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PLAN'EAT

TCA Data Gaps Report

Deliverable D3.1

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DELIVERABLE PLAN'EAT – D3.1
TCA (True Cost Accounting) Data Gaps Report

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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.	

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Abbreviations and acronyms

CAP	Common Agricultural Policy	**PIC**	Prior informed consent
CVD	Cardiovascular diseases	**SDG**	Sustainable Development Goals
DALY	Disability adjusted life years	**SETAC**	Society of Environmental Toxicology and Chemistry
EFSA	European Food Safety Authority	**SHDB**	Social Hotspot Database
EHS	Environmentally harmful subsidies	**WWF**	World Wild Fund for Nature
FAO	Food and Agriculture Organization of the UN	**S-LCA**	Social Life Cycle Assessment
FTE	Full-time equivalent	**SMART**	Specific, Measurable, Achievable, Relevant, and Time-bound
GHG	Greenhouse gas	**TCA**	True Cost Accounting
ISO	International Organization for Standardization	**TEEB**	The Economics of Ecosystems and Biodiversity
JRC	Joint Research Centre	**TEEBAgriFood**	The Economics of Ecosystems and Biodiversity for Agriculture and Food
LCA	Life Cycle Assessment (Analysis)	**UNEP**	United Nations Environment Programme
LCI	Life Cycle Inventory	**USDA**	United States Department of Agriculture
LCIA	Life Cycle Impact Assessment	**WBCSD**	World Business Council for Sustainable Development
NCD	Non-communicable disease	**WHO**	World Health Organization
PEF	Product Environmental Footprint	**WISH**	World Index for Sustainability and Health

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Executive summary

True Cost Accounting (TCA) is a novel approach to holistically consider the environmental, social and health impacts of systems and to help identify strategies for reducing their associated hidden costs that occur elsewhere or in the future. By framing sustainability issues in monetary terms, TCA simplifies the communication and integration of sustainability aspects into decision making by consumers, businesses and policy makers. In the context of dietary analysis, TCA can be used to identify the key factors contributing to the negative impacts and true costs of European diets, prioritize improvement actions and develop effective strategies to promote sustainable and healthy food systems. TCA has the potential to inform the transition to sustainable and healthy diets and inevitably fixing our broken food systems.

TCA analyses heavily depends on data, which is often reported as either unavailable or challenging to obtain. This report puts those assumptions to the test by looking at the secondary data sources currently available and their suitability for conducting a TCA analysis of European diets. It assesses the feasibility of such analysis using secondary data sources and highlights existing data gaps. This report thereby introduces a novel methodology for dietary assessment using TCA, an approach that has been little explored in this context to date. To prioritize the often-overlooked and significantly large negative externalities of diets, the report exclusively evaluates the hidden costs, omitting the hidden benefits of current diets. At last, the report delves into the challenges posed by data gaps and limitations, outlining the consequences of these data deficiencies on various stakeholders, and offers a set of comprehensive recommendations to bridge these data gaps and enhance the overall quality, accessibility, and usability of TCA data by highlighting the existing data gaps and deficiencies, researchers and policymakers can prioritize future research and data collection efforts, ultimately leading to more accurate assessments and informed decision-making.

The findings of the report highlight the significant challenges in conducting a comprehensive TCA analysis of European diets due to gaps in secondary data availability, accessibility, and usability. Information regarding food consumption and composition for the European Union countries is of good availability, access and usabiity. More sophisticated nutritional analyses are only accessible via subscription-based services, which can potentially affect the accessibility and completeness of food composition data. Information regarding production and consumption processes – such as data on inputs (e.g. energy use) and outputs (e.g. waste) as well as regarding management practices (e.g. working conditions) – becomes scarcer as one moves further down the value chain, with consumption stage data almost non-existent. While this production and consumption data is to some extent available at country-level (e.g. annual water use by the agricultural sector), it often lacks product-specific details (e.g. annual water use in potato production), with paid life cycle inventory databases offering more detailed information. Data on the environmental impacts of food production provided by various Life Cycle Analysis (LCA) databases are very well available and of very good quality compared to data on social and human capital impacts which have very limited availability and contain large uncertainties. While environmental LCA data is freely available for some countries of production (e.g. France), access to data for other countries require expensive subscriptions, which makes access more difficult. The few sources for social and human capital impact data often require payment for access, too. Well available monetization methods and factors allow translation of environmental impacts into monetary values, though data quality varies. The valuation of social and human capital impacts is still proving difficult, while progress is being made regarding the development of monetisation of already developed qualitative social and human capital impact indicators. The table below summarizes the findings of the report of the key data gaps.

Key data gaps

	Data availability	Data accessibility	Data usability
Food consumption and composition data	Green	Yellow	Green
Food supply chain data	Orange	Orange	Yellow
Environmental impact data	Green	Yellow	Green
Social impact data	Orange	Orange	Green
Human impact data (incl. health data)	Orange	Orange	Green
Environmental impact valuation data	Yellow	Green	Green
Social impact valuation data	Green	Green	Green
Human impact valuation data	Yellow	Green	Green

Notes: Green indicates that the data is widely available, accessible, and usable. Yellow indicates a lower level of availability, accessibility, and usability. Orange denotes very rare availability, accessibility, and usability.

The consequences of these data gaps are far-reaching and affect various stakeholders. Policymakers may struggle to formulate effective strategies for promoting sustainable and healthy diets, while businesses may fail to recognise opportunities for transformation. Consumers lack comprehensive information to guide their dietary choices, and TCA researchers face data limitations in providing essential analysis for decision-making.

To address these challenges, the report offers a set of recommendations:

- **Enhancing data availability:** for international standard setting bodies to develop standardized data collection frameworks, establish data collection mandates, develop standardized methodology and reporting guidelines. On national level dedicated funding for should be allocated for research and data collection efforts.
- **Enhancing data accessibility**: Improve data accessibility through publicly accessible databases or repositories, foster data sharing and collaboration among stakeholders, and encourage EU governing bodies, international organizations, national governments, and research institutions to adopt open data policies.
- **Enhancing data usability and quality through methodological improvements:** Enhance TCA data quality and usability through improvement and harmonization of TCA methodologies, account for spatial and temporal variations in agricultural production, and enable a more efficient utilization of data for multiple purposes, hence optimizing resources and reducing data collection efforts.
- **Establish data governance:** Establish a data governance framework, align TCA data harmonization with existing EU initiatives, incorporate TCA data into the European Data Portal, designate the Joint Research Centre as the TCA data governing body, and scale up Agribalyse on a European level.
- **Future research directions:** Conduct scenario analysis, focus on holistic, systems assessments, conduct more TCA assessments of diets, and establish links between consumption and production-related impacts.

Due to the lack of data, it can be assumed that a comprehensive TCA analysis of dietary patterns in Europe based on secondary data alone is currently not possible, particularly when attempting to capture all three environmental, social, and health costs of diets. While natural capital assessments based on secondary data can be performed well, it becomes evident that comprehensive TCA analyses necessitate additional and substantial efforts in primary data collection for human and social capital related data.

In summary, the report underscores the power of TCA to become a valuable tool to drive sustainability and fairness within food systems, not only in Europe but on a global scale while at the same time underlining the current data related challenges in the advancement of TCA as a tool for informing dietary transitions.

1. Introduction

This chapter sheds light on the crucial role of data in understanding the environmental, social, and health impacts of food, along with their associated costs, in driving food systems towards sustainability. Within the context of the European Union (EU), it provides an overview of the present impact and hidden costs and benefits linked to food systems and consumption patterns. It unravels the reasons behind these hidden costs and benefits that call for a reform of the economic system and agricultural policies. The chapter introduces True Cost Accounting (TCA) as a solution to this issue as it can be used to comprehensively account for all the costs and benefits associated with food systems and their products. It therefore can serve as a valuable tool for directing and monitoring the transformation of food systems. However, data availability, accessibility and quality play a pivotal role in enabling well-informed decision-making with TCA. Finally, this chapter outlines the research objectives and provides a preview of the content covered in this report.

1.1 Background

Over the past five decades, there have been substantial shifts in the global dietary patterns towards energy-intensive and animal-based foods, unfolding significant environmental damage and the rising prevalence of obesity and non-communicable diseases (NCDs), posing a significant challenge to the health and well-being of the global population and the environment (GBD, 2019). Unhealthy diets, characterized by inadequate consumption of fruits, vegetables, and whole grains, and excessive intake of red and processed meat, sugar, and salt, have emerged as prominent risk factors for premature mortality and various diseases. In 2019, dietary risks were the third highest risk group contributing to the global burden of disease, following high blood pressure and tobacco (ibid). In the same year, according to the same study, almost 2 million deaths globally were attributed to high-sodium diets, while 11 million deaths in 2017 were associated with dietary risk factors.

The dietary situation in the EU is also undergoing a complex transformation. Notably, in terms of **health** implications, dietary habits play a crucial role in public health outcomes. According to the European Food Safety Authority (EFSA), poor diets have been attributed to a substantial proportion, up to 50%, of total cardiovascular diseases (CVDs) in Europe and with CVD, particularly coronary heart disease being the leading cause of death and disability. According to the GBD (2019) dietary risks contributed to approx. 1.6 million deaths (20%) in Europe. Food security represents one of the main sustainability challenges listed among the Sustainable Development Goals (SDG 2). **Hunger, obesity, and undernourishment** are some of main challenges that the increasing human population is facing globally. According to the World Health Organisation's (WHO) European Regional Obesity Report 2022 (WHO, 2022) almost two-thirds of adults and one-third of children are overweight or obese in the European Region. According to the report, obesity is the cause of 13 different types of cancer and increases the risk for strokes, heart attack, type 2 diabetes and other **NCDs.**

In terms of **environmental impacts** of diets, on a global level, food consumption has been associated with more than a quarter of anthropogenic greenhouse gas (GHG) emissions including those from land use and land use change, as well as other environmental impacts, such as terrestrial acidification and freshwater eutrophication. Global food systems are the main cause of biodiversity loss (Benton et al., 2021) and resource-intensive agriculture is directly linked to natural resource depletion (Poore & Nemecek, 2018).

In the EU, in 2021 48.3% of the overall consumption-based environmental footprints, i.e. the environmental and climate impacts that result from EU citizens' consumption of goods and services including impacts from production and trade whether produced within or outside the EU, were associated with food consumption[1]. Additionally, EU food consumption heavily relies on agricultural imports and international trade, thus further contributing to the global GHG emissions, deforestation and biodiversity loss. It is estimated that EU is a "net importer of environmental impacts" meaning that the Consumption Footprint is higher than the Domestic Footprint (European Commission, 2023). A recent report by Ruiz Mirazo et al. (2022) shows that despite being a large agri-food exporter, EU carries a significant trade deficit when measured in nutritional terms, such as calories and proteins. According to Schiavo et al. (2021), in 2020-21 EU was a net importer of calories and proteins, equivalent to 11% and 26% respectivly, which largely resulted from animal feed imports for meat and dairy production. **Food**

[1] Consumption Footprint Platform/EPLCA https://eplca.jrc.ec.europa.eu/ConsumptionFootprintPlatform.html accessed on September 15

loss and food waste have emerged in the last decades as major challenges both globally and on the European level. According to Eurostat (2021), in the EU approximately 59 million tonnes of food waste with associated market value estimated at around 130 billion euros (ibid) are generated annually, which is roughly 10% of food made available to EU consumers. Given that in 2021 the EU food import costed around 150 billion euros, the EU is wasting almost as much food as it is importing. While the European Commission has committed to halving food waste by 2030 through the "Farm to Fork" initiative, critics doubt that this target will be met. Furthermore, current agriculture is characterized by intensive farming practices resulting in excessive use of chemical inputs, such as **fertilizers, pesticides, and herbicides**. The annual global use of pesticides in 2021 was estimated at 3,53 million tonnes (FAOSTAT, 2023). The use of chemical inputs that contain heavy metals such as cadmium, zinc, etc. is also common in intensive agricultural practices. This poses risks of water and soil contamination and further negative impacts on biodiversity but also health. The EU is one of the world's biggest markets for pesticides (Tostado & Bollmohr, 2022). In this context, the EU Farm to Fork Strategy has proposed legally binding EU-level targets to reduce 50% of chemical pesticides. However, data availability on pesticide use remains a major issue. The proxy indicator to pesticides use is the sales of pesticides. In the EU this number has remained significantly stable at around 360 thousand tonnes per year valued at around 12 billion euros (in 2019). However, detailed statistics that will link the pesticides to the type of crop and country are currently unavailable for most crops and countries in the EU.

Dietary patterns have far-reaching **social implications** that extend beyond health and environmental considerations. Their impact on livelihoods is one such notable aspect given the food industry's major role in employment. Many workers in the food industry still face low wages and inadequate labour protection (Fanzo & Davis, 2019). Furthermore, European diets which heavily rely on global supply chains are not immune to the issues outside of Europe such as child and forced labour exploitations and social concerns. Addressing the social aspects of food systems in Europe requires a multi-faceted approach that not only promotes healthier eating patterns but also advocates for fair labour practices, living wages, and child labour-free supply chains to ensure that food provisioning does not come at the expense of livelihoods, workers' rights, and vulnerable populations worldwide (European Comission, 2020).

The intricate picture of sustainability challenges associated with European diets becomes even more complex when we consider the diversity of countries and population groups across the EU. For instance, the PLAN'EAT project partners at CREA carried out a dietary pattern mapping exercise in 11 countries and nine target population groups in Europe. They looked at the similarities and differences between local and national dietary patterns and compared the actual food consumption with the national recommended guidelines. The results of the dietary pattern mapping showed heterogeneity in the consumption patterns across various countries and population groups. For instance, Italy, Spain, and Greece performed better in terms of sustainability and health when applying the World Index for Sustainability and Health (WISH) than other EU countries. It also showed gender-related disparities, such as females following better dietary patterns than males with respect to health and sustainability. Similar disparities were also revealed among various population age groups. For instance, the elderly in southern European countries showed the highest WISH, pointing to healthy and sustainable eating habits. This kind of heterogeneity makes the task of policy makers to address the growing health and environmental crisis associated with our food systems even harder and highlights the impossibility of "one size fits all" policies (Verkerk, 2019).

The current food systems not only fail to address growing crises, such as the climate and biodiversity crisis associated with how we produce and consume food but show steady trends of exacerbating these crises (IPCC, 2019). The failure is two-sided: economic and political. The cost of food extends far beyond the price displayed at the checkout counter. The cost of food at the point of sale encompasses expenses associated with food production, processing, distribution, and retail as well taxes and subsidies. However, the price tag fails to incorporate the expenses incurred by healthcare due to diet-related illnesses, the present and future environmental consequences such as from deforestation, pollution and GHG emissions, or social injustices such as the exploitation of underpaid farm workers or the utilization of forced child labour (Hendriks et al., 2023).

These aspects discussed above are commonly referred to as negative externalities. The United Nations environment initiative The Economics of Ecosystems and Biodiversity for Agriculture and Food (TEEBAgriFood) defines external costs or externalities as "third-party costs (or benefits) of bilateral economic transactions whose counterparties have not accounted for these costs (or benefits) when undertaking their transaction" (TEEB 2018, p. 2). In simpler terms, externalities are costs or benefits that are not directly factored into economic transactions between buyers and sellers. Besides negative externalities, some agricultural production models also cause benefits to society, such as landscape conservation, community cohesion and employment opportunities in rual areas. These services are usually provided free of charge, although they generate important (economic) benefits for society.

Despite the importance of these externalities, traditional market mechanisms often fail to adequately account for the externalities generated by food systems. The current costing, pricing, accounting, and reporting structures of businesses do not fully capture the environmental, social, and health costs and benefits associated with food production and consumption. As a result, market failures occur, leading to inefficient allocation of resources and unsustainable practices.

The disconnect and the huge gap between the costs that businesses consider, and the prices consumers pay compared to the broader economic, social, and environmental consequences of their choices creates an incentive structure that perpetuates harmful practices. Unsustainable farming methods, overreliance on resource-intensive production processes, and wasteful consumption patterns persist due to the limited market signal about their negative impacts. Consequently, this results in a cycle of environmental degradation and social inequality that can only be interrupted by addressing the gaps in our understanding of the hidden costs and correcting the market failures with respective market regulations.

Policy failures further exacerbate the problem by perpetuating the existing imbalances and failing to incentivize sustainable food systems. The Common Agricultural Policy (CAP) is one of the biggest recipients of the EU budget funds. In 2021, European member states allocated a significant portion of their funds, specifically EUR 55.7 billion, which accounted for 33% of the total EUR 168 billion, to support agriculture and food production through the CAP. An uneven distribution of the funds can be observed when looking closer at the CAP direct aid at farm level: 75% of CAP beneficiaries received around 15% of funds, while approx. 2% of farms (122 thousand farms out of 6.3 million) received 31% of total direct aid paid out in 2019. Though the CAP subsidies have been associated with negative environmental impact in the past, such as encouraging over-intensification of agriculture, which has led to deforestation and further degradation of land and biodiversity loss, as well as increase in the use of chemical inputs and pesticides (Brunner & Huyton, 2009), it is still not clear if the new CAP will yield substantial climatic and environmental advantages (Guyomard et al., 2023). The EU and its Member States have committed to gradually phase out the environmentally harmful subsidies although no specific targets and goals have been defined. The agricultural sector currently accounts for 35% of all the mapped environmentally harmful subsidies in the EU and hence will be one of the first sectors to be considered by the reform of environmentally harmful subsidies (European Commisson, 2022). Furthermore, the influence of these subsidies extends beyond European borders, impacting developing countries' livelihoods and economic stability. The imbalances created by the system can lead to unfair competition and hinder the growth of sustainable food systems in these nations (Scown et al., 2020). The system in place – with both harmful and conflicting subsidies – incentivizes the maintenance of an unsustainable European food system. Recognizing and addressing these market and policy failures is crucial to build an economic and political system that supports sustainable food systems (ibid).

