU member states in 2019 (European Comission, 2021).

Table 32: Shares of production volumes for portion and large trouts in the LL countries (EC, 2011).

LL Country	Portion trout		Large trout	
	Volume [t]	Share	Volume [t]	Share
Germany	6.315	80.43%	1.537	19.57%
Ireland		0.00%	500	100.00%
France	26.000	64.20%	14.500	35.80%

Marine fish

We differentiate between farmed fish and fish caught in the wild.

The EU reports that in 2021, the consumption of fish divides as follows: farmed 3.04 million t, wild caught 7.56 million t (European Commission 2024b). This is a total of 10.60 million t, resulting in shares of 28.68% farmed and 71.32% wild caught fish consumption in Europe. We use these shares for all LL countries.

There are several different fishing methods that are unequally destructive for the environment and therefore require different environmental methods. Therefore, we use the share of fishing methods in the EU overall to describe and model the differences in fishing methods. We use the same shares for all three LL countries. Pedersen et al. (2009) collect data on the different catching methods (in tonnes) as shown in Table 33.

Table 33: Types of fishing gear in the EU.												
Gear Type	Demersal seine	Dredge	Gillnet	Large beam trawl	Otter trawl	Pelagic trawl	Small beam trawl	Longline	Pots	Trammel net	Unknown	Total (tonnes)
Catches (tonnes)	**839**	1443	621	14605	**77952**	**218**	21734	**2**	763	**379**	51	118580
Share of total catches (%)	**0.71**	1.22	0.52	12.32	**65.74**	**0.18**	18.33	**0.00**	0.64	**0.32**	0.04	
Gear type shares distributi on (%)	**1.06**				**98.19**	**0.27**		**0.00**		**0.48**		**79390**

LCI exist for about 67% of these fishing methods (bold). We normed their share and use this as a modelling share for our marine fish LCI model. The fishing methods are modelled in Agribalyse partially for other fish species than salmon. However, the models primarily including the fishing infrastructure like boats and nets and can therefore be used for all species.

Since we use European averages, the external costs of marine fish in the three LL countries do not differ substantially from one another. The variation primarily arises in the feed for farmed fish and the transportation costs for both farmed and wild-caught fish. Given the interconnected nature of the European fish market, this approach seems reasonable to us.

Peanuts

There is no FAO data available for peanut. We use the preexisting models in Agribalyse for Argentinian and Chinese peanuts. These add up to more than 50% of the consumed nuts in all three LL countries. We use the RoW process for the other countries of origin.

Eggs

We distinguish different production systems: cage, free range (outdoors), barn (indoors), organic. These are modelled according to the shares they hold in each country of origin.

The organic production cycle refers more to the style of husbandry and housing, rather than the feed fed to the animals.

Table 34: Share of laying hen holding systems in EU (European Commission 2022) and UK (Gov.Uk 2022). Data for EU countries was only available based on laying hens in holding, whereas UK data is for eggs from holding.

Country	Year	Cage	Free range	Barn	Organic	Total
		[%]				
Belgium	2021	36.2	13.5	42.8	7.4	100
Denmark	2021	9.9	8.1	49.0	33.0	100
France	2019	54.1	23.0	11.7	11.2	100
Germany	2021	5.5	22.1	58.8	13.6	100
Ireland	2021	48.5	46.4	1.4	3.7	100
Netherlands	2021	7.8	22.8	60.9	8.6	100
Portugal	2021	75.0	4.7	19.5	0.8	100
Spain	2021	73.3	9.1	16.1	1.6	100
UK	2021	35.4	59.0	1.8	3.8	100

Broilers

For the production of broilers, we differentiate between different housing systems. These are conventional, organic and free-range broiler husbandry. Data for broiler husbandry is very rare, most statistics are about laying hen husbandry, rather than broiler. Therefore, we assume the husbandry shares from Table 34 with cage and barn-laying hen husbandry form the shares for conventional broiler production.