Addressing the ways in which food is produced, consumed, and regulated plays a crucial role in diminishing the overall environmental and social impact at EU level. At the same time, this transformation represents a significant potential for enhancing the dietary habits of EU citizens and promoting fairness, justice, and food security within the EU and beyond its borders. This endeavour also provides an opportunity to reassess and redirect government support towards the existing system. According to the Food and Land Use Coalition (FOLU, 2019) the advantages gained from transforming the food system are estimated to surpass the initial investment costs by a factor of 15.

Healthy and sustainable diets are crucial for transforming food systems, with increasing evidence supporting the environmental and health benefits of plant-based diets. The EAT-*Lancet* Commission's planetary health diet, published in early 2019 (Willett et al., 2019) emphasizes the need to double the global consumption of healthy foods like fruits, vegetables, legumes, and nuts while reducing the consumption of less healthy foods such as added sugars, saturated fats, and red meat to less than half of current levels. High-income countries, in particular, must make significant reductions in the consumption of unhealthy foods to align with the Commission's guidelines. Achieving a sustainable and healthy food system requires multiple strategies, including improving food production practices, reducing food loss and waste and shifting towards the planetary health diet (ibid).

To guide the transformation process effectively, we need to understand how to attain sustainable and healthy diets for everyone. This requires a comprehensive understanding of the health, environment, social and economic impacts associated with different aspects of food production, distribution, and consumption and potential trade-offs between the different sustainability dimensions. For example, promoting local and traditional diets can support cultural heritage, but might clash with the goal of reducing the environmental impact of certain food choices.

Addressing these trade-offs requires a holistic and systemic approach such as TCA. TCA offers a promising method to transform food systems. It measures the environmental, social, health and economic impacts of food production and consumption and estimates the associated costs and benefits. By considering the full range of impacts associated with food production and consumption, TCA provides a comprehensive framework for decision-making. TCA enables the identification of the hidden costs and benefits that are currently not considered in market transactions, thereby enabling a more accurate assessment. In doing so, the attempt is to facilitate sustainable decision making by governments, consumers, businesses and other stakeholders in the food system (Gemmill-Herren et al., 2021). TCA acknowledges that relying solely on indicators such as yields, profits, calories, or proteins to determine the success and suitability of food systems is deceptive. Such narrow metrics can lead to unintended and far-reaching consequences, incurring significant costs to the environment, human health, and society at large.

While TCA offers a comprehensive framework for assessing the true costs and benefits of food systems, some people have raised scepticism regarding its data intensity, complexity, and extensive need of financial, time and intellectual resources. Lack of data is described as one of the main barriers of adopting TCA (TMG-Think Tank for Sustainability & WWF, 2021).

Despite the importance of assessing the true costs of European diets, data gaps persists. These gaps arise from the complex nature of gathering comprehensive data across multiple sectors, including agriculture, health, environment, and labour. The fragmented and diverse data sources available pose significant challenges for conducting an integrated analysis of the true cost of diets. Without a comprehensive and standardized dataset, policymakers, researchers, and stakeholders face difficulties in accurately estimating and comparing the true costs associated with different dietary patterns in the EU.

1.2 Research objectives

The primary objective of this report is to analyse the availability or the lack of secondary data for assessing the true cost of European diets. By identifying the data availability, accessibility, existing limitations, and data deficiencies, we aim to provide valuable insights into the possibilities but also challenges faced when evaluating the true costs associated with European dietary patterns. To prioritize the often-overlooked and significantly large negative externalities of diets, the report exclusively evaluates the hidden costs, omitting the hidden benefits of current diets. Specifically, this report seeks to:

1. Explore the current methodologies and indicators used to estimate the cost of European diets
2. Identify the secondary data that is needed to perform TCA of European diets.
3. Analyse the secondary data availability and identify the key data gaps and deficiencies that hinder accurate assessments of the true costs associated with European diets.
4. Investigate the potential consequences of data gaps on and opportunities of TCA for policy-making, sustainability targets, and public health initiatives.
5. Propose recommendations for enhancing data availability, accessibility and quality, address TCA data governance and to bridge the identified data gaps as well as research gaps.

1.3 Significance of the research

Understanding the true cost of European diets is of utmost importance for several reasons. Firstly, it allows policymakers to make informed decisions when formulating agricultural, environmental, and health policies. Accurate TCA assessments can help identify the trade-offs and synergies between different sustainability goals, such as reducing GHG emissions, conserving natural resources, and promoting human health. By quantifying the true costs of policy interventions, policymakers can prioritize interventions that align with sustainable development objectives and promote more sustainable and resilient food systems.

Secondly, TCA can play an essential role in promoting sustainable and healthy dietary choices among European consumers. By providing a comprehensive assessment of the true costs associated with different diets, individuals can make more informed choices regarding their food consumption patterns.

Lastly, this report aims to contribute to the scientific literature on the true costs of food and diets, particularly in the European context. By highlighting the existing data gaps and deficiencies, researchers and policymakers can prioritize future research and data collection efforts, ultimately leading to more accurate assessments and informed decision-making.

Addressing this data gap is crucial to support evidence-based decision-making and inform policy interventions that can drive sustainable changes in food consumption patterns. By filling this gap, we can identify the most significant contributors to the true cost of European diets, prioritize actions for improvement, and develop effective strategies to promote sustainable and healthy food systems.

By addressing the data gaps for assessing the true cost of European diets, this report aims to contribute to the ongoing efforts towards the transition to sustainable food systems, healthier dietary choices, and evidence-based decision-making.

1.4 Structure of the report

This report is organized into six chapters. Chapter 1 has introduced the research topic, outlining the background, research objectives, and the significance of the research. Chapter 2 presents a comprehensive review of the existing literature on the TCA of European diets, including information on Life Cycle Assessment. Chapter 3 outlines the TCA method for diets and identifies the data needed to assess the true cost of diets. Furthermore, it outlines the data mapping, data search criteria and approach. Chapter 4 presents the results of the data mapping and evaluates the secondary data availability, data accessibility and data quality and usability. Chapter 5 identifies the key data gaps for TCA of diets and discusses the potential consequences of these gaps. Finally, Chapter 6 concludes the report and presents recommendations for improving data situation, data governance and addressing future research directions.

2. Literature overview

This chapter provides a short overview of the existing literature on TCA in the context of the analysis of European dietary patterns. It examines the frameworks, principles, and methods used in previous research and studies to estimate the true costs associated with food production and consumption. Furthermore, it provides a definition of diets in the TCA context.

2.1 True Cost Accounting of diets

'True Cost Accounting' (short: TCA), the practice of defining, quantifying and monetizing (food system) impacts, has seen a rise in international interest over the past years. Multiple organizations have recently published reports on the benefits and needs of TCA to inform the transformation of food systems (FAO, 2023). However, most of these reports remain on a relatively high level and do not specify methodological details (de Adelhart Toorop et al., 2021), while some offer procedural guidelines and suggestions for indicator and valuation approaches (True Cost Initiative, 2022). This sub-chapter outlines the relevant available literature that can be utilized for the analysis of the true costs and benefits of European diets.

The TEEBAgriFood framework, outlined in the TEEBAgriFood Scientific and Economic Foundations report (TEEB, 2018) outlines the basis for a systemic economic evaluation of food systems. It was developed by the TEEBAgriFood Initiative, which was launched in 2015 by the United Nations Environment Programme (UNEP) in collaboration with the Food and Agriculture Organization of the United Nations (FAO), the EU and others. It makes a strong case for applying systems thinking to the evaluation of food systems by articulating the interrelationships and interdependencies between the different constituents of food systems. The TEEBAgriFood Evaluation Framework outlines four key components – stocks, flows, outcomes and impacts – which facilitate a standardized assessment of eco-agri-food systems. By offering clear definitions and specifying measurement concepts and boundaries, the framework determines the specific aspects of eco-agri-food systems that should be considered in a thorough evaluation or appraisal (ibid). The framework expresses the need to clearly represent all material interactions between the environment (natural capital), economy (produced capital), society (social capital) and health (human capital) at all stages of the supply chain, from cradle to grave (see Table 1 and Figure 1). Since its publication, the TEEBAgriFood framework has been widely embraced as THE point of reference for TCA for food systems analysis.

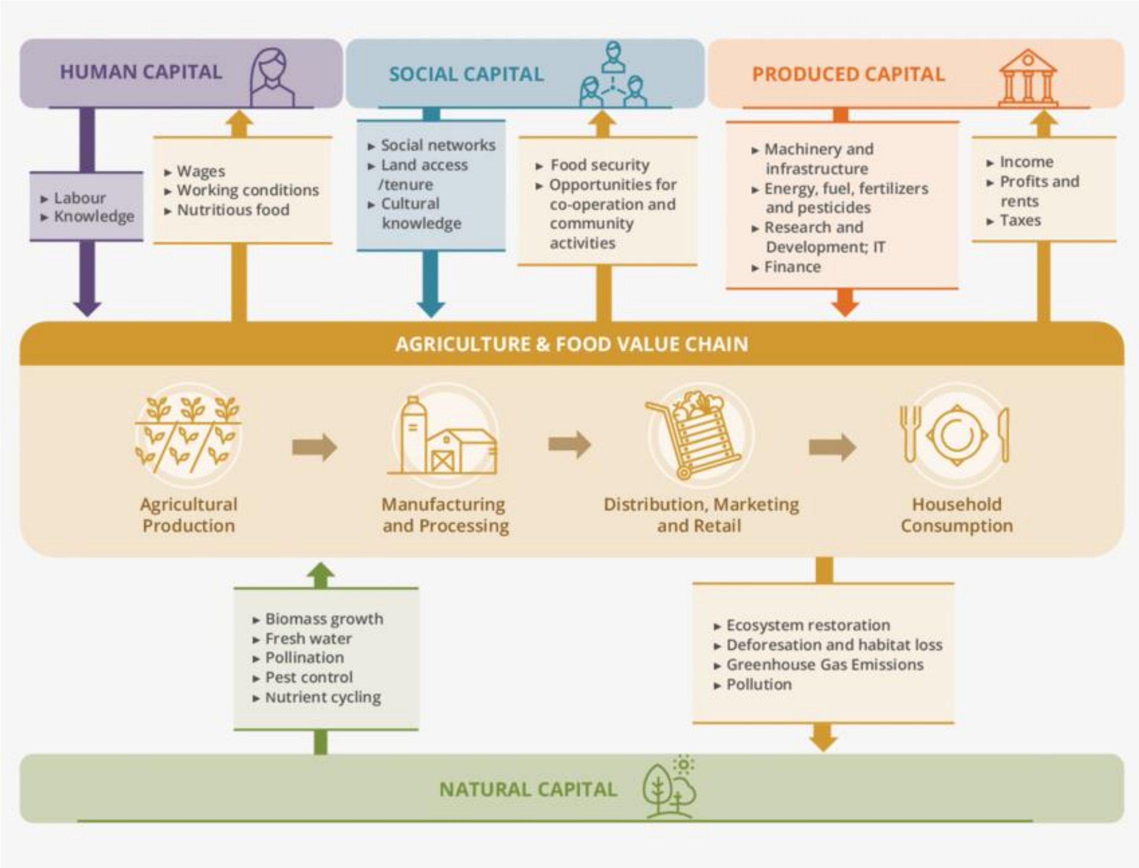
Table 1: Capitals based approach

NATURAL CAPITAL	HUMAN CAPITAL	SOCIAL CAPITAL	PRODUCED CAPITAL
The limited stocks of physical and biological resources found on Earth, and the limited capacity of ecosystems to provide ecosystem services.	The knowledge, skills, competencies, and attributes embodied in individuals that facilitate the creation of personal, social, and economic well-being.	Networks, including institutions, that share norms, values, and understandings that facilitate cooperation within or among groups.	All manufactured capital, such as buildings, factories, machinery, and physical infrastructure (roads, water systems), as well as all financial capital and intellectual capital (technology, software, patents, brands, etc.).

Source: TEEB (2018)

The TEEBAgriFood framework is guided by the principles of **universality, comprehensiveness,** and **inclusiveness**. This means that the framework is applicable across different contexts, includes the entire value chain and relevant elements (hidden costs, benefits, dependencies, and impacts), covers all capitals, including produced, natural, human, and social capital and accommodates various assessment approaches.

Figure 1: Food Value Chain and Capitals Approach



Source: TEEB (2018)

The TEEBAgriFood Scientific and Economic Foundations report mentions dietary comparison as one of the five families of application of the framework; for example comparing diverse set of diets such as Mediterranean diet, plant-based diet and vegetarian diet. The report draws on two case study examples where TEEBAgriFood framework was adapted to dietary analysis. Table 2 illustrates a snapshot of the two case studies.

Table 2: Dietary case studies presented in TEEBAgriFood

Family of application	Case study	Aspects along the agri-food value chain	Comparison	Geographic scope	Valuation methods and evaluation models	Sources
Dietary comparison	Welfare and sustainability effects of diets	Household consumption	Multiple sustainability dimensions of dietary recommendations	France	Life cycle assessment, cost benefit analysis, avoided cost	Irz et al., (2016)
Dietary comparison	Ten different diet scenarios ranging from meat based to vegetarian diets	Agricultural production, Manufacturing, Distribution, Household consumption	Bio-physical impacts of different diets on land use and carrying capacity	United States of America	Land use and biophysical models, LCA	Peters et al., (2016)

Source: TEEB (2018)

The first case study, by Irz et al. (2016), assesses the welfare and sustainability effects of diets in France. It evaluates French dietary recommendations across sustainability dimensions, using a rational consumer behaviour model to align preferences with dietary guidelines. It considers taste, cost, welfare, deaths avoided, GHG emissions, and acidification and utilizes Life Cycle Assessment for environmental effects. The study employs cost and benefit methodology and uses monetary valuation to assess various effects collectively.

The second case study, by Peters et al., (2016), looks at ten different diet scenarios ranging from meat based to vegetarian diets in the United States (U.S.) and “human carrying capacity” (persons fed per unit land area) of agricultural land in the U.S. (ibid, p. 2). It investigates how dietary changes affect land use and carrying capacity using various diet scenarios and a "Foodprint model". The study concludes that shifting towards plant-based diets in the U.S. has the potential to significantly reduce agricultural land requirements and increase the carrying capacity of agricultural resources. The analysis emphasizes the importance of considering the partitioning of land between different uses and suggests that diets with low to modest amounts of meat, including vegetarian diets with dairy products, outperform vegan diets in terms of land use efficiency.

While there are previous studies that have explored dietary patterns and their environmental aspects, very few have used TCA to assess natural, human and social capital impacts simultaneously and monetised the corresponding indicators (Minotti et al., 2022). Although there are studies analyzing the sustainability of diets that have taken a TCA-like approach and examined individual aspects like greenhouse gas emissions and corresponding global warming, they did not put a monetary value on their findings (TMG-Think Tank for Sustainability & WWF, 2021; Hallström et al., 2017). Others have employed TCA but applied it solely to food production systems (Sandhu et al., 2021). Another study by the Rockefeller Foundation (Rockefeller Foundation, 2021a) estimated the monetary value of externalities generated by the entire U.S. food system and found that in 2019 American consumers spent an estimated $1.1 trillion on food, but when accounting for all the hidden costs the true cost of the U.S. food system is at least three times as big—$3.2 trillion per year. In a different study by the Rockefeller Foundation (Rockefeller Foundation, 2021b), they used TCA to look at seven impact areas namely, human health, environment (GHG emissions, water use and soil erosion), economy, biodiversity (land use and pollution), livelihoods, animal welfare and resilience of U.S. school feeding programs, highlighting their value beyond the financial investment and applying equity as a key component. Baltussen et al., (2016) examined the impact of livestock production systems on human systems and ecosystems in Tanzania. Although some studies have adopted a comprehensive perspective analysing entire diets or food system (Barrett C. et al., 2021; Fitzpatrick et al., 2019; Perotti, 2020), they yet again have used other methods than TCA and hence this area remains relatively unexplored.

One of the recent and comprehensive attempts to apply TEEBAgriFood framework to analyse the sustainability and healthiness of diets, is the study by Minotti et al. (2023). It assessed the costs and impacts of adopting more sustainable and healthy diets in Italy using TCA. The study focused on understanding the environmental, social and health impacts of dietary choices. The study is also notable for solely using existing secondary data sources for their assessment which are open access or accessible upon request. Despite the shortcomings, such as the consideration of limited number of indicators per area of impact (environmental, health and socio-economic) or the small group of food products included in the baseline Italian diet, the study provides a TCA methodology that can be applied to other dietary patterns or geographical areas.

Since the publication of the TEEBAgriFood Scientific and Economic Foundations report in 2018 (TEEB, 2018) different organisations – mainly business consultancies and universities – have been working towards developing context specific methodologies (Capitals Coalition, 2023). For example, the True Cost Initiative has developed the True Cost Accounting Agrifood Handbook (True Cost Initiative, 2022), which in detail describes the TCA methodology, including measurement indicators, monetisation factors, data collection and reporting for agricultural and food supply chains. However, so far, no specific methodology for the TCA of diets has been developed. The recent development of TCA methodologies by various organizations has helped increase transparency in the food sector, but it has also made it difficult to compare the results obtained through different methodologies. In 2020, the Global Alliance for the Future of Food commissioned the Impact Institute as a member of the working group on the “harmonization” of the TCA Accelerator to conduct an analysis to better understand the opportunities and barriers to harmonizing the different TCA approaches for agrifood systems (De Adelhart Toorop et al., 2021). In this study, the authors analysed prominent TCA methodologies across five functional areas covered by their assessment frameworks: products, organizations, systems, geographical regions, and investments. The results indicated that the majority of existing frameworks are focused on products and/or organizations. The study identified common features, including the assessment of externalities/dependencyies, consideration of economic, environmental, and social impacts, and the application of standardized measures. However, discrepancies were observed in suggested indicators, monetary valuation, and the process of aggregation. True Cost Accountint Inventory Report (Soil & More Impacts et al., 2020), a collaborative effort of TMG-Think Tank for Sustainability and Soil and More Impacts, provides a collection of methodologies, case studies, and valuation approaches for TCA as well as links to frameworks, tools and databases. The variations in TCA methods showcase that there has not been an agreement on "the one" method for TCA.

To advance TCA while calling for greater consistency in the dynamically evolving field, the Global Alliance for the Future of Food commissioned in 2020 a guide entitled *Applying the TEEBAgriFood Evaluation Framework – Overarching Implementation Guidance*, which outlines the necessary methodological steps of TCA and aims to ensure that TEEBAgriFood applications are coherent and consistent (Eigenraam et al., 2020). The guidelines outline four phases and 23 steps that each TCA assessment needs to undertake. The four phases include: (1) The "**Frame**" step involves defining the assessment's questions, purpose, and stakeholders; (2) In the "**Describe and scope**" phase, the relevant eco-agri-food system is described, impact pathways are identified, and the assessment's scope is defined, including geographic coverage, time period, and the range of impacts to be considered; (3) "**Measure and value"** focuses on selecting analytical methods, collecting and validating data, and addressing data gaps and uncertainties, often including assigning a monetary value to impacts; (4) The final step, "**Take action**," emphasizes the communication and application of assessment results to drive actions and influence policies, typically in collaboration with stakeholders and partners.

The TEEBAgriFood evaluation framework does not specify one specific method to apply for the impact assessment of food systems. Instead, it supports both qualitative and quantitative approaches. It outlines five evaluation methodologies that allow to evaluate and assess the impacts of food systems elements (ibid, p. 271):

i. Cost Benefit Analysis
ii. Life Cycle Assessment
iii. Evaluating the role of merit goods
iv. Integrated approaches that evaluate several goals
v. Multi-Criteria Analysis and Cost-effectiveness Analysis

Other impact measurements referred to in the literature are scenario analysis, natural resource damage assessments, strategic target-setting and monitoring and risk assessment (ibid). However, until now, Life Cycle Assessment (LCA) has been the most popular impact assessment method for the assessment of the true costs and benefits of food.

Besides LCA, TCA shares most similarities with Cost Benefit Analysis employed by governments for decision-making. While Cost Benefit Analysis involves subtracting costs from benefits to arrive at net monetary amounts, TCA extends beyond Cost Benefit Analysis by assessing a broader range of positive and negative externalities in food systems (Merrigan, 2021).

Though disputed, reaching a final cost estimation is a crucial aspect of TCA's practicality. The distinctive "added value" of employing a TCA approach includes the valuation of changes in natural, social, human and produced capital due to human activities. TCA allows for the assessment and comparison of foods and diets by assigning value to positive and negative externalities associated with dietary patterns.

Monetary valuation or monetization is the quantification and conversion of external impacts into monetary measures (Pizzol et al., 2015). It is built on the principles of (i) quantification of sustainability issues/externalities in indicators; (ii) conversion of indicators into monetary values; (iii) aggregation of monetary values to determine the total cost or value of the impact (Ponsioen et al., 2020).

While there are various methods and approaches to monetization, transparency and broad acceptability are important requirements for each method. Common monetary valuation methods are the following:

- **Market price proxies** use data from existing markets to determine, approximate or derive values for goods for which a market exists. Some of the methods that fall under direct market value approaches include measurements of Production Functions and Dose Response Functions, analysis of Averting or Defensive Expenditure, Residual Imputation methods, and various cost-based techniques (Replacement/Restoration/Cost Savings).

- **Stated preference methods** create hypothetical markets in which respondents state their willingness to pay or accept directly or indirectly. These methods include contingent valuation, choice experiments, conjoint choice and group valuation.
- **Revealed preference methods** use data from existing markets to assign values to goods for which no market exists. These methods include averting costs/defensive expenditures, hedonic pricing and travel costs.

Currently there are several publications available, which offer monetisation factors for mainly environmental impacts, but also some social and human capital impacts, which can be applied to TCA studies using the value transfer approach (De Bruyn et al., 2018).

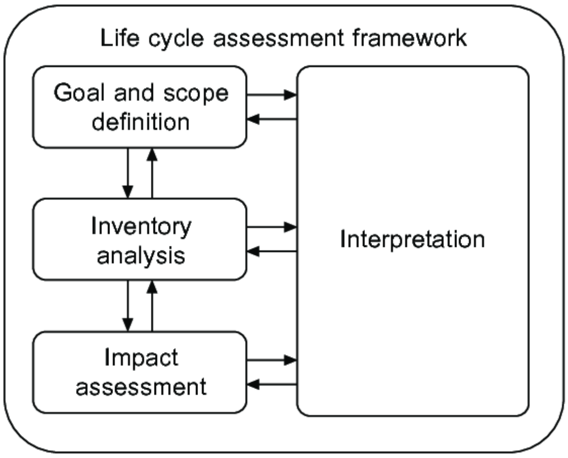
The TCA method has faced previous criticisms regarding the contention that monetization may not always be universally feasible or suitable, especially in the context of social capital considerations. In response, organizations like True Price have formulated the “Principles for True Pricing” which establish normative foundations of true pricing rooted in a rights-based framework (True Price Foundation, 2020). This approach centres on the inherent rights of both present and future generations, as well as the responsibilities incumbent upon economic actors to uphold these rights (ibid).

In conclusion, our literature review has illustrated the absence of a standardized approach for assessing the true cost of diets. Nevertheless, within the broader field of food systems assessment, we have identified valuable guidance documents and relevant studies that offer essential insights. Building upon this foundation, Chapter 3 of our report will introduce the methodology we suggest for the TCA of diets. This methodology will serve as the cornerstone for our subsequent analysis, which will explore both the demand for and accessibility of data required for TCA of diets within the European context.

2.2 Life Cycle Assessment of diets

LCA is one of the most popular impact assessment methods used for TCA and since it will be the method used in this report, we will briefly provide an introduction to this method. LCA is a widely recognized method by international bodies including the EU for assessing the environmental impacts of products, processes, or systems. It systematically quantifies these impacts throughout a product's life cycle, including raw materials, production, transportation, use, and disposal. LCA offers a holistic environmental footprint of products, aiding in identifying areas where adverse environmental impacts can be reduced and highlighting potential trade-offs across the value chain. Besides the evaluation of environmental impacts, also the analysis of social impacts through LCA (called s-LCA) exists, however, it is much less developed.

Figure 2: LCA framework



Source: ISO 14040 (2006)

In contrast to the relatively nascent TCA method, LCA has been around since the 1960s and was first standardised in 1996 by the International Organization for Standardization. Today, ISO 14040 (ISO, 2006) describes the principles and framework, while ISO 14044 (ISO, 2006) specifies requirements and provides guidelines for LCA.

The LCA method consists of 4 steps: (1) **goal & scope definition** which defines the purpose of the study, the system boundaries, functional unit and various impacts; (2) **life cycle inventory (LCI)** step which gathers data across the stages of the system boundary; (3) **impact assessment** step which converts the inventory data into environmental impact categories; (4) **interpretation** step which analyses the results and draws conclusions regarding food's environmental performance (see Figure 2).

TCA borrows the concept of the functional unit from LCA, ideally a measure of the function of the object under analysis. When analysing and comparing diets an ideal functional unit would be a combined measurement of calories and nutrients. However, there is no consensus among the scientific community when it comes to the choice of a functional unit when it comes to including health and nutrition considerations in an LCA assessment of diets. Common examples of food-related functional units are 1 kg of beef, 100 calories of food, or 1 ha of land. These measures, however, fall short of making reference to both nutritional quality and energy level of the food product, the main functions of food. Also, LCA usually compares foods based on a single functional unit (product quantity measured by yield or area), which might fail to fully reflect the natural multi-functionality of foods and diets (Heller et al., 2013).

Implementation of a food systems approach requires a comprehensive set of metrics, i.e., relevant indicators that are designed to serve as a tool for measuring, comparing, or tracking the performance of a system. These metrics play a crucial role in various aspects, such as describing the current status of food systems, quantifying the relationships necessary for exploring causal mechanisms, establishing baseline references to measure progress towards key objectives, evaluating the consequences of system changes and proposed alterations, assessing the effectiveness of interventions, and ultimately facilitating the expansion of successful initiatives (Allen & Prosperi, 2014).

Furthermore, food system metrics and indicators serve as valuable tools for structuring high-level discussions as well as communicating scientific data to policymakers and the public (Lehtonen et al., 2016). In this regard, they not only contribute to raising awareness and enhancing transparency but also extend their utility beyond mere monitoring and evaluation. Ideally, a standardized methodology and set of indicators could be employed globally and over time to enable meaningful comparisons.

S-LCA are conceptually defined by UNEP and Society of Environmental Toxicology and Chemistry (SETAC) Guidelines for the Social Life Cycle Assessment (UNEP, 2020). They cover five stakeholder categories, and the impact categories are linked to 31 impact subcategories, along with indicators and inventory data sources:

- Worker/human rights: freedom of association and collective bargaining, child labour, fair salary, working hours, forced labour, equal opportunities/discrimination, health and safety, social benefits/social security.
- Consumer/cultural heritage: health & safety, feedback mechanism, consumer privacy, transparency, end of life responsibility.
- Local community/working conditions: access to material resources, access to immaterial resources, delocalization and migration, cultural heritage, safe & healthy living conditions, respect of indigenous rights, community engagement, local employment, secure living conditions.
- Society/health and safety: public commitments to sustainability issues, contribution to economic development, prevention & mitigation of armed conflicts, technology development, corruption.
- Value chain actors/governance: fair competition, promoting social responsibility, supplier relationships, respect of intellectual property rights.

In the past, the study of nutrition, health, and environmental aspects of food was separate, but over the last two decades, there has been a notable increase in research combining these elements. The number of LCAs that address health and/or nutrition related aspects has risen according to Scopus from 56 in 2000 to 693 in 2020, indicating growing interest and data availability in this integrated approach (McLaren et al., 2021). There is also a growing body of literature that addresses the aspect of nutrition in LCA by questioning whether nutrition should be considered a factor (e.g. element of the functional unit) or an impact in those analyses (Weidema & Stylianou, 2020). While nutrition is one of the obvious functions of food, a diet that is not nutritionally balanced can cause human health impacts. This dual role of nutrition has led to some confusion on how to include nutritional measures in LCA (ibid).

The literature suggests that for the impact assessment of human health categories using LCA includes human toxicity indicators: (i) particulate matter formation potential; (ii) human carcinogenic toxicity potential; (iii) human non-carcinogenic toxicity potential; (iv) ionizing radiation potential; (v) ozone formation potential—ecosystems; (vi) ozone depletion potential. Though these are mostly confined to industrial products, human toxicity is nevertheless relevant for agriculture. A common metric to express health impacts is Disability Adjusted Life Years (DALY).

2.2.1 FOOD LCA AND DIET LCA (NUTRITIONAL LCA)

A diet can be defined as the compilation of food items consumed by an individual or a broader community over an extended period, representing their habitual food intake (McLaren et al., 2021).

In Chapter 1 we looked at various diet related sustainability and health challenges. In response, sustainable diets have emerged as crucial solutions to address these challenges and align with the 2030 Agenda for Sustainable Development SDGs. The concept of sustainable diets aims to incorporate nutritional adequacy, cultural acceptance, environmental sustainability, and economic affordability to shape future consumption patterns.

The lack of consensus among countries regarding what constitutes a healthy and sustainable diet prompted the FAO and the World Health Organization (WHO) to produce the Sustainable Healthy Diets Guiding Principles in 2019. Unlike previous definitions, this new approach placed health as the primary consideration while still highlighting the importance of all relevant aspects. Sustainable healthy diets were therefore defined as "dietary patterns that promote all dimensions of individuals' health and wellbeing, have low environmental pressure and impact, are accessible, affordable, safe and equitable, and are culturally acceptable." The guiding principles comprised 16 aspects of sustainability grouped under three categories: health, environmental, and sociocultural, all of which must be collectively considered to achieve sustainable healthy diets (FAO and WHO, 2019). It is here that TCA can support in striving towards more sustainable diets by looking at and weighting all the dimension of sustainable diets as defined by FAO.

Sustainable Healthy Diets

Sustainable healthy diets are dietary patterns that promote all dimensions of individuals' health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable. The aims of Sustainable healthy diets are to achieve optimal growth and development of all individuals and support functioning and physical, mental, and social wellbeing at all life stages for present and future generations; contribute to preventing all forms of malnutrition (i.e. undernutrition, micronutrient deficiency, overweight and obesity); reduce the risk of diet-related NCDs; and support the preservation of biodiversity and planetary health. Sustainable healthy diets must combine all the dimensions of sustainability to avoid unintended consequences. (FAO/WHO, 2019)

There are numerous studies which assess the environmental footprints of specific diets (e.g. omnivorous, vegan, vegetarian) applying LCA methodology (Pimentel & Pimentel, 2003; Coelho et al., 2016). One of the recent developments of the food LCA has been the increased interest in the relationship between nutritional qualities and environmental aspects of the diets (Aleksandrowicz et al., 2016).

In LCA studies analyzing diets, the primary emphasis is on evaluating the overall environmental performance of the entire diet, with discussions occasionally extending to specific food items. However, the central focus of diet LCA results is on the comprehensive assessment of entire dietary patterns rather than individual food items. Several LCA studies have been conducted in relation to diets. For instance, the study on Atlantic dietary pattern (Esteve-Llorens et al., 2019) or a study on various dietary scenarios worldwide by González-García et al. (2018). The takeaways from those studies as in comparison to food LCA studies which look at a single food product, are the following:

- Consumption-oriented dietary LCAs focus on comparing the environmental footprints of different diets and altering diet composition to reduce overall environmental impacts (Frehner et al., 2021a)

- These assessments rely on various data sources, but they often simplify the nutritional aspect by primarily considering macronutrients or calories, which may not fully represent the nutritional complexity of foods and dietary patterns (Thoma et al., 2022)

When evaluating the environmental impact of food items, a **product-level analysis** is typically employed, focusing on specific inputs, outputs, and emissions associated with each food item's life cycle such as understanding the resource usage, greenhouse gas emissions, land and water usage, and other ecological consequences associated with the production, distribution, and consumption of specific foods. This requires detailed data on agricultural practices, transportation, processing, and waste management for individual foods. The system boundaries in this case are typically defined as the "cradle-to-gate" or "cradle-to-farm gate" level. This means that the analysis includes all of the environmental impacts associated with the production of the food product, from the extraction of raw materials to the delivery of the product to the factory gate.

Table 3: Methodological differences between different dietary patterns

	Individual diet	National and sub-national diet	Hypothetical diets
Scope and scale	The focus is on an individual's consumption patterns, considering the entire life cycle of the food consumed, from production to disposal. The analysis is typically on a smaller scale, focusing on the impacts of specific food choices made by an individual.	The analysis considers the overall food consumption patterns within a country, accounting for the impacts of different food items, production systems, and supply chains. The scale of analysis is larger, covering the entire nation's food system.	The analysis extends from individual and national/sub-national levels to global food systems. Global food supply chains are to be considered.
Data requirements	Data collection may involve dietary surveys, food consumption data, and information on the environmental, health and social impacts of specific food items. Collecting detailed data on individual preferences, nutritional requirements, and behavioural patterns is crucial for an accurate TCA analysis.	Data collection for national diets involves a combination of primary and secondary data sources, including large-scale national surveys or representative sample of population, agricultural statistics, trade data, and environmental impact assessments. At this dietary level it is also important the cultural, demographic and socio-economic factors that influence dietary choices.	Data requirements include detailed lists of food items and food groups that are included in the hypothetical diet. When assessing the human capital health impacts of these diets, the food composition databases can be used to estimate the nutritional content of the diet. The established dietary guidelines or health and nutrition recommendations on the national level provide reference standards for carrying out comparisons.