Thailand and Brazil are further countries of origin for chicken meat consumed in the the three LL countries. Data for these countries are not available at the time of preparation. As both countries are generally characterized by intensive poultry production, we assume 100% conventional poultry production for both countries.

The organic production cycle refers more to the style of husbandry and housing, rather than the feed fed to the animals.

Milk

We differentiate between grass-fed and fodder-fed dairy cows. These are modelled according to the shares they hold in each country of origin. Values are from van den Pol-van Dasselaar et al. (2020) based on expert opinions. These values include dairy cows that are partially and full-time grass fed, therefore somewhat overestimating the grass-fed share in our model. If ranges are given, we use the means for modelling.

Table 35: Percentage of dairy cows that are grass fed in the countries of origin (van den Pol-van Dasselaar et al. 2020).

Country	Year	Literature	Model
		[%]	
Austria	2019	44	44.0
Belgium		30-95	62.5
Denmark		20-25	22.5
France		90	90.0
Germany		15-40	27.5
Ireland		95-100	97.5
Spain		20-30	25.0
UK		70-80	75.0
Italy	2018	10-30	20.0
Netherlands		71	71.0

Beef

We differentiate between beef from dairy systems and from suckler systems. Within the dairy cull cows, we differentiate between grass fed and fodder fed (see Table 35). Within the suckler systems, we differentiate between less than 1.2 livestock unit (LU) per ha and more than 1.2 LU per ha for the countries of origin according to their average LU. 1.2 is the threshold defined in Agribalyse.

No certain value for the share between grass-fed and fodder-fed beef in Brazil was available. However, considering studies report that the majority of deforestation in the Brazilian Amazon is due to its transformation into pastures for cattle grazing (Tyukavina et al., 2017, Barona et al., 2010, Lima Filho et al., 2021), we assume that all beef is grass-fed.

Table 36: Livestock density in LU per ha in the countries of origin. Data for Europe is from Eurostat (2023). For the UK we use Ireland as a proxy value, as the DEFRA publishes a range between 1.0 and 1.5 LU/ha. Data for Brazil is from Arantes et al. (2018).

Country	Year	Livestock density	Agribalyse model
		[LU/ha]	
Austria	2020	0.9	<1.2
Belgium		2.7	>1.2
Denmark		1.6	>1.2
France		0.7	<1.2

Germany		1.0	<1.2
Ireland		1.3	>1.2
Italy		0.7	<1.2
Netherlands		3.4	>1.2
UK	nA	1.3	>1.2
Brazil	2014/2015	0.97	<1.2

The National Institute for Agricultural Research (INRA) (INRA, 2021) publishes data on the type of bovine produced in Europe in carcass weight equivalent (cwe). We use these shares for modelling the distribution within the countries of origin. The share of 'cows' is both from dairy and suckling cattle; we distribute equally between both in our model. We use the same model for young bulls and bullocks, which likely underestimates the impact from bullocks as they are culled at a higher age. We could not find numerical data for Brazil, however reports point towards a rather large importance of bull meat within the production of Brazilian beef (Nogueira, 2023, de Castro Nunes et al., 2024). Therefore, we use the German Irish data for the Brazilian production share.

Table 37: Share of bovine types produced in the countries of origin. Share is given in percent. The rest (adding up to 100%) is from calves and young cattle and is neglected in our model. When there is no data available for a country, we use the most similar country available as its proxy. a: Germany, b: France, c: Ireland

Country	**Year**	**Bulls**	**Cows**	**Heifers**
		[%]		
Austria[a]	2016	46	35	14
Belgium		28	49 (dairy)	22
Denmark[a]		46	35	14
France		26	44	15
Germany		46	35	14
Ireland		53	19	28
Italy		45	21	21
Netherlands[b]		26	44	15
UK[c]		53	19	28
Brazil[c]		53	19	28

Pork

We differentiate between two different forms of husbandry: conventional pork husbandry, which is characterized by no access to outdoor space and husbandry with free-range access, which in Agribalyse is modelled after the French Label Rouge (Label Rouge Viandes, 2024). Respective data for the countries of origin is from different sources. Generally, data is very difficult to find, compared to other livestock data (e.g. laying hens). We have to use approximations for some countries and use data from other countries as their proxy (cf. Table 38).