Source: own elaboration

However, when assessing the environmental impact of diets, a **systems-level approach** is necessary, considering the combined effects of various food items consumed within a dietary pattern, considering not only the environmental burdens of individual foods but also the complex interactions between various food items and their production processes, reflecting the interconnectedness of the broader food system that arise when various foods are combined. This requires data on consumption patterns, dietary compositions, and the relative proportions of different foods within diets. Additionally, estimating the overall environmental impact of diets involves accounting for interactions and potential synergies among food items, which requires sophisticated modelling techniques and comprehensive LCA data. The system boundaries in this case are typically defined at the “cradle-to-grave” level. This means that the analysis includes all of the environmental impacts associated with the production, consumption, and disposal of the food product. This also includes the environmental impacts associated with transportation, storage, preparation, and cooking.

There are differences in scope, scale, and complexity when applying TCA to analyse food patterns compared to the more common approach of applying TCA to individual food supply chains or specific food production systems. TCA can be applied to a variety of different diets at different levels, for example, individual diets, national diets (e.g. French diet), regional diets (e.g. Western diet, Mediterranean diet, and Nordic diet) including religious and cultural diets (e.g. Islamic diet) and different types of diets due to health conditions (e.g. Dietary Approaches to Stop Hypertension (DASH) diet), by choice (e.g. vegan diet, pescatarian diet) or hypothetical diets (e.g. EAT-*Lancet* diet). The main difference when applying TCA analysis to diets lies between the individual, national and hypothetical diets and are outlines in Table 3.

3. Methodology and data requirements for True Cost Accounting of European diets

In this chapter, a structured methodology for calculating the true costs of European diets is presented, following the steps as outlined in the TEEBAgriFood framework. Key indicators for natural, human, and social capital impacts are collated and the data needs to perform TCA assessment of diets are identified. Finally, our data search approach for the assessment of secondary data sources, including the selection criteria for data sources search are outlined.

3.1 TCA method of diets

The TCA methodology as per TEEBAgriFood comprises several key steps. Firstly, it involves framing the analysis to clarify its purpose. The second step involves defining the scope, boundaries, and assumptions of the analysis, including the geographic and agri-food value chain boundaries, the processes considered, and the selection of a functional unit. The methodology then proceeds to identify and determine the relevant impact categories for natural, human, and social capitals associated with diets.

3.1.1 FRAME: WHY?

The first step of a TCA analysis is to frame why (for what purpose) it is being carried out. The PLAN'EAT project seeks to address the issue of unsustainable and unhealthy food consumption patterns. The overarching aim of a TCA analysis of European diets is to expand the understanding of the impacts of food production and consumption of current European diets on natural, human and social capitals. Additionally, it helps to identify the associated hidden costs and communicate the magnitude and consequences of these impacts to a non-scientific audience. The identification of dietary challenges and opportunities by accounting for a full range of impact pathways and system trade-offs can facilitate the diet improvement through systematic changes.

The primary audience for a TCA analysis of European diets encompasses policymakers seeking to enhance the overall well-being of their citizens, farmers and food industry experts exploring avenues for production improvement, nutrition advisors offering guidance to individuals, and researchers pinpointing areas requiring innovative solutions. However, the TCA analysis of European diets can also provide insights to other food systems stakeholders, such as farmers and food processors, where impact hotspots lie in the range of products, processing methods and supply chain overall and where there is room for improvement.

3.1.2 SCOPE: WHAT?

The second step of the TCA analysis defines the scope and boundaries and outlines the assumptions made. In particular, it determines the systems behind various components of diets, such as setting a geographic boundary of the assessment, defining the agri-food value chain boundary, the processes within that boundary, selecting the functional unit of the assessment and listing the potential impacts.

Subject of analysis

When assessing dietary impact, a comprehensive **diet-level approach** is crucial, considering both the individual food items and their combined effects within dietary patterns. This necessitates data on consumption patterns, dietary compositions, and food proportions. Presently, due to the scarcity of data regarding the interconnections among food items and their production and consumption processes, we suggest a method wherein the overall impact of a diet is approximated by summing the impacts of individual food products. In a first step, total consumption of food and non-alcoholic drinks in the respective country or for the respective target group is estimated. Next, trade data are used to identify the country of production. National statistical data are used to determine production activities and local environmental and social conditions. LCA data are used to estimate the environmental, social, and health impacts of individual food categories/items. Valuation factors are used to estimate the value of the externalities.

Functional unit

In the context of assessing diets and comparing different dietary options, the choice of functional unit is crucial, typically focusing on daily per capita dietary consumption. Heller et al. (2013) highlight that the selection of functional units in food system analyses should align with the specific goals and scope of the analysis. For instance, they recommend a daily energy intake as a reference unit when the objective is to compare dietary patterns. Though the daily caloric intake in European countries varies substantially per country and population groups, the Panel on Dietetic Products, Nutrition and Allergies has recommended a 2000kcal day/person level (EFSA, 2009) and this value is often considered in the literature (van de Kamp et al., 2018). Conversely, when comparing various food items, it may be more suitable to employ an index of nutrient quality for a fair basis of comparison (Heller et al., 2013). In cases where the study aims to analyse variations in agricultural production or processing methods for a specific food, a functional unit based on mass or volume would suffice again per capita per day and for each food commodity.

Environmental assessment of diets is linked with the assessment of the environmental burden predominantly on the production level, while nutritional assessment of the diet is linked with consumption. Food serves various functions: apart from its main nutritional role, it provides pleasure based on taste, and plays a cultural and social role. Within this study, we focus on diet sustainability in terms of environmental and social burdens and healthiness in terms of the nutritional function of food consumption. Hence, ideally, the functional unit should consider these characteristics. The selection of the appropriate functional unit largely hinges on data availability and the specific objectives of the study. Below is a summary list of the main functional units suggested in the scientific literature that could be considered when conducting a TCA assessment of diets, along with their recommended use cases and data requirements, where applicable.

Environmental impact assessment of diets

- ➔ Mass/volume based functional unit: per unit weight (per kg, per g, per serving of a meal) of food items. While this is one of the most common functional units in food LCA used for direct food comparisons, it is not practical for dietary analysis as it doesn't contain nutritional content information (Hellweg & Canals, 2014).

Nutritional impact assessment of diets

- ➔ Nutritional/per nutrient unit: per gram of protein, per gram of fat, or other nutrients of food items. This is suitable for evaluating specific nutrient components of diets and is focusing on key nutrients.

Caloric assessment

- ➔ Per dietary energy need (e.g. per days' worth of kcal)

Geographical boundary

For the purposes of this study, we are interested in the **average national diets observed in the EU member states as well as the average dietary patterns of sub-population of PLAN'EAT's Living Lab countries** (see Table 4), also because it is impossible and meaningless for the development of interventions to arrive at a European diet that would be representative of all countries (see the difference in the methodology to other diets in Table 3, Chapter 2.2). This is especially relevant in the context of the assessment of the healthiness of the dietary patterns based on nutrient requirements, which vary depending on the age, gender, and life stage of the population.

Table 4: Living Lab countries and respective sub-population groups

Country	Consumer group
Belgium	National population
France	Children, Adolescents
Germany	Adolescents
Greece	Elderly
Hungary	Young adults
Ireland	Young adults
Italy	People with diabetic and low socio-economic status
Poland	Children, Adolescents
Spain	Elderly
Sweden	Children
The Netherlands	National population

The geographic boundaries of the TCA assessment and that of our data search, therefore, is the EU. While the EU imports large amounts of food from outside the EU, this report will focus on the food consumption of EU production only to keep the data mapping exercise manageable in the short timeframe of this project activity. This implies that the report is unable to draw conclusion on the data availability, accessibility and usability of TCA data for non-European food products.

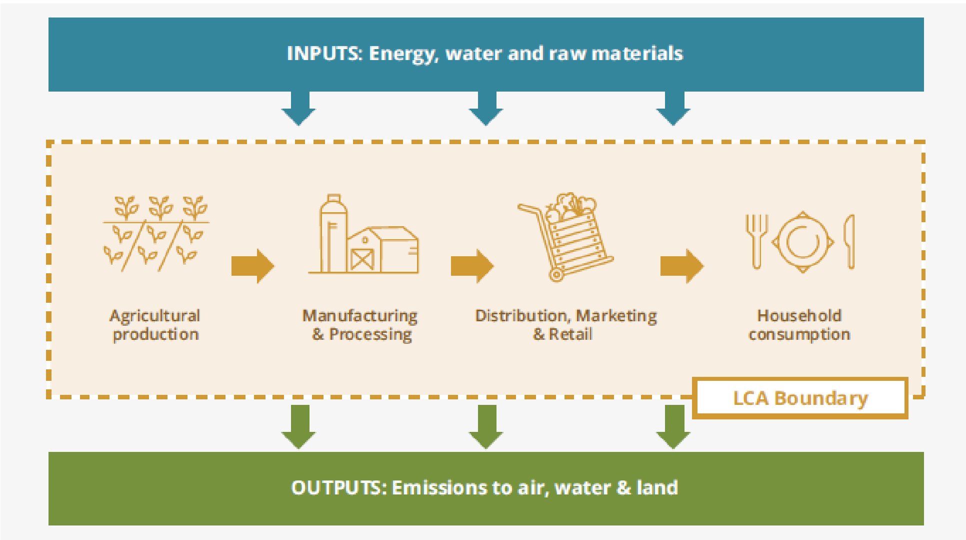
Agri-food value chain scope

Since TCA takes a systems approach, the TCA methodology in this report follows a comprehensive definition of food systems encompassing all the activities involved, from food production to food consumption (see Figure 3). Hence for the purposes of this report, the boundary of the diet to be modelled is the food production and consumption in the EU including environmental, social and health impacts assessed from **cradle-to-consumer**. This boundary includes agricultural cultivation, food processing, distribution, retail and consumption. The data mapping exercise is focused on food supply chain data including input and management data from food production, processing, distribution and retail and consumption stages, and impact data on natural, social and human capitals. While we did not specifically focus on activities like the manufacturing of fertilizers, machinery, packaging, and waste management in data mapping, but it is worth noting that they are usually included to some extent in various LCI databases. Additionally, research and development, marketing and branding, as well as activities from food services are excluded from the data mapping, due to resource constraints. However, the data assessment includes the impact of raw material production, manufacturing, and waste management, as comprehensive LCA databases consider these impacts within their system boundaries.

Impacts on the various key stakeholders of food systems are being considered, including not only the consumers of the diet, but also the people involved in the production of the food and (local) communities impacted by the external effects of food production and consumption.

Arguably, the highest negative impacts along the food supply chain are at cradle-to-gate boundary, owing to the fact that externalities in the form of land use change (including GHG emissions), environmental degradation from over-intensification of farming and input use, agri-chemicals that harm biodiversity (including fertilisers, pesticides and herbicides) all have huge impacts on natural capital, as well as human and social capital in the form of unfair working conditions, unjust wages, the high prevalence of child labour in agriculture and the human health impacts of handling toxic chemicals. However, there is a growing literature that argues the necessity to expand the most common cradle-to-gate boundary and include consumer stage in food LCAs (Gruber et al., 2016; Hallström et al., 2015). This seems specifically relevant in the context of dietary analysis. Considering the research gaps, for dietary analysis we propose to apply a full supply chain system boundary to also include consumer stage in the assessment.

Figure 3: Life Cycle Assessment boundaries



Source: TEEB (2018), p. 274

Below is a detailed description of the various components and stages considered in the cradle-to-consumer boundary:

1. **Agricultural production stage**
- Agricultural practices: all activities related to growing crops and raising livestock, such as crop cultivation, irrigation, pesticides and fertilizer application, livestock management. At this stage it is essential to identify the use of resources such as land, water, energy, nutrients and raw materials.

2. **Manufacturing and processing**
- Processing facilities: Raw agricultural products are transformed into packaged goods. At this stage the energy use, waste generation and emissions during processing are assessed.
- Transportation: the assessment of the energy use required for the transportation of raw materials to the processing facilities, as well as different types of transportation

3. **Distribution and retail**
- Supply chains: various distribution networks, such as warehouses, distribution centres, retailers.
- Energy use: at the distribution facilities, refrigeration, food storage facilities, waste management.

4. **Consumption**
- Transportation: how the food is transported by the consumer from retail facilities
- Home preparation: energy consumption during cooking and storage at home, appliances (refrigerator) and various energy sources e.g. electricity, gasoline.

3.1.3 MEASURE AND VALUE: HOW?

The glimpse of the multitude of methodological possibilities of assessing the environmental, social and health impacts offered in Chapter 2.1 highlights the need to focus and narrow the impact assessment method for the data mapping of this report. Therefore, we have decided to take a LCA approach for the impact assessment, due to its popularity and well-established methodology and existing databases. LCA provides possibilities to examine environmental, as well as some health and social effects of European diets. LCA allows for the assessment of impacts across the full life cycle and across the three impact categories.

This report builds on the concept of four capitals described in Chapter 2.1 and looks at environmental (natural capital), social (social capital) and health (human capital) impacts of the activities described in the scope of the assessment above. We exclude the data mapping for produced capital, assuming that it is largely reflected in the price of the food already.

The methodology described in this section determines the relevant impact categories of diets. According to ISO standards (ISO 14040:2006) impacts that hold the most significance within the context of both the studied system (diets) and the intended utilization of results by the target audience (comparison of diets, diet optimisation) need to be identified. It is prohibited to selectively omit impact categories to avoid reporting aspects that might not favour the system being studied.

In total, 61 externalities attributed to different parts of the food systems or food supply chain related to diets were collected. The environmental externalities were predominantly collected from the impact assessment methodology most commonly used in LCA: ReCiPe (Huijbregts et al., 2016). Additional impacts were collected from FAO (2014), Fitzpatrick et al. (2019) and True Price (2020). Social externalities were derived from UNEP/SETAC Guidelines for the Social Life Cycle Assessment (UNEP, 2020), the Handbook for Product Social Impact Assessment (2020), Frehner et al. (2021), Perignon et al. (2016), Turner et al. (2018) as well as True Price (2020) and True Cost Initiative (2022). Human health as well as other impacts related to human capital were partly derived from the World Business Council for Sustainable Development (WBCSD, 2018) framework. Tables 5-7 show the collected externalities relevant to European diets.

The impact metrics are not exhaustive and are prioritized based on potential impact and quantitative data availability, including monetization factors. Most externalities are directly connected to the production and/or consumption of food, while minor set of indirect externalities, like elevated suicide rates among farmers, are incorporated to underscore the necessity for a more profound comprehension of the complexity of externalities within food systems. Some of the externalities relate to multiple areas of impact. For example, environmental externalities such as GHG emissions, water use or soil erosion may have significant future impacts on food security due to climate change, or human health externalities such as medical costs attributed to unhealthy diets can have future (secondary) impacts on the form of exacerbated mental health issues. In such instances, the externality was assigned to its primary area of impact, although the secondary and even tertiary effects might also carry significance. Some externalities lack clearly defined scientific indicators, however, they might be considered important and hence were still included in the overview. As the externalities were selected using existing scientific literature, the areas of impacts that have not been studied well such as human health impacts, social impacts, or biodiversity impacts, are expected to have bigger indicator gaps in comparison to environmental impacts which have a longer history of literature as well as data coverage.

For a full picture of the true costs of diets, the values of all these externalities need to be considered. In reality, however, many of them are currently not quantifiable due to a lack of quantitative methods or the lack of valuing qualitative information. Also, not all impacts can be monetized, especially social ones, due to the complexity and multidimensionality of social factors that extend beyond traditional economic valuation, making them challenging to quantify solely in monetary terms. The data search was performed for all types of valuation approaches as outlined in Chapter 2.1.

Natural Capital

The environmental domain is the most researched and standardized one in the literature. A widely accepted list of indicators exists for the assessment of dietary outcomes along a number of impact categories. The table below provides an overview of relevant environmental indicators.

Table 5: Overview of globally relevant environmental externalities of diets

Impact category*	Externality	Unit	Source
Contribution to climate change	Greenhouse gas emissions	kg CO_2-eq	Huijbregts et al. (2016)
Contribution to climate change	Carbon dioxide losses due to land conversion	kg CO_2	FAO (2014)
Pollution of the living environment	Particulate matter formation	kg $PM_{2.5}$-eq	Huijbregts et al. (2016)
Pollution of the living environment	Ammonia emissions	kg NH3	Fitzpatrick et al. (2019)
Pollution of the living environment	Photochemical oxidant formation	kg NMVOC-eq	True Price (2020)
Pollution of the living environment	Acidification	kg SO_2-eq	Huijbregts et al. (2016)
Pollution of the living environment	Ozone layer depleting emissions	kg CFC11-eq	Huijbregts et al. (2016)
Degradation of land	Soil loss from wind erosion	kg soil lost	Fitzpatrick et al. (2019)
Degradation of land	Soil loss from water erosion	kg soil lost	Fitzpatrick et al. (2019)
Degradation of land	Soil organic carbon loss/build up	kg SOC	Fitzpatrick et al. (2019)
Depletion of scarce abiotic resources	Fossil fuel depletion	kg oil-eq	Huijbregts et al. (2016)
Depletion of scarce abiotic resources	(Other) non-renewable material depletion	kg Cu-eq	Huijbregts et al. (2016)
Depletion of scarce abiotic resources	Scarce water use (blue water)	m^3	Huijbregts et al. (2016)
Pollution of the living environment	Terrestrial ecotoxicity (air pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Pollution of the living environment	Terrestrial ecotoxicity (water pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Pollution of the living environment	Freshwater eutrophication	kg P-eq to freshwater	Huijbregts et al. (2016)
Pollution of the living environment	Marine eutrophication	kg N-eq to marine water	Huijbregts et al. (2016)
Pollution of the living environment	Terrestrial ecotoxicity (soil pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Pollution of the living environment	Freshwater ecotoxicity (soil pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Pollution of the living environment	Marine ecotoxicity (soil pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Degradation of biodiversity and ecosystems	Land occupation	MSA ha yr	True Price (2020)
Degradation of biodiversity and ecosystems	Land transformation	ha	True Price (2020)
Animal welfare**	Animal years suffered	ALYs (Animal life years suffered)	Scherer et al. (2018)

* Based on TEEB (2018)

**According to the new TEEB Operational Guidelines (Capitals Coalition, 2023), the animal welfare is under Natural Capital, in contrast to the earlier TEEB Framework which included it under Social Capital.

Human capital

The metrics that characterize the dietary impacts on human capital have also been studied more thoroughly and standardized set of indicators has been developed, most common ones being cancer, mortality, type 2 diabetes, CVDs, etc. As Webb et al. (2023) conclude, no current studies have looked into health outcomes related to nutrient-deficiency diseases or undernutrition. The table below provides an overview of relevant human capital externalities identified in the literature.

Table 6: Overview of globally relevant human capital externalities of diets

Impact category*	Externality	Unit	Source
Occupational health and safety risks	Workers who experienced non-physical, non-sexual harassment	Number of workers	True Price (2020)
Occupational health and safety risks	Non-fatal occupational incidents	Incidents	True Price (2020)
Occupational health and safety risks	Fatal occupational incidents	Incidents	True Price (2020)
Occupational health and safety risks	Health conditions due to excessive working hours	DALYs	True Cost Initiative (2022)
Mental health	Contribution to increased suicide rates in agriculture (indirect)	n/a	n/a
Human rights violation	Underage workers below minimum age	Child FTE	True Price (2020)
Human rights violation	Forced labour	FTE DALY	True Price (2020) True Cost Initiative (2022)
Production-related human health impacts	Human toxicity (air pollution)	DALYs	Huijbregts et al. (2016)
Production-related human health impacts	Human toxicity (water pollution)	DALYs	Huijbregts et al. (2016)
Production-related human health impacts	Human toxicity (soil pollution)	DALYs	Huijbregts et al. (2016)
Consumption-related human health impacts	Health impact of undernutrition**	DALYs	Fitzpatrick et al. (2019)
Consumption-related human health impacts	Health impact of malnutrition**	DALYs	WBCSD (2018)
Consumption-related human health impacts	Health impact of overweight and obesity	DALYs	WBCSD (2018)
Consumption-related human health impacts	Health impact of hypertension	DALYs	WBCSD (2018)
Consumption-related human health impacts	Health impact of noncommunicable diseases	DALYs	WBCSD (2018)
Consumption-related human health impacts	Health impact of dementia	DALYs	Fitzpatrick et al. (2019)

Consumption-related human health impacts	Health impact of food poisoning	DALYs	WBCSD (2018)
Consumption-related human health impacts	Health impact of pesticide exposure	DALYs	WBCSD (2018)
Public health threats from livestock production	Health impact of antibiotic use	DALYs	Fitzpatrick et al. (2019)
Public health threats from livestock production	Contribution to the exposure to zoonotic diseases (indirect)	DALYs	n/a
Income	Wage gap below minimum wage	€	True Price (2020)
Income	Wage gap below living wage	€	True Cost Initiative (2022)
Income security	Workers without legal social security	FTE	True Price (2020)

* Based on TEEB (2018)
**Externalities marked in grey represent diet/food system level externality

Social capital

The social domain has the least coverage in the scientific literature when it comes to validated metrics for dietary impact assessment. The table below provides an overview of relevant social externalities of diets and their indicators.

Table 7: Overview of globally relevant social externalities of diets

Impact category*	Externality	Unit	Source
Food security	Ratio of change in price of a basic food basket per change in price of a product	Index	Capitals Coalition (2023)
Benefits sharing	Change in number of people reached through community engagement	Index	Capitals Coalition (2023)
Lack of union rights	Instances of denied freedom of association	Violations	True Price (2020)
Gender equity	Gender gap in hours worked	Minutes per day	OECD (The Organisation for Economic Co-Operation and Development)
Gender equity	Gender pay gap	€	True Cost Initiative (2022)
Laws and regulations	V-Dem Accountability Index	Index	FSCI (2023) based on Varieties of Democracies
Laws and regulations	Corruption Perceptions Index	0-100 Index	Transparency International, Corruption Perception Index
Laws and regulations	Prior Informed Consent (PIC) procedures for trade of pesticides and chemicals	Number of export notifications and responses	European Chemical Agency: PIC-ECHA
Food affordability	Food price in relation to standard income	Index	Food Affordability Index
Social risk	Social risk on the production side	Index	Frehner et al., (2021)
Food availability	Net imports relative to production	%	Turner et al., (2018)
Acceptability	Mean departure from observed diet	%	Perignon et al., (2016)
Income	Wage gap from unequal opportunities (gender, racial, religious, etc. discrimination)	€	True Price (2020)
Integration of workforce into communities	Change in number of migrant workers with feeling of exclusion	Index	Capitals Coalition (2023)

* Based on TEEB (2018)

3.2 The data needed for assessing the true cost of diets

This section delves into the essential data requirements for TCA of European diets, with a focus on food/diet data, food supply chain data, and impact data. More detailed impact data, in the form of impact indicators for three capitals, has been comprehensively covered in the preceding sub-chapter 3.1.

3.2.1 FOOD AND DIET DATA

The starting point of a dietary analysis is the dietary scenario, the **food consumption**, i.e. what is consumed by an individual or a broader community over an extended period (McLaren et al., 2021). Diet scenario is based on the intake of food groups which is an estimate of the quantity of the food commodities supplied in a diet, as well as the primary equivalents of agricultural commodities from which the foods are derived. Diet scenarios can be estimated either based on actual population consumption data or estimates based on food availability for human consumption using for example food balance sheets or household budget surveys.

For the purpose of this study diet is identified as a compilation of food items which is consumed over an extended period and is representative of the food intake. The food consumption can be expressed in kg per household per year across all food commodity groups.

In addition to food consumption data, **food composition** data is also needed to evaluate diets' nutritional quality. The literature distinguishes between essential, non-essential and conditionally essential nutrients, as well as macro- and micronutrients (ibid).

Though not exhaustive, the Table 8 summarizes some of the main nutrients used to assess the nutritional profile of food items based on McLaren et al (2021).

Table 8: Food composition data (nutrition)

Macronutrients	Micronutrients		Selected health metrics
	Vitamins	Minerals	
Fat (g) Protein (g) Carbohydrate (g)	Vitamin A (µg) Vitamin C (mg) Vitamin D (µg) Vitamin E (mg) Vitamin B6 (mg) Vitamin B12 (µg) Vitamin K (µg) Folate B9 (µg)	Calcium (mg) Magnesium(mg) Iron (mg) Zinc (mg)	Sugars (g) Fiber (g) Cholesterol (mg) Saturated fats (g)

Source: McLaren et al., (2021)

3.2.2 FOOD SUPPLY CHAIN DATA

This section analyses the data needs for different stages of the food supply chain within the cradle-to-consumer boundary that were detailed in the Chapter 3.1. This system boundary is a comprehensive approach that considers all of the environmental, human and social impacts associated with the production, processing, distribution and consumption of food in Europe. The table below summarizes the main data needs for different stages of the food supply chain within the cradle-to-consumer system boundary, according to the stage, input and management data and provides description.

Table 9: Food supply chain data

	Input and management data	Description
Production stage	Land use (e.g. yield, land management) Water use Energy use Seeds Machinery Fertilizer use Manure management Pesticide use Livestock feed and husbandry system Labour input (e.g. working hours) Working conditions (e.g. housing, wages, protective clothing) Food-loss	Data on the inputs used to produce food in Europe, such as land, water, energy, fertilizers, pesticides, herbicides, and livestock feed, is needed to assess the environmental, social and human costs of the production stage. Social and human costs, such as the wages and working conditions of farmers and food workers, should also be considered. Post-farm production food-loss is to be considered in this stage.
Processing stage	Energy use Water use Labour input (e.g. working hours) Working conditions (e.g. housing, wages, wages per gender) Food loss	Data on the inputs used to process the food in Europe, such as energy, water, labour input, as well as working condition data is needed to assess the environmental and social costs of this stage. Food waste data is also important to consider, as it can be a significant source of environmental impact.
Distribution and retail stage	Energy use Transportation mode Distance travelled Labour input (e.g. working hours) Working conditions (e.g. housing, wages) Food prices Food-loss (e.g. improper handling, food safety standards (expired food))	Data on the inputs used to distribute food in Europe, such as energy, transportation mode, and distance travelled, is needed to assess the environmental and social costs of this stage. At a retail stage it is important to assess the energy and area use for food storage. From the social and human impact perspective wages and working conditions of transportation and retail workers are important to assess. Food loss at distribution and retail stage are to be considered.
Consumption stage	Energy use Water use Food-waste (e.g. from food preparation, excess food, expired food, spoiled food, plate waste)	The consumption patterns, such as energy and water use for food preparation, storage and refrigeration, as well as transportation from retail to home are to be assessed. Food-waste at consumption stage is a significant source of environmental impact at consumer level.

3.2.3 IMPACT DATA

Some research groups have compiled harmonized food LCA data into standardized environmental impact databases accessible to the public (Heller et al., 2018; Mertens et al., 2019a; Petersson et al., 2021; Poore and Nemecek, 2018). These efforts provide trustworthy and publicly accessible information on the environmental impacts of food commodities, making it particularly valuable in countries where comprehensive and reliable LCA data are limited (Morais et al., 2016).

To address the necessity for LCI background data, various databases have been developed and are now included in most commercial LCA software packages. However, historically, these databases mainly focused on industrial processes, paying less attention to agricultural ones (Notarnicola et al., 2012). Instead, as LCA applications in agri-food systems grow, initiatives have emerged to provide more LCAs of the agri-food process. This demand for agri-food databases has been amplified by the increasing use of Environmental Product Declarations and Product Environmental Footprints to promote environmentally friendly practices in industry (ISO 2006). These schemes often require specific inventory data or "selected generic" data representing at least 90% of the overall environmental impact, which can be sourced from databases (EPD 2019).

3.3 Approach for the analysis of data sources

For the accuracy, credibility, and completeness purposes of the TCA to analyse European diets, our analysis hinge upon meticulous approach to data source selection. For those purposes, a systematic methodology has been developed that encompasses well-defined selection criteria to guide our search. These criteria include considerations such as data quality and timeliness, geographic coverage and accessibility. Following the establishment of the criteria, the selection process follows an established inclusion/exclusion approach. This approach involves a thorough screening of potential data sources, assessing them against our predefined criteria and making decisions regarding their suitability for inclusion in our analysis. Once we have amassed our selected data sources, the following step involves a mapping exercise of the data sources against the data needs identified earlier. In this section, we will explain the specifics of our selection criteria, inclusion/exclusion methodology and the process of mapping data sources.

3.3.1 SELECTION CRITERIA FOR DATA SOURCES

At this stage, it is important to recognise that secondary data sources will be sought to answer the primary question of this research, whether TCA of diets is feasible using secondary data sources and to reveal the challenges and associated data gaps. The following criteria for data collection are proposed:

- **Data timeliness**: Agriculture is not immune from technological progress, especially with superior inputs, precision-type farming systems, while at the policy front, there is enormous pressure to make European agriculture more sustainable and climate-friendly (Environmental, Social and Governance regulations). Therefore, we have prioritized data sources with recent time stamps, with data spanning from 2015 onwards, to ensure an accurate assessment of TCA impacts.
- **Data quality**: To evaluate the quality of our data sources, we will assess whether they have undergone peer review and consider the number of citations each data source has received. This will provide us with valuable insights into the reliability and trustworthiness of the data.
- **Geographic coverage**: Since our research focuses on European agriculture, it is essential that the data sources cover the European region. This ensures that our analysis is relevant to the context of our study.
- **Accessibility**: We will explore a wide spectrum of data sources, including those that are openly accessible (open access) as well as those that are private and require subscription, or paywall access but which, however, provide sufficient data and/or methodology description to understand the content of the data.

3.3.2 SEARCH APPROACH

To ascertain the availability of agricultural/food supply chain data/input data, a thorough online search was conducted. The used search words were: Agricultural supply chain data, European supply chain data per country/per food product, fertilizer utilization for food, agricultural water consumption, agricultural supply chain statistics, energy consumption in agriculture, and energy consumption in food supply chain to navigate the vast expanse of the World Wide Web. By this search we looked for agricultural/food supply chain data presented in detail in Table 9.

Similarly, to delve into the impacts of food, a dedicated search was initiated. The used search words were: Agriculture/food LCA data, LCA databases, food environmental/social/health impact data, European/Global food LCA, dietary health data, global health data, TCA monetization factors, European/Global monetization factors. Our search was centred around the following information:

- Environmental, social, and health impacts of food and its production
- Comprehensive databases and studies focusing on LCA specific to food and agriculture

- Meta-studies on food LCAs
- Global/European food LCA data
- Databases for social and health impacts of food
- Health impact assessment databases
- Global health data, agricultural/food human toxicity data.
- Data sources concentrating on agricultural or food-related human toxicity, including global and European centric LCA data
- TCA monetization factors for impact data

Our efforts to collate data in alignment with the criteria outlined in Chapter 3.3.1 led us to several sources.

4. The current data situation

This section thoroughly assesses the current status of secondary data pertaining to diet and food, supply chain and impact as well as monetization data related to natural, human and social capitals. To provide an insightful overview of the existing data sources, we structure the analysis into three key areas: data availability, data accessibility and data usability and quality, which are shortly defined and described below in the Table 10.

Table 10: Definitions and descriptions of data

	Definition	Description
Data availability	Data availability refers to the presence of data in each dataset or database. It assesses whether the data needed exists and can be collected or obtained.	Data availability focuses on whether the required data is available in any form, regardless of its condition or quality. It is the first step in the data management process, as without data availability it is not possible to proceed to access, use, or improve the data.
Data accessibility	Data accessibility refers to the ease and efficiency with which data can be retrieved or obtained once it is available. It assesses factors such as the location of data repositories, permissions, and the required access methods or tools.	Data accessibility pertains to the speed and convenience with which data can be located and retrieved. This concept considers various factors, including the location of data repositories, the availability of requisite permissions, and the tools or methods necessary for data retrieval.
Data usability and quality	Data usability is a measure of the data's suitability for its intended purpose. It assesses whether the data can effectively support tasks like analysis, reporting, or decision-making. Data quality encompasses the accuracy, reliability, and overall integrity of the data. It evaluates whether the data is free from errors, inconsistencies, or biases.	Data usability takes into account factors such as data format, structure, consistency, and completeness. Ideally, data should be organized, free of inconsistencies, and in a format that allows users to derive meaningful insights with minimal effort. Data quality is perhaps the most critical aspect of data management, encompassing attributes such as accuracy (absence of errors), completeness (lack of missing values), consistency (absence of contradictions), timeliness (up-to-date status), and relevancy (suitability for its intended use). High-quality data is dependable and faithfully represents real-world entities)

4.1 Food and diet data

This section examines the availability, accessibility, usability and quality of food and diet data needed to carry out a TCA assessment of European diets. Information on European diets, current food consumption and composition data can come from various sources. Considering the selection criteria for the data sources in Chapter 3.3, Table 11 and Table 12 summarize the mapping of the food consumption and composition data outlined in Chapter 3 respectively.