Table 38: Share of conventional and outdoor pig husbandry in the countries of origin. a: no official statistics available, yet reports point towards a close to zero husbandry with outdoor spaces (AgriAware 2024, Ethical Farming Ireland 2024)

Country	Conventional	Outdoor space	Source
	[%]		
Belgium	99.8	0.2	Martinez Aviles et al. (2019) and FAOSTAT
Denmark	99	1	Data from Germany
France	92.9	7.1	IFIP (2023)
Germany	99	1	Destatis (2021)
Ireland	100	0	diverse[a]
Italy	95	5	Data from Spain
Netherlands	92.9	7.1	Data from France
Spain	95	5	Martìnez Avilés et al. (2019)
UK	60	40	Agriculture and Horticulture Development Board (AHDB) (2024)

Appendix 1.3: Mapping of the diets to FPN

Table 39: Mapping of the three German diets according to the FPN food group classifications.

FPN food groups	Representative products	Quantity (g) German LLD	Quantity (g) German NRD	Quantity (g) German PHD
Fruits	Pomaceous fruit (apple)	80.37	220.82	142.85
	Exotic fruit (banana)	15.67	43.05	27.85
	Berries (strawberries)	3.03	8.34	5.39
	Citrus fruit (orange)	6.65	18.27	11.82
	Stone fruit (peach)	6.8	18.68	12.08
Vegetables	Fruiting vegetables (tomato)	58.4	160.45	199.85
	Root vegetables (carrot)	8.91	24.49	30.5
	Leafy vegetables (salad)	16.41	45.09	56.17
	Collard vegetables (white cabbage)	3.94	10.82	13.48

Starchy Staples	Wheat	182.35	232.31	179.65
	Rice	12.08	15.39	11.9
	Oat	1.4	1.78	1.38
	Rye	39.66	50.52	39.07
	Potato	58.86	35.71	50
Animal-Sourced Foods	Beef	8.58	2.11	2.26
	Pork	44.56	10.96	11.74
	Poultry	12	2.95	29
	Venison	0.2	0.05	0
	Pork beef	32.98	8.11	0
	Mix meat	6.26	1.54	0
	Egg	7.26	8.57	13
	Marine fish (salmon)	3.78	13.27	14.45
	Freshwater fish (trout)	0.21	0.73	0.79
	Shellfish (mussels)	0.2	0.71	0.77
	Fish mix	3.13	11	11.98
	Milk	129.07	148.35	154.53
	Yoghurt	30.78	35.38	36.85
	Processed milk (ice cream or custard)	23.01	26.45	27.55
	Hard cheese (emmental/gouda)	20.06	23.05	24.01
	Soft cheese (mozzarella/brie)	5.9	6.78	7.06
Legumes, Nuts and Seeds	Peas (garden peas)	1.93	8.95	37.59
	Lentils (brown)	0.7	3.27	13.72
	Beans (common beans)	1.2	5.57	23.4
	Chickpeas	0.01	0.07	0.29
	Almonds	4.78	20.63	41.25
	Peanuts	0.92	3.95	7.91
	Sunflower seeds	0.1	0.42	0.84

Oils and Fats	Olive oil	1.76	1.92	7.69
	Sunflower oil	0.45	0.49	1.97
	Margarine	6.93	7.59	30.35
	Peanut oil	0	0	0
	Butter	9.58	10	11.8
	Animal fat	0.54	0	0.63
Beverages	Tea	206.33	0	0
	Chocolate	26.5	0	0
	Coffee	48.82	0	0
	Water	796.45	1500	0
	Soda	200.87	0	0
	Beer	64.39	0	0
	Wine	3.81	0	0
	Juice, mixed fruit	320.44	57.14	0
Sweeteners and Condiments	Chocolate	10.96	0	0
	Sugar	6.71	0	31
	Salt	0.01	0	0

Table 40: Mapping of the three French diets according to the FPN food group classifications.