Table 11: Summary of food consumption data sources

Data Source	About the data	Geographic scope	Food items coverage	Data availability	Data accessibility	Data usability and quality
The EFSA Food Consumpton Database	The database provides food consumption data for individuals living in Europe. The database presents detailed information on the foods and drinks that people consume over a period of time. The survey data is collected using a variety of methods, including food diaries, food records, and 24-hour recalls.	27 European countries	EFSA categorizes food consumption data into seven exposure levels, starting with broad food groups (L1) to more detailed food items (L7). The database includes information on the amount of food consumed, the frequency of consumption in grams per day (g/day) or grams per day per kilogram of body weight (g/kg bw per day).	The database provides information on food consumption across the EU. EFSA gathers data related to food consumption on national level, dietary exposure and food safety across various population groups from infants to very elderly, including three special groups.	The database is freely accessible to the public.	The data is regularly updated to ensure that it is as accurate and up-to-date as possible. EFSA database is using FoodEX2 for classifying and describing food. FoodEX2 comprises detailed descriptions of numerous individual food items organized into food groups and more complex food categories, arranged in a hierarchical parent-child relationship
EuroSTAT Household budget surveys	Eurostat is the statistical office of the EU and through its budget surveys it provides households' expenditure data on goods and services, including expenditure on food.	All European Union member states	The surveys cover a wide range of food items. The collected data is on the amount of food purchased, the price paid, and the frequency of purchase. The surveys are designed to collect data on income, expenditure and well-being of the households of the EU member states.	Eurostat is a primary source for official statistics in the European Union. It provides comprehensive data on various aspects of food consumption including dietary habits, production and trade.	Eurostat data is accessible to general public and can be retrieved from their website, making it widely accessible for use and research purposes.	The household surveys are a high-quality dataset. The surveys are conducted using rigorous methods and the data is subject to quality control procedures. From TCA perspective, this source has its advantages for providing not only food consumption data, but also socio-economic, income and geographical data allowing for comparisons between different areas in Europe. Regarding expenditures

						on food, the surveys provide information on food expenditure, food consumption, price indices.
FAO Food Balance Sheets	The FAO Food Balance Sheets present a comprehensive overview of the food supply at national level. They use primary commodity and a number of processed commodities potentially available for human consumption - the sources of supply and its utilization	All countries in the world	The balance sheets cover a wide range of food items, including cereals, pulses, oilseeds, vegetables, fruits, meat, milk, eggs, fish, and fats and oils. The database also includes information on the amount of food produced, imported, exported, used as feed and losses.	The balance Sheets cover a wide range of food items and for all countries. However, the level of detail and accuracy of the data can vary from country to country.	The FAO Food Balance Sheets are freely accessible to the public.	The quality and level of detail of the FAO Food Balance Sheets can vary from country to country.
National dietary surveys	These surveys capture food consumption patterns at the national level. They provide information on food quantities, frequencies, and dietary preferences of the population.	Individual European countries	Coverage varies from survey to survey. Most surveys collect data on a wide range of food items, such as processed foods, unprocessed foods, and beverages.	Since the national dietary surveys are conducted by individual European countries, the level of detail and accuracy of the data can vary from survey to survey.	The accessibility of national dietary survey data may vary from country to country.	The quality and the level of usability of the national dietary surveys vary from country to country. While the surveys adhere to high and rigorous data collection standards, some of them are outdated or represent uncertainties in the form of underreporting in consumption.

Table 12: Summary of food composition data sources

Data Source	About the data	Data availability	Data accessibility	Data usability and quality
EFSA food composition database	The EFSA Food Composition database, which provides the food composition data for the EFSA Comprehensive European Food Consumption Database, contains data on over 2,000 nutrients.	The database gives information on the amount of vitamins and minerals contained in different foods. Data are provided for seven countries – Finland, France, Germany, Italy, Netherlands, Sweden, and the United Kingdom. Vitamins and minerals included are calcium; copper; cobalamin; magnesium; niacin; phosphorus; potassium; riboflavin; thiamin; iron; selenium; vitamin B6; vitamin E; vitamin K; zinc.	Freely accessible online	The food composition data is based on a variety of sources, including food composition tables, analytical data from food samples, and literature reviews. The DB represents high quality data, regularly reviewed and updated.
FAO INFOODS	FAO oversees the INFOODS, which compiles a directory of global food composition databases. FAO/INFOODS provides contact details and links to these databases at national and regional level. Additionally, the World Nutrient Databases for Dietary Studies by the International Life Sciences Institute catalogues 90 electronically available food composition databases.	Data for macronutrients, vitamins, minerals, and other food components for food items consumed all over the world, including Europe.	Freely accessible online	Data quality varies depending on the country or region from which the data was collected.
EuroFIR	EuroFIR is a comprehensive food composition database that covers a wide range of European foods, over 47,000 food items. It aggregates data from various European countries and provides standardized nutrient profiles, including macronutrients, micronutrients, antioxidants, and phytochemicals. The database also includes information on the energy content of foods and food composition variations. The EuroFIR database is compiled using a variety of methods, including food analysis, food composition tables, and literature reviews.	Comprehensive data for macronutrients, vitamins, minerals, and other food components, including traditional European foods and foods from ethnic cuisines.	Some data is freely accessible online; however, the harmonized nutrition data is behind a paywall.	EuroFIR maintains high data quality standards and follows rigorous methodologies for data compilation. However, data completeness vary due to differences in data sources and updates

National food composition databases	Below is the list of some of the food composition databases in Europe: • Austrian Food Composition Table (UVI OENWT Österreichische Nährwerttabelle) • Belgian Food Composition Table (NUBEL) • Czech Food Composition Database (NUTRIDATABAZE) • Danish Food Composition Databank (DTU) • Finnish Food Composition Database (Fineli) • French Food Composition Table (Ciqual) • German Nutrient Database (BLS) • Greece - Composition tables of foods and Greek dishes (CTFG, HHF) • Hungarian Food Composition Tables (Online table) • Italian Food Composition Database (CREA), Food Composition Database for Epidemiological Studies (IEO) • Netherlands Food Composition Database (NEVO) • Polish Food Composition Table (NFNI) • Spanish Food Composition Database (BEDCA) • Swedish Food Composition Database (Svenska Livsmedelsverket)	Data availability for main food composition nutrients varies depending on the country.	Data accessibility varies depending on the country.	Data quality varies depending on the country or region from which the data was collected.
USDA FoodData Central	The USDA FoodData Central is a centralized and authoritative source for comprehensive food composition data, offering detailed information on the nutrient content, ingredients, and other attributes of a wide array of foods and food products.	It provides comprehensive data on nutrients and other components found in a wide variety of foods and food products for U.S. and some European foods. It includes five distinct data types that provide information on food and nutrient profiles: Foundation Foods, Food and Nutrient Database for Dietary Studies 2019-2020, National Nutrient Database for Standard Reference Legacy Release, USDA Global Branded Food Products Database and Experimental Foods.	High quality data, regularly reviewed and updated	High quality data, regularly reviewed and updated

Overall, the EFSA Food Composition Database and EuroFIR are the most comprehensive and reliable food composition data sources for the analysis of European diets. However, the FAO INFOODS database, USDA Food Composition Database, and national food composition databases can also be useful resources, depending on the specific needs of the analysis.

4.2 Supply chain data

This section examines the availability of data on the supply chain situation, according to the data needs described in Chapter 3.2.2. Various sources cover agriculture and food supply chain data with different format. The information for different stages of the supply chain can be sourced from national/European statistics and LCI databases. While national statistical data typically provide country level information, they often lack detailed data at the food product level. Open access statistics such as FAOSTAT, FAO AQUASTAT provide data on production stage (e.g. water use, energy use, land use, fertilizer use, crop yield) but the information is aggregated at country level. Nevertheless, product-specific data can often be found in paid LCI databases. Besides paid data sources, IFASTAT is the only open access database covering mineral fertilizer use by crop/product for limited countries and product groups (Ludemann et al., 2022). Most of the supply chain input data available focuses on the production stage. Some databases do extend coverage to processing and distribution stages, but data availability tends to decrease further down the supply chain. Especially for consumption stage, secondary data is hardly available. Food loss data is the hardest information to come by while none of the open access databases provides information on food waste per product at any stages of supply chain except the Joint Research Centre’s (JRC) technical report ‘Building a balancing system for food waste accounting at National Level’ (De Laurentiis et al., 2021). The report models food waste at each stage of the food supply chain for certain food groups for EU member states. However, the modelling has been done for the years 2000 to 2017. World Food LCA by ESU Services mentions in their website that they include data on food loss in their inventory database, but the exact information is behind a paywall (ESU World Food LCA Database). In this section, we give an overview of supply chain data availability from different sourcesClick or tap here to enter text. For a more in-depth explanation please refer to the Appendix 2.

Table 13: Summary of data availability, accessibility and quality/usability of supply chain data

Data source	Supply chain stage	Supply chain data	Availability by		Acces sibility	Quality/Usability
			Country	Product		
Agri-Footprint database*	Production	Agricultural inputs (food, feed, biomass, fertilizer use) Detailed information is behind a paywall	✓(Detailed information is behind a paywall)	✓(Detailed information is behind a paywall)	Paid	High data quality assessment. Easy to use format and structure, data is expected to be consistent and complete. LCI data is suitable for TCA of food and diets.
		Energy and processing -Detailed information is behind a paywall	✓(Detailed information is behind a paywall)	✓(Detailed information is behind a paywall)		
FAO AQUASTAT	Production and processing	Water use	✓	X	Open access	High data quality assessment. Data comes in excel or csv format, it is complete and consistent and well organized. It can be used to estimate environmental impacts at the farm gate for country level. In this format it does not allow a product level assessment and it would not be suitable for TCA of food and diets.
Ecoinvent*	Production, processing, distribution, and consumption	Agricultural supply chain data (Detailed information is behind a pay wall)	✓(Detailed information is behind a paywall)	✓(Detailed information is behind a paywall)	Paid	High data quality assessment. Expected easy to use format and structure, data is expected to be consistent and complete. Life cycle inventory data is suitable for TCA of food and diets.
Eurostat (2021)	Production	Agricultural production (area of cultivation, harvest amounts, yields, livestock)	✓	X	Open access	High data quality assessment. Data comes in excel or csv format, it is complete and consistent and well organized. It can be used to estimate environmentalimpacts at the farm gate for country level. Direct use of the data in the current format is not suitable for TCA of food and diets . It can be used to estimate environmental impacts complemented with other data.

FAOSTAT	Production	Crops (production, yield, crop area harvested) and Livestock (livestock numbers, livestock products such as meat, milk, eggs)	✓	X	Open access	High data quality assessment. Data comes in excel or csv format, it is complete and consistent and well organized. It can be used to estimate environmental impacts at the farm gate for country level. In this format it does not allow a product level assessment and it would not be suitable for TCA of food and diets.
		Energy used in Agriculture	✓	X		
		Land use	✓	X		
		Fertilizers by nutrient	✓	X		
		Fertilizers by product	✓	X		
		Livestock manure	✓	X		
		Pesticide use	✓	X		
		Agricultural machinery	✓	X		
		Agricultural employment	✓	X		
IFASTAT	Production	Fertilizer by crop	✓	✓	Open access	Estimations for many countries are linked with significant uncertainties. Data comes in excel format and it is consistent. It is useable for product level assessment and suitable for TCA of food and diets.

JRC Science and Policy Report Energy use in the EU food sector: State of play and opportunities for improvement (Bertoldi et al., 2015)	Production, processing, distribution and consumption	Energy used in food production	EU average	✓	Open access	High data quality assessment. While the publication is open access, there is no direct reach to compiled energy data via the report. The data is incorporated within the text or figures. Structure of the data is not fully suitable for TCA of food and diets. It requires further insights and data manipulation.
JRC Technical Report (De Laurentiis et al., 2021)	Production, processing, retail and distribution, food services, and household consumption	Quatifies food waste at each stage of supply chain for selected food groups and EU member states	✓	✓	Open access	High data quality assessment. The publication is open access and all background data and results are available as excel sheets. Balancing system for food waste accounting excel sheet presents food waste at each supply chain for selected food groups for EU member states. Data can be used for TCA of food and diets.
Ladha-Sabur et al. (2019). Mapping energy consumption in food manufacturing	Production, processing and distribution	Energy consumption data through production and distribution of food	✓	Available for food product groups	Open access	The accuracy of the data reported could not be ascertained. Data does not come in a directly usable format and might need further manipulation. Energy consumption data per food product groups can be used as proxies for TCA of food and diets.
World Food LCA by ESU Services*	Production, processing, distribution and consumption	Food supply chain data - Detailed information is behind a paywall	✓(Detailed information is behind a paywall)	✓(Detailed information is behind a paywall)	Paid	High data quality assessment. Easy to use format and structure, data is expected to be consistent and complete. Life cycle inventory data is suitable for TCA of food and diets.

Notes: *No access to detailed information on further availability of exact supply chain data due to paywall. ✓ indicates that data is available. X indicates that data is not available.

4.3 Impact and monetization data: Natural capital

LCA studies and databases have become fundamental tools in assessing the environmental impact of food production. Numerous databases have been developed, each offering a detailed insights on the environmental impacts associated with different foods and their production processes. While some databases are open and free to the public, others require a subscription. Databases such as Agrifootprint, Ecoinvent, and World LCA by ESU Services, cover wide range of agricultural products and food systems, while others like Agribalyse focus on specific regions like France. Most databases offer detailed insights into agricultural value chains and food production. Monetization factors, which translate environmental footprints into monetary values, can be found in sources like the TCA Agrifood Handbook and True Price.

In the tables below, we offer an overview of data availability, accessibility, and usability using a color-coded system. The color green signifies that the data is widely available, accessible, and usable. Yellow indicates a lower level of availability, accessibility, and usability. Orange denotes rare availability, accessibility, and usability. Meanwhile, red indicates a complete absence of data, while white represents situations where there is no information on data availabilitiy. In the next tables, we increase the level of detail on available sources, impact indicators covering impacts under natural capital data, monetization factors, their access and data quality and usability. In-depth explanation of these data sources can be found in the Appendix 3.

Table 14: Data assessment of environmental impact indicators

Impact category	Impact indicator	Availability	Accessibility	Usability	Source
Contribution to climate change	GHG emissions				Agribalyse, Agrifootprint*, Clark et al. (2022), Ecoinvent*, FAOSTAT Climate Change Domain , Idemat, Poore and Nemecek, (2018), RIVM database, World LCA by ESU Services*
Contribution to climate change	Carbon dioxide losses due to land conversion				
Pollution of the living environment	Particulate matter formation				AGRIBALYSE, Agrifootprint*, Ecoinvent*, Idemat, (2018), Worl LCA by ESU Services*
Pollution of the living environment	Ammonia emissions				Agrifootprint*
Pollution of the living environment	Photochemical oxidant formation				Agribalyse, Agrifootprint*, Ecoinvent*, Idemat, (2018), Worl LCA by ESU Services*
Pollution of the living environment	Acidification				Agribalyse, Agrifootprint*, Ecoinvent*, Idemat, Poore and Nemecek, (2018), RIVM database, Worl LCA by ESU Services*
Pollution of the living environment	Ozone layer depleting emissions				Agribalyse, Agrifootprint*, Ecoinvent*, Idemat, (2018), Worl LCA by ESU Services*
Degradation of land	Soil loss from wind erosion				
Degradation of land	Soil loss from water erosion				

Degradation of land	Soil organic carbon loss/build up				
Depletion of scarce abiotic resources	Fossil fuel depletion				Agribalyse, Agrifootprint*, Ecoinvent*, Idemat, Worl LCA by ESU Services*
Depletion of scarce abiotic resources	(Other) non-renewable material depletion				Agribalyse, Agrifootprint*, Ecoinvent*, Idemat, Worl LCA by ESU Services*
Depletion of scarce abiotic resources	Scarce water use (blue water)				Agribalyse, Agrifootprint*, Clark et al., (2022), Ecoinvent*, Idemat, Poore and Nemecek, (2018), RIVM database, Worl LCA by ESU Services*
Pollution of the living environment	Terrestrial ecotoxicity (air pollution)				
Pollution of the living environment	Terrestrial ecotoxicity (water pollution)				
Pollution of the living environment	Freshwater eutrophication				Agribalyse, Agrifootprint*, Clark et al., (2022), Ecoinvent*, Idemat, Poore and Nemecek, (2018), RIVM database, Worl LCA by ESU Services*
Pollution of the living environment	Marine eutrophication				Agribalyse, Agrifootprint*, Clark et al., (2022), Ecoinvent*, Idemat, Poore and Nemecek, (2018), RIVM database, Worl LCA by ESU Services*
Pollution of the living environment	Terrestrial ecotoxicity (soil pollution)				
Pollution of the living environment	Freshwater ecotoxicity (soil pollution)				Agribalyse, Agrifootprint*, Ecoinvent*, Idemat, (2018), Worl LCA by ESU Services*
Pollution of the living environment	Marine ecotoxicity (soil pollution)				
Degradation of biodiversity and ecosystems	Land occupation				
Degradation of biodiversity and ecosystems	Land transformation/Land use				Agribalyse, Agrifootprint*, Clark et al., (2022), Ecoinvent*, Idemat, Poore and Nemecek, (2018), RIVM database, Worl LCA* by ESU Services
Animal welfare	Animal years suffered				

Notes: * Comprehensive information regarding the availability of precise impact indicators is accessible through a paywall, although it is anticipated that these indicators will be addressed.
Green indicates that the data is widely available, accessible, and usable. Yellow indicates a lower level of availability, accessibility, and usability. Orange denotes rare availability, accessibility, and usability. Red indicates a complete absence of data.White cells represents situations where there is no information on data availabilitiy and further assessment is not possible.