FPN Food groups	Food Item	French LLD (g)	French NRD (g)	French PHD (g)
1. Fruits	Pomaceous fruit (apple)	45.8	93.35	96.74
	Exotic fruit (banana)	14.81	30.19	31.28
	Berries (strawberries)	11.45	23.35	24.19
	Citrus fruit (orange)	13.63	27.78	28.79
	Stone fruit (peach)	9	18.33	19
2. Vegetables	Fruiting vegetables (tomato)	88.08	179.54	188.57
	Root vegetables (carrot)	40.99	83.54	87.74
	Leafy vegetables (salad)	10.2	20.79	21.83

	Collard vegetables (white cabbage)	0.87	1.76	1.85
3. Starchy Staples	Wheat	226.41	557.32	215.5
	Rice	14.14	34.8	13.46
	Oat	0.39	0.96	0.37
	Rye	2.81	6.91	2.67
	Potato	95.81	0	50
4. Animal-Sourced Foods	Beef	47.94	24.61	8.4
	Pork	31.98	16.42	5.6
	Poultry	44.4	22.79	29
	Venison	0.04	0.02	0
	Pork beef	10.78	5.53	0
	Mix meat	3.18	1.63	0
	Egg	14.31	0	13
	Marine fish (salmon)	20.81	23.73	22.91
	Freshwater fish (trout)	0.59	0.67	0.65
	Shellfish (mussels)	1.67	1.91	1.84
	Fish mix	2.36	2.69	2.6
	Milk	209.39	154.52	149.53
	Yoghurt	80.12	59.12	57.22
	Processed milk (ice cream or custard)	31.3	0	22.35
	Hard cheese (emmental/ gouda)	20.2	14.91	14.43
	Soft cheese (mozzarella/brie)	9.06	6.69	6.47
5. Legumes, Nuts and Seeds	Peas (garden peas)	2.96	7.96	25.94
	Lentils (brown)	1.59	4.27	13.92
	Beans (common beans)	3.52	9.46	30.85
	Chickpeas (chickpeas)	0.49	1.32	4.29
	Almonds	0.72	23.09	38.48
	Peanuts	0.17	5.34	8.89
	Sunflower seeds	0.05	1.57	2.62

6. Oils and Fats	Olive oil	5.36	0	26.9
	Sunflower oil	1.01	0	5.07
	Margarine	1.52	0	7.61
	Peanut oil	0.08	0	0.43
	Butter	6.92	0	11.8
	Animal fat	0	0	0
7. Beverages	Tea	20.13	0	0
	Chocolate	8.94	0	0
	Coffee	10.43	0	0
	Water	677.88	0	0
	Soda	128.22	0	0
	Beer	3.3	0	0
	Wine	1.31	0	0
	Juice, mixed fruit	119.31	0	0
8. Sweeteners and Condiments	Chocolate	11.05	0	0
	Sugar	6.22	0	31
	Salt	0.76	0	0

Table 41: Mapping of the three Irish diets according to the FPN food group classifications.