Table 15: Summary of data availability, accessibility and quality/usabilitiy of environmental impact data

Data source	Impact category	Impact indicator	Availability	Accessibility	Quality/Usability
Agribalyse	Contribution to Climate change	• Greenhouse gas emissions	Offers an in-depth LCA detailing the environmental footprint of agricultural and food products for France.	Open access	High data quality assessment applied. Database is available in excel format. Easy to use format and structure, data is consistent and complete. LCA data is suitable for TCA of food and diets.
	Pollution of the living environment	• Ozone depletion • Ionizing radiation • Photochemical ozone formation • Particulate matter • Land and freshwater acidification • Freshwater eutrophication • Marine eutrophication • Land eutrophication • Ecotoxicity for freshwater aquatic ecosystems			
	Depletion of scarce abiotic resources	• Water resource depletion • Energy resource depletion • Mineral resource depletion			
	Degradation of biodiversity and ecosystems	• Land use			
Agrifootprint*	Not specified-behind a paywall	19 impact indicators -details behind a paywall	Extensive data on agricultural inputs including feed, food and biomass. Exact content is unknown due to the paywall.	Paid	High data quality assessment applied Impact indicators are suitable for TCA use. Expected easy to use format and structure, data is expected to be consistent and complete. LCA data is suitable for TCA of food and diets.

Ecoinvent*	Not specified-behind a paywall	Not specified-behind a paywall.	Various data from agriculture and animal husbandary sector. Exact content is unknown due to a paywall.	Paid	High data quality assessment applied. Expected easy to use format and structure, data is expected to be consistent and complete. LCA data is suitable for TCA of food and diets.
Clark et al., (2022)	Contribution to climate change	Greenhouse gas emissions	Impacts on food products consumed widely in UK and Ireland.	Open access	Applied sensitivity analysis to test the robustness of their approach. Background data and LCA data is partly available in excel format. For further information author communication is needed. Impact indicators are suitable for TCA of food and diets.
	Pollution of the living environment	Aquatic eutrophication potential			
	Depletion of scarce abiotic resources	Water stress			
	Degradation of biodiversity and ecosystems	Land use			
FAOSTAT Climate change domain	Contribution to climate change	Greenhouse gas emissions	Provides data on GHG emissions from agrifood systems	Open access	High data quality assessment applied Database comes in excel and csv format. Easy to use format and structure, consistent and complete. Impact data can be used for country level assessment. It is not suitable for TCA of food and diets.
Idemat	Contribution to Climate change	Greenhouse gas emissions	Includes some agricultural products.	Open access	Includes certain assumptions and uncertainties. Data accuracy and timeliness is ensured. Database is available in excel sheet. Easy to use format and structure, consistent and complete.
	Pollution of the living environment	• Acidification • Freshwater ecotoxicity • Particulate matter • Marine eutrophication • Freshwater eutrophication			

		• Terrestrial eutrophication • Ionising radiation • Ozone depletion • Photochemical ozone formation			LCA data is suitable for TCA of food and diets.
	Depletion of scarce abiotic resources	• Fossil resource use • Mineral and metal resource use • Water use			
	Degradation of biodiversity and ecosystems				
Poore and Nemecek (2018)	Contribution to climate change	Greenhouse gas emissions	A comprehensive meta-analysis on environmental impacts of food products. The database covers 40 products and five impact indicators.	Open access	High data quality assessment applied Background data and LCA data is available in excel format. Impact indicators are suitable for TCA of food and diets.
	Pollution of the living environment	Acidifying and eutrophying emissions.			
	Depletion of scarce abiotic resources	Freshwater withdrawals weighted by local water scarcity			
	Degradation of biodiversity and ecosystems				
RIVM Food consumption database	Contribution to climate change	Greenhouse gas emissions	Environmental impact of around 250 foods commonly consumed in the Netherlands	Open access	No information regarding data quality assessment provided. Database is available in excel sheet. Easy to use format and structure, consistent and complete. LCA data is suitable for TCA of food and diets.
	Pollution of the living environment	• Freshwater eutrophication • Marine eutrophication • Soil acidification			

	Depletion of scarce abiotic resources	Blue water consumption			
	Degradation of biodiversity and ecosystems	Land use			
World LCA by ESU Services*	Not specified-behind a paywall	Not specified-behind a paywall	Extensive data on agriculture, food processing and consumption activities	Paid	High data quality assessment applied Expected easy to use format and structure, data is expected to be consistent and complete. LCA data is suitable for TCA of food and diets.

*No access to detail about information on further availability on exact indicators due to paywall restrictions.

Table 16: Assessment of the monetization factors of environmental impacts

Impact category	Impact indicator	Availability	Accessibility	Usability	Source
Contribution to climate change	GHG emissions				Ecocosts Value – Sustainability Impact Metrics, True Price (2023), True Cost initiative (2022), Rockefeller Foundation (2021a)
Contribution to climate change	Carbon dioxide losses due to land conversion				
Pollution of the living environment	Particulate matter formation				True Price (2023)
Pollution of the living environment	Ammonia emissions				True Price (2023)
Pollution of the living environment	Photochemical oxidant formation				Ecocosts Value – Sustainability Impact Metrics, Monetization factors for true pricing
Pollution of the living environment	Acidification				Ecocosts Value – Sustainability Impact Metrics, True Price (2023), True Cost initiative (2022)
Pollution of the living environment	Ozone layer depleting emissions				Monetization factors for true pricing
Degradation of land	Soil loss from wind erosion				True Price (2023), True Cost initiative (2022), Rockefeller Foundation (2021a)
Degradation of land	Soil loss from water erosion				True Price (2023), True Cost initiative (2022), Rockefeller Foundation (2021a)
Degradation of land	Soil organic carbon loss/build up				True Price (2023), TCA Agrifood Handbook
Depletion of scarce abiotic resources	Fossil fuel depletion				True Price (2023)
Depletion of scarce abiotic resources	(Other) non-renewable material depletion				True Price (2023)
Depletion of scarce abiotic resources	Scarce water use (blue water)				True Price (2023), True Cost initiative (2022), The True Cost of Food report by The Rockefeller Foundation
Pollution of the living environment	Terrestrial ecotoxicity (air pollution)				True Price (2023)
Pollution of the living environment	Terrestrial ecotoxicity (water pollution)				True Price (2023)

Pollution of the living environment	Freshwater eutrophication				Ecocosts Value – Sustainability Impact Metrics, True Price (2023), True Cost initiative (2022), Rockefeller Foundation (2021a)
Pollution of the living environment	Marine eutrophication				Ecocosts Value – Sustainability Impact Metrics, True Price (2023), True Cost initiative (2022), Rockefeller Foundation (2021a)
Pollution of the living environment	Terrestrial ecotoxicity (soil pollution)				Monetization factors for true pricing
Pollution of the living environment	Freshwater ecotoxicity (soil pollution)				Ecocosts Value – Sustainability Impact Metrics, True Price (2023), True Cost initiative (2022), Rockefeller Foundation (2021a)
Pollution of the living environment	Marine ecotoxicity (soil pollution)				True Price (2023)
Degradation of biodiversity and ecosystems	Land occupation				True Price (2023)
Degradation of biodiversity and ecosystems	Land transformation/Land use				Ecocosts Value – Sustainability Impact Metrics, True Price (2023), True Cost initiative (2022), Rockefeller Foundation (2021a)
Animal welfare	Animal years suffered				

Green indicates that the data is widely available, accessible, and usable. Yellow indicates a lower level of availability, accessibility, and usability. Orange denotes rare availability, accessibility, and usability. Red indicates a complete absence of data. White cells represents situations where there is no information on data availabilitiy and further assessment is not possible.

Table 17: Summary of data availability, accessibility and quality/usability of the monetization factors of environmental impact

Data source	Impact category	Impact indicator	Availability	Accessibility	Quality/Usability
Ecocosts Value – Sustainability Impact Metrics	Contribution to climate change	• Greenhouse gas emissions	Ecocosts value provides monetization factors for six environmental impact indicators	Open access	The Ecocostvalue website does not explicitly provide a data quality assessment. Monetization factors are globally usable for TCA of food and diets.
	Pollution of the living environment	• Acidification • Eutrophication, • Photochemical oxidant formation • Ecotoxicity			
	Degradation of biodiversity and ecosystems	• Land use			
True Price (2023)	Contribute to climate change	• GHG emissions	True Price monetization factors are provided for various environmental impact indicators	Open access	True Price work on monetization factors is still in progress and recognizes its limitations. Monetization factors are globally usable for TCA of food and diets.
	Pollution of the living environment	• Toxic emissions to air • Nitrogen deposition (NH3/NOx) • Particular matter formation • Photochemical oxidation formation • Acidification • Ozone layer depleting emissions • Toxic emissions to water • Freshwater eutrophication • Marine eutrophication • Toxic emissions to soil			
	Degradation of biodiversity and ecosystems	• Land occupation • Land transformation			
	Depletion of scarce abiotic resources	• Fossil fuel depletion • (Other) nonrenewable material depletion • Scarce water use			

	Degradation of land	• Soil organic carbon loss • Soil loss from wind erosion • Soil loss from water erosion • Soil compaction			
True Cost Initiative (2022)	Contribution to climate change	• GHG emissions	TCA handbook provides monetization factors for nine natural capital indicators	Open access	Data quality assessment has not applied. Monetization factors are globally usable for TCA of food and diets.
	Pollution of the living environment	• Water pollution • Acidification Eutrophication • Eco-toxicity			
	Depletion of scarce abiotic resources	• Water stress			
	Degradation of land	• Carbon Stock • Soil erosion • Soil organic matter build-up			
Rockefeller Foundation (2021a)	Contribution to climate change	• Greenhouse gas emissions	The report outlines the true cost of food in the United States and provides monetization factors for a few environmental impacts.	Open access	The report does not specify data quality and data limitations issues. Monetization factors are the US based and usable for TCA of food and diets for the US.
	Pollution of the living environment	• Soil pollution • Air pollution • Water pollution • Eutrophication			
	Degradation of biodiversity and ecosystems	• Land use			
	Depletion of scarce abiotic resources	• Scarce water use			
	Degradation of land	• Soil erosion			

4.4 Impact and monetization data: Social capital

The data availability for social impact from agriculture and food production systems is notably limited compared to the data on environmental impacts. While it is common practice to conduct environmental LCAs to estimate the environmental impacts of food products, there is a scarcity of social LCA studies reporting the social impacts of food production. Additionally, quantifying social impacts is significantly more challenging than quantifying environmental impacts. Although very few studies cover the social impacts of agriculture and food production, these publications can serve as a starting point to guide the evaluation of the social impacts of food products. However, there are two extensive social LCIA databases that can be utilized to conduct a S-LCA and understand the impacts of different production systems on various indicators such as child labour, forced labour, fair salary, working time, employment, and more. There are two sources providing open access monetization factors for social impact indicators. It's challenging to determine the precise application of these databases in the context of TCA for food and diets due to the paywall. However, there are examples in the literature, such as the study by Mancini et al., (2023) which used paid S-LCA databases to evaluate the social impacts of food production. Hence, it is reasonable to assume that these databases can be applied to assess the social impacts of food products and TCA for food and diets. In this section, we provide an overview of these databases. As described earlier in the natural capital impacts chapter, the same color-coding system is employed to illustrate data availability, accessibility, quality, and usability of social impact data and monetization factors in the tables below. Furthermore, we present detailed tables on available sources, impact indicators, monetization factors, their accessibility, data quality, and usability. A comprehensive explanation of these data sources can be found in the Appendix 3. Detailed explanation of social impact and monetization data can be found in the Appendix 3.

Table 18: Data assessment of social impact indicators

Impact category	Impact indicator	Availability	Accessibility	Usability	Source
Food security	Ratio of change in price of a basic food basket per change in price of a product	Red			
Benefits sharing	Change in number of people reached through community engagement	Red			
Workers' representation	Freedom of association and collective bargaining	Green	Orange	Green	PSILCA* SHDB* soca*
Gender equity	Gender gap in hours worked	Orange	Orange	Green	SHDB*
Gender equity	Gender pay gap	Green	Orange	Green	PSILCA* SHDB* soca*
Laws and regulations	V-Dem Accountability Index	Red			
Laws and regulations	Corruption Perceptions Index	Red			
Laws and regulations	PIC procedures for trade of pesticides and chemicals listed in Annex I and V	Red			
Food affordability	Food price in relation to standard income	Red			
Social risk	Social risk on the production side	Red			
Food availability	Net imports relative to production	Red			
Acceptability	Mean departure from observed diet	Red			
Income	Wage gap from unequal opportunities (gender, racial, religious, etc. discrimination)	Green	Orange	Green	PSILCA* SHDB* soca*
Integration of workforce into communities	Change in number of migrant workers with feeling of exclusion	Green	Orange	Green	PSILCA* SHDB* soca*

Notes: *PSILCA, soca and SHDB databases are paid, and detailed information regarding the impact indicators is access through a paywall. However, an examination of the online documentation for these databases reveals that there are impact indicators available for the green-marked impact categories, although the indicator names may vary from those indicated here.

Green indicates that the data is widely available, accessible, and usable. Yellow indicates a lower level of availability, accessibility, and usability. Orange denotes rare availability, accessibility, and usability. Red indicates a complete absence of data. *White cells represents situations where there is no information on data availabilitiy and further assessment is not possible*.

Table 19: Summary of data availability, accessibility and quality/usabilitiy of social impact data

Data source	Impact category	Impact indicator	Availability	Accessibility	Quality/Usability
PSILCA database*	• Child labor • Forced labor • Fair salary • Working time • Discrimination • Social benefits, legal issues • Workers' rights • Fair competition • Corruption • Promoting social responsibility • Contribution to economic development • Prevention and mitigation of conflicts • Respect for Indigenous rights • Safe and healthy living conditions • Migration	69 qualitative and quantitative social indicators	PSILCA database can be used to assess the social impacts of food production. The PSILCA database is a comprehensive database for S-LCA.	Paid	High quality data assessment. Expected easy to use format and structure, data is expected to be consistent and complete. LCA data is suitable for TCA of food and diets.
SHDB*	Six categories and 30 subcategories- details are behind a paywall	160 indicators – details are behind a paywall	Collection of secondary data on social risks associated with global supply chains. It can be used to assess the social impacts of products and services.	Paid	High quality data assessment. Expected easy to use format and structure, data is expected to be consistent and complete. LCA data is suitable for TCA of food and diets.
soca*	Based on the PSILCA database, soca database is expected to cover the same indicators as in PSILCA.	Based on the PSILCA database. Contains more than 70 social indicators.	soca is an add-on for ecoinvent LCI databases providing information for Social LCA.	Paid	High quality data assessment. User-friendly format & consistent and complete data expected. LCA data is suitable for TCA of food and diets.

* No access to detailed information on specific indicators due to a paywall.

Table 20: Assessment of the monetization factors of social impacts

Impact category	Impact indicator	Availability	Accessibility	Usability	Source
Food security	Ratio of change in price of a basic food basket per change in price of a product				
Benefits sharing	Change in number of people reached through community engagement				
Workers' representation	Freedom of association and collective bargaining				True Price (2023)
Gender equity	Gender gap in hours worked				
Gender equity	Gender pay gap				True Cost initiative (2022), True Price (2023)
Laws and regulations	V-Dem Accountability Index				
Laws and regulations	Corruption Perceptions Index				
Laws and regulations	PIC procedures for trade of pesticides and chemicals listed in Annex I and V				
Food affordability	Food price in relation to standard income				
Social risk	Social risk on the production side				
Food availability	Net imports relative to production				
Acceptability	Mean departure from observed diet				
Income	Wage gap from unequal opportunities (gender, racial, religious, etc. discrimination)				True Cost initiative (2022), True Price (2023)
Integration of workforce into communities	Change in number of migrant workers with feeling of exclusion				

Green indicates that the data is widely available, accessible, and usable. Yellow indicates a lower level of availability, accessibility, and usability. Orange denotes rare availability, accessibility, and usability. Red indicates a complete absence of data. White cells represents situations where there is no information on data availabilitiy and further assessment is not possible.

Table 21: Summary of data availability, accessibility and quality/usabilitiy of social capital monetization factors

Data source	Impact category	Monetization factor for impact indicator	Availability	Accessibility	Quality / Usability
True Price (2023)	Discrimination	• Gender discrimination	True Price provides monetization factors for various social impact indicators.	Open access	True Price work on monetization factors is still in progress and recognizes its limitations. Monetization factors are globally usable for TCA of food and diets.
	Non-guarantee of a decent living standard	• Underpayment in the value chain • Lack of social security • Excessive and underpaid overtime • Insufficient income			
	Lack of union rights	• Lack of freedom of association			
True Cost initiative (2022)		• Gender pay gap • Living wage gap • Excessive working hours	TCA handbook provides monetization factors for 3 social indicators	Open access	No data quality assessment applied. Monetization factors are globally usable for TCA of food and diets.

4.5 Impact and monetization data: Human capital

Similar to social impact data, the data availability on human and health impacts of food products are limited. The Agri-footprint, Ecoinvent, and Agribalyse databases all provide insights into human toxicity impacts, emphasising both carcinogenic and non-carcinogenic toxicities associated with agricultural and food products. The USEtox model, developed by UNEP/SETAC, offers an extensive evaluation of human toxicity, encompassing various chemical emissions and product uses, and details exposure related to food contact materials. The Global Burden of Disease (GBD) Study 2019 offers an in-depth analysis of health outcomes, with data spanning from 1990-2019, focusing on dietary risks and health impacts across different countries and age groups. S-LCA databases mentioned earlier in the social impact chapter provide indicators for occupational health and safety risks. There are two sources providing open access monetization factors for human toxicity impact. The human capital impact data available in these databases can be used for TCA of food and diets, however, there is a wide range of data missing on health impact of nutrition, other diseases, antibiotic use and more. In this section, we provide an overview of these databases. As described earlier in the natural capital impacts chapter, the same color-coding system is employed to illustrate data availability, accessibility, quality, and usability of human capital impact data and monetization factors in the tables below. Furthermore, we present detailed tables on available sources, impact indicators, monetization factors, their accessibility, data quality, and usability. A comprehensive explanation of these data sources can be found in the Appendix 3.