FPN Food groups	Food Item	Irish LLD (g)	Irish NRD (g)	Irish PHD (g)
1. Fruits	Pomaceous fruit (apple)	37.41	93.35	96.74
	Exotic fruit (banana)	27.21	30.19	31.28
	Berries (strawberries)	4.25	23.35	24.19
	Citrus fruit (orange)	13.47	27.78	28.79
	Stone fruit (peach)	3.93	18.33	19
2. Vegetables	Fruiting vegetables (tomato)	60.59	179.54	188.57
	Root vegetables (carrot)	51.87	83.54	87.74
	Leafy vegetables (salad)	7.61	20.79	21.83
	Collard vegetables (white cabbage)	8.85	1.76	1.85
3. Starchy Staples	Wheat	196.42	557.32	215.5

	Rice	11.78	34.8	13.46
	Oat	36	0.96	0.37
	Rye	11.51	6.91	2.67
	Potato	128.77	0	50
4. Animal-Sourced Foods	Beef	58.28	24.61	8.4
	Pork	39.09	16.42	5.6
	Poultry	62.26	22.79	29
	Venison	0	0.02	0
	Pork beef	14.89	5.53	0
	Mix meat	1.02	1.63	0
	Egg	17.04	0	13
	Marine fish (salmon)	20.68	23.73	22.91
	Freshwater fish (trout)	0.5	0.67	0.65
	Shellfish (mussels)	2.01	1.91	1.84
	Fish mix	0.62	2.69	2.6
	Milk	213.81	154.52	149.53
	Yoghurt	31.63	59.12	57.22
	Processed milk (ice cream or custard)	8.26	0	22.35
	Hard cheese (emmental/ gouda)	13.37	14.91	14.43
	Soft cheese (mozzarella/brie)	6.62	6.69	6.47
5. Legumes, Nuts and Seeds	Peas (garden peas)	4.48	7.96	25.94
	Lentils (brown)	0.33	4.27	13.92
	Beans (common beans)	6.83	9.46	30.85
	Chickpeas (chickpeas)	0.92	1.32	4.29
	Almonds	1.21	23.09	38.48
	Peanuts	1.23	5.34	8.89
	Sunflower seeds	0.54	1.57	2.62
6. Oils and Fats	Olive oil	0.59	0	26.9
	Sunflower oil	0.1	0	5.07
	Margarine	14.08	0	7.61
	Peanut oil	0	0	0.43

	Butter	4.63	0	11.8
	Animal fat	0	0	0
7. Beverages	Tea	422.46	0	0
	Chocolate	1.01	0	0
	Coffee	32.23	0	0
	Water	698.26	0	0
	Soda	115.74	0	0
	Beer	242.52	0	0
	Wine	88.08	0	0
	Juice, mixed fruit	51.53	0	0
8. Sweeteners and Condiments	Chocolate	8.95	0	0
	Sugar	7.9	0	31
	Salt	0.68	0	0

Appendix 1.4: Data sources

Table 42 shows all data sources used for this study.

Table 42: Data sources for the herein presented assessment of all impact areas (environmental, social, health) and diet affordability.

Analysis		**Data source**	**Source description**
Diets	LLD	CREA	PLAN'EAT D1.2
	NRD	France, table A1.8	
		FAO: Food dietary guidelines of regions and countries (FAO 2019)	FAO compilation of dietary guidelines, for France
		Santé publique France: Recommendations concerning diet, physical activity and sedentary behaviour for adults (Delamaire, 2019)	National Dietary Guidelines for France
		Santé publique France: 50 petites astuces pour manger mieux et bouger plus (Santé Publique France, 2023)	Interpretation of dietary guidelines for serving sizes etc.
		Ireland, table A1.4	

		Department of Health, Irish Government: The Food Pyramid (Gov.ie 2019)	National dietary guideline of Ireland; Interpretation of dietary guideline for serving sizes etc.
		Germany, table A1.7 German Nutrition Society (DGE): Gut essen und trinken – die DGE Empfehlungen (DGE 2024)	National Dietary Guideline of Germany
	PHD	Eat LANCET Commission "The Planetary Health Diet" (Willett et al., 2019)	Planetary health diet recommendation that is healthy for people and the planet
	Diet mapping	EFSA data, specifically decoding scheme for hierarchy levels	National survey data with their respective exposure hierarchies
	Countries of origin	Import	Trade data from IR2 of PLAN'EAT
Environmental	LCI	Agribalyse	Secondary data on LCIs for products of different origin
		Ecoinvent, WFLDB	Some background and underlying LCIs for modelling
		FAOSTAT	Data on yield, pesticide use, fertilizer use, cropland
		AQUASTAT	Irrigation data
		Various sources (cf. 2.2.2 f and Appendix 1.2)	Share of greenhouse and open-field production, data for animal husbandry, etc.
	LCIA	ReCiPe 2016	Environmental impact assessment for 18 impact categories
	Monetization	CE Delft: Environmental Prices Handbook	Damage costing approach for 15 impact categories based on ReCiPe
		UBA: Methodological Convention 3.1 for the Assessment of Environmental Costs	Marginal damage costing of global warming potential
Social	LCI	Social Hotspot Database (SHDB)	LCI database describing performed work hours within different sectors and countries for the production of commodities
	LCIA	Social Hotspots Index	LCIA method adhering to SHDB, translating inputted work hours to hours at medium risk level for several risk categories (e.g. labour rights, health and safety)
	Functional unit mapping	Price monitoring of the European Commission (EC 2024a) Food Price Monitoring and Analysis (FPMA) (FAO 2024a)	Price data for foodstuff to map the functional unit of SHDB (per € of product) to our functional unit (per kg of product)

		Natural Resource Institute Finland (Luke 2024) Statistisches Bundesamt (Destatis 2024)	Additional source for price data on fish, since no data is available in the primary data sources of the EC and FPMA
Health	Method	Seidel et al. (2023)	Assessment of dietary health costs based on Cost of Illness
	Dietary risk factors	Institute for Health Metrics and Evaluation from the University of Washington	DALY rates of LL countries and DALY rates for dietary risk factors
		Populations and social conditions (EUROSTAT 2024b)	Population data on a national level for calculations
	Direct and indirect health cost	CVD costs: European Cardiovascular Disease Statistics (Wilkins et al., 2017)	Documents cardiovascular disease mortality, morbidity, costs, risk factors and other key statistics from all over Europe
		T2D costs: Systemic review of economic studies on costs for diabetes mellitus (France and Germany) (Stegbauer et al. 2020) Estimating the current and future costs of Type 1 and Type 2 diabetes in the UK, including direct health costs and indirect societal and productivity costs (Hex et al. 2012) Direct Medical Costs of Type 2 Diabetes in France: An Insurance Claims Database Analysis (Charbonnel et al. 2018) Impact of type 2 diabetes on health expenditure: estimation based on individual administrative data (Baudot et al. 2019) Cost burden of type 2 diabetes in Germany: results from the population-based KORA studies (Ulrich et al. 2016)	Literature review on cost analysis of type 2 diabetes, focused on France and Germany. This will be used to assume sensible factors for Ireland. Study on Health Economics of Type 2 diabetes in the UK. We used this as a proxy for Ireland. Study on direct medical costs for T2D in France. Study including indirect costs of T2D expenditures in France. Study on direct and indirect cost of T2D in Germany.

		Neoplasm costs: The cost of cancer in Europe (Hofmarcher et al. 2020)	Total cost of cancer differentiated for countries all across Europe.
Diet affordability	Method	Herforth et al., 2022	Method to monitor the cost and affordability of a healthy diet globally, adjusted to be applied to the various diets analysed in this study.
	Diet cost data	ICP FPN - International Comparison Program's Food Prices for Nutrition data	The ICP FPN (International Comparison Program's Food Prices for Nutrition) data provides standardized, cross-country food cost and diet affordability data.
	Income data	EU-SLIC - Eurostat's European Union Statistics on Income and Living Conditions (EUROSTAT 2024a)	Comprehensive data source that provides cross-national information on income, poverty, social exclusion and living conditions across European countries.
Overall	Inflation	Consumer Price Index: World Bank Open Data (World Bank 2024a)	Used for inflation adjustment to adjust health and environmental external costs to 2022