Table 22: Data assessment of impact indicators for human capital

Impact category	Impact indicator	Availability	Accessibility	Usability	Source
Occupational health and safety risks	Workers who experienced -non-physical, non-sexual harassment				
Occupational health and safety risks	Non-fatal occupational incidents				PSILCA* SHDB*
Occupational health and safety risks	Fatal occupational incidents				PSILCA* SHDB*
Occupational health and safety risks	Health conditions due to excessive working hours				
Mental health	Contribution to increased suicide rates in agriculture (indirect)				
Human rights violation	Child labour				PSILCA* SHDB*
Human rights violation	Forced labour				PSILCA* SHDB*
Production-related human health impacts	Human toxicity (air pollution)				Agribalyse, Agrifootprint**, Ecoinvent**, Idemat, Usetox
Production-related human health impacts	Human toxicity (water pollution)				Agribalyse, Agrifootprint**, Ecoinvent**, Idemat, Usetox
Production-related human health impacts	Human toxicity (soil pollution)				Agribalyse, Agrifootprint**, Ecoinvent*, Idemat, Usetox
Consumption-related human health impacts	Health impact of undernutrition				
Consumption-related human health impacts	Health impact of malnutrition[31]				
Consumption-related human health impacts	Health impact of overweight and obesity				
Consumption-related human health impacts	Health impact of hypertension				
Consumption-related human health impacts	Health impact of non-communicable diseases				The Global Burden of Disease Study 2019

Consumption-related human health impacts	Health impact of dementia				
Consumption-related human health impacts	Health impact of food poisoning				
Consumption-related human health impacts	Health impact of pesticide exposure				
Public health threats from livestock production	Health impact of antibiotic use				
Public health threats from livestock production	Contribution to the exposure to zoonotic diseases (indirect)				
Income	Wage gap below minimum wage				PSILCA* SHDB* soca*
Income	Wage gap below living wage				PSILCA* SHDB* soca*
Income security	Workers without legal social security				

Notes: *PSILCA, soca and SHDB databases are paid, and detailed information regarding the impact indicators is access through a paywall. However, an examination of the online documentation for these databases reveals that there are impact indicators available for the green/yellow marked impact categories, although the indicator names may vary from those indicated here.

**Comprehensive information regarding the availability of precise impact indicators is accessible through a paywall, although it is anticipated that these indicators will be addressed.
Green indicates that the data is widely available, accessible, and usable. Yellow indicates a lower level of availability, accessibility, and usability. Orange denotes rare availability, accessibility, and usability. Red indicates a complete absence of data. White cells represents situations where there is no information on data availabilitiy and further assessment is not possible.

Table 23: Summary of data availability, accessibility and quality/usabilitiy of health impact data

Data source	Impact category	Impact indicator	Availability	Access	Quality/Usability
Agribalyse	Production-related human health impacts	• Human toxicity non-carcinogenic substances • Human toxicity carcinogenic substances	Offers an in-depth LCA detailing the environmental footprint of agricultural and food products for France.	Open access	High data quality assessment. Easy to use format and structure, data is consistent and complete. LCA data is suitable for TCA of food and diets.
Agrifootprint*	Production-related human health impacts	• Human toxicity non-carcinogenic substances • Human toxicity carcinogenic substances	Exact content is unknown due to a paywall.	Paid	High data quality assessment. Expected easy to use format and structure, data is expected to be consistent and complete. LCA data is suitable for TCA of food and diets.
Ecoinvent*	Production-related human health impacts	• Human toxicity non-carcinogenic substances • Human toxicity carcinogenic substances	Exact content is unknown due to a paywall.	Paid	High data quality assessment. Expected easy to use format and structure, data is expected to be consistent and complete. LCA data is suitable for TCA of food and diets.
Idemat	Production-related human health impacts	• Human toxicity non-carcinogenic substances • Human toxicity carcinogenic substances	Some agriculture product related data is available	Open access	Includes certain assumptions and uncertainties. Data accuracy and timeliness is ensured. Easy to use format and structure, data is consistent and complete. LCA data is suitable for TCA of food and diets.
PSILCA *	Health and safety	• Accident rate at workplace • Fatal accidents at workplace • DALYs due to indoor and outdoor air and water pollution • Presence of sufficient safety measures • Workers affected by natural disasters	The Product Social Impact Life Cycle Assessment (PSILCA) database can be used to assess the social impacts of food production. The PSILCA database is a comprehensive database for S-LCA	Paid	High data quality assessment. Expected easy to use format and structure, data is expected to be consistent and complete. The impact data is expected to be suitable for TCA of food and diets.
SHDB*	Health and safety	• Occupational toxics and hazards	It is a collection of secondary data that	Paid	High data quality assessment.

		• Occupational injuries and deaths More detail is behind a paywall	provides information on social risks associated with global supply chains. It can be used to assess the social impacts of products and services.		Expected easy to use format and structure, data is expected to be consistent and complete. The impact data is expected to be suitable for TCA of food and diets.
soca*	Based on the PSILCA database, soca database is expected to cover the same indicators as in PSILCA .	• Based on the PSILCA database soca contains more than 70 social indicators in total.	soca is an add-on for ecoinvent LCI databases providing information for Social LCA.	Paid	High quality data assessment. Expected easy to use format and structure, data is expected to be consistent and complete. LCA data is suitable for TCA of food and diets.
USEtox[2]	Production-related human health impacts	• Human toxicity non-carcinogenic substances Human toxicity carcinogenic substances	The Cumulative impact results summary presents the human toxicity impacts of food contact material	Open access	The Usetox model undergoes procedures for quality assurance, transparency, and peer review. The model needs to be opened in the USEtox application. Data is consistent and complete. Impact data is suitable for TCA of food and diets.
The Global Burden of Disease Study 2019	Consumption-related human health impacts	DALYs from leading chronic diseases attributable to dietary risk factors	The study provides dietary risk exposure estimates.	Open access	High data quality assessment. Easy to use format and structure, The data is available through Global Health Data Exchange interface and be downloaded in csv format. The dietary risk data is suitable might need manipulation to use for TCA of diets.

*No access to detail about information on further availability on exact indicators due to paywall.

[2] USEtox is a model providing midpoint and endpoint characterization factors for human toxicological impacts of chemical emissions in LCA.

Table 24: Assessment of the monetization factors of human capital impacts

Impact category	Impact indicator	Availability	Accessibility	Usability	Source
Occupational health and safety risks	Workers who experienced -non-physical, non-sexual harassment				True Price (2023)
Occupational health and safety risks	Non-fatal occupational incidents				True Price (2023), True Cost Initiative (2022)
Occupational health and safety risks	Fatal occupational incidents				True Price (2023), True Cost Initiative (2022)
Occupational health and safety risks	Health conditions due to excessive working hours				
Mental health	Contribution to increased suicide rates in agriculture (indirect)				
Human rights violation	Child labour				True Price (2023), True Cost Initiative (2022)
Human rights violation	Forced labour				True Price (2023), True Cost Initiative (2022)
Production-related human health impacts	Human toxicity (air pollution)				True Price (2023), True Cost Initiative (2022)
Production-related human health impacts	Human toxicity (water pollution)				True Price (2023), True Cost Initiative (2022)
Production-related human health impacts	Human toxicity (soil pollution)				True Price (2023), True Cost Initiative (2022)
Consumption-related human health impacts	Health impact of undernutrition				
Consumption-related human health impacts	Health impact of malnutrition[31]				
Consumption-related human health impacts	Health impact of overweight and obesity				
Consumption-related human health impacts	Health impact of hypertension				
Consumption-related human health impacts	Health impact of non-communicable diseases				

Consumption-related human health impacts	Health impact of dementia				
Consumption-related human health impacts	Health impact of food poisoning				
Consumption-related human health impacts	Health impact of pesticide exposure				
Public health threats from livestock production	Health impact of antibiotic use				
Public health threats from livestock production	Contribution to the exposure to zoonotic diseases (indirect)				
Income	Wage gap below minimum wage				True Price (2023)
Income	Wage gap below living wage				True Price (2023)
Income security	Workers without legal social security				True Price (2023)

Green indicates that the data is widely available, accessible, and usable. Yellow indicates a lower level of availability, accessibility, and usability. Orange denotes rare availability, accessibility, and usability. Red indicates a complete absence of data. White cells represents situations where there is no information on data availabilitiy and further assessment is not possible.

Table 25: Summary of data availability, access, quality and usability of monetization factors of human capital impacts

<table>
<tr><th>Data source</th><th>Impact category</th><th>Monetization factor for impact indicator</th><th>Availability</th><th>Accessibility</th><th>Quality / Useability</th></tr>
<tr><td rowspan="4">True Price (2023)</td><td>Child labour</td><td>Child labour</td><td rowspan="4">True Price provides monetization factors for five human impacts.</td><td rowspan="4">Open access</td><td rowspan="4">True Price work on monetization factors is still in progress and recognizes its limitations.

Monetization factors are globally usable for TCA of food and diets.</td></tr>
<tr><td>Forced labour</td><td>• Forced labor</td></tr>
<tr><td>Occupational health and safety risks</td><td>• Occurrence of harassment
• Negative effects of employee health & safety</td></tr>
<tr><td>Air/Soil/Water pollution</td><td>Human toxicity</td></tr>
<tr><td rowspan="3">True Cost Initiative (2022)</td><td></td><td>• Forced labour
• Child labour</td><td rowspan="3">Under the handbook monetization factors for four human indicators can be found.</td><td rowspan="3">Open access</td><td rowspan="3">Data quality assessment has not applied.

Monetization factors are globally usable for TCA of food and diets.</td></tr>
<tr><td>Occupational health and safety</td><td>• Occupational health and safety</td></tr>
<tr><td></td><td>• Human Toxicity</td></tr>
</table>

5. Mind the gap: potential consequences of data gaps

In the previous chapter, the data mapping exercise revealed significant gaps in the secondary data availability, accessibility and quality/usability, which pose challenges to conducting a comprehensive TCA analysis of European diets. In this section, we provide an overview of the current feasibility of TCA of diets by drawing on the findings of the previous chapter, with a specific focus on these data gaps. Additionally, we highlight the consequences that these data limitations have on diverse stakeholders.

5.1 Summary of current feasibility of TCA of diets and key data gaps

The feasibility of the TCA application on dietary analysis depends on a number of factors, including the methodology and data situation (described in detail in the previous section), the complexity of the system (in this case, the dietary analysis) as well as practical aspects such as the costs associated with conducting a TCA analysis:

- **Methodology**: While advanced methodologies and tools are available for quantifying the environmental sustainability of European dietary patterns, challenges persist. Solely relying on secondary data sources is a challenge when performing a full TCA analysis, given the current limitations of secondary data availability. Moreover, it's important to note that the assessment of biodiversity and its associated loss remains a key area for further research. Furthermore, the evaluation of social and human capital implications related to food is still in its early stages, with many social issues lacking quantitative indicators and robust valuation approaches.
- **Data**: Although there is a growing body of data and methodology concerning the environmental impacts of food production and consumption, data gaps remain. While natural capital impact data exists, and TCA of natural capital can be well performed (though there are still data gaps, especially in the case of biodiversity), there is a significant lack of data related to human and social capitals. However, the gradual expansion of S-LCA databases can help address this data gap over time.
- **Complexity of the system**: The European food system is inherently complex, involving a wide array of stakeholders. As previously outlined in this report, the complexity of sustainability and health assessment in the context of European dietary patterns becomes even more challenging when considering the entire life cycle of food products consumed in Europe, sourced from various countries of origin. It is worth noting that a full TCA of dietary analysis has never been performed, and this poses feasibility challenges, as there are no references or established methodologies for guidance. Additionally, diet-LCA and the inclusion of consumption aspects into the broader LCA framework are relatively new concepts.
- **Costs**: The financial aspects of conducting TCA studies can present challenges. This includes situations where necessary data is behind paywalls, as in the case of some LCA databases for natural capital impact data and S-LCA data, as well as the necessity to collect primary data when secondary data sources are unavailable and resulting in significant financial investments.

In conclusion, undertaking a comprehensive TCA analysis solely based on secondary data proves unfeasible, particularly when attempting to capture all three environmental, health, and social costs of European diets, as foreseen by TEEB (2018). Though it is feasible to assess natural capital impact using secondary data, it is essential to highlight data gaps here as well, particularly in biodiversity. However, when addressing social and human capital domains, secondary data prove insufficient. Despite these limitations, the relevance of TCA analyses persists. Acknowledging the constraints, it becomes evident that comprehensive TCA analyses today, given the current data situation, necessitate dedicated efforts in primary data collection.

Based on the data mapping in Chapter 4 we have identified the following key data gaps presented below which require future data gathering.

Food and diet data: The analysed food consumption data sources in Table 11 provide freely available data suitable for various types of individual, national or hypothetical dietary analyses. Most of the food composition data is also freely available, however, with varying data availability and usability. There are also commercial sources that offer subscription-based services that aggregate nutritional data, such as EuroFIR, which provides datasets and allows users to analyse the nutritional composition of food items and to calculate the nutrient density of multiple ingredients within a single product, helping assess complex foods with various components.

Supply chain data: The availability of supply chain data varies across different stages, with national statistics offering country-level information but often lacking product-level detail. Open access statistics like FAOSTAT and AQUASTAT provide aggregated data on the production stage. Paid LCI databases focused on agriculture and food products contain more product-specific data, but they come at a cost. Information becomes scarcer as one moves further down the supply chain, with consumption stage data almost non-existent. Researched databases do not cover food consumption data, given that information related to the consumer stage is generally based on primary data or assessed using high-level averages. Similarly, secondary databases typically do not incorporate transportation data, as it is often highly specific to particular cases and sourced from primary data. Food waste data is particularly hard to obtain, and open access sources typically lack information on food waste per product. The JRC technical report on Building a balancing system for food waste accounting at National Level provides a modelling of food waste for food supply chain for EU member countries. The food waste data dates to 2017. However, the modelling can be repeated for most recent years if more up to data background data is available.

Natural capital data: While numerous LCA databases offer insights into environmental impacts, data availability varies. Some databases are open and free to the public, while others require a subscription. Monetization factors are available for some sources, offering the translation of environmental footprints into monetary values. The data situation shows mixed results, with some environmental impact indicators widely available, accessible, and usable (green), while others remain rare (orange) or completely absent (red). Nevertheless, it can be stated that natural capital impact data for common impact indicators like greenhouse gas emissions, eutrophication, acidification, water scarcity, and land use are readily accessible. However, open data sources are deficient in impact indicators such as soil loss, soil organic carbon, and terrestrial and marine ecotoxicity. Additionally, the consideration of animal welfare impact is currently absent from all LCA databases. Paid LCA databases generally offer broader coverage of indicators and are anticipated to encompass a more extensive range of impact indicators. Natural capital data is generally applicable for TCA of food and diets.

Social capital data: Social impact data related to agriculture and food production are notably limited compared to natural capital impact data. Conducting a S-LCA to understand social impacts is challenging due to the scarcity of data. There are two extensive social LCIA databases, but both are paid, and detailed impact indicators are behind a paywall. Descriptions regarding the content of these databases and the covered impact indicators are available on the web. However, there is no specific information available on the coverage of agriculture and food products. Indicators related to food security, food loss and waste, food availability, and affordability are noticeably absent from these databases, which results in a data gap concentrated in these areas of social capital. Open access monetization factors are available for some social impact indicators. The overall data situation for social impact is predominantly red (absence), with some areas of orange and green. Social impacts can be included in TCA of food and diets only at a very limited extent with the available literature data.

Human capital data: Human and health impact data for food products are also very limited. While some databases offer insights into human toxicity impacts associated with agricultural and food products, they focus primarily on certain toxicities. The GBD (2019) study provides in-depth analysis of health outcomes, but it primarily focuses on dietary risks. Similar to social impact data, the overall data situation for human capital impact is mixed, with some areas of green, red, and orange. Some monetization factors are available for certain human toxicity impacts, while data for others is unavailable. It is possible to assess some aspects of human capital impacts in TCA of food and diets with the available human toxicity and human labour impacts. However, there is a knowledge and research gap in the literature on health impacts of nutrition/malnutrition, diseases such as obesity, hypertension, dementia and more.

In summary, data gaps exist across various domains, impacting data availability, accessibility, and quality/usability. The supply chain data situation varies depending on the stage, with consumption stage data being particularly scarce. Natural capital data availability is mixed, with some areas well-covered and others lacking data. Social capital data is notably limited, with paid databases offering some insights. Human capital data is also limited, with variations in toxicity impact coverage. The need for comprehensive data and collaborative efforts is evident to enhance the field of TCA for European diets.

5.2 Consequences of data gaps

The consequences of TCA data gaps have various effects on the decision making of different stakeholders. Owing to insufficient data, there is a risk of overlooking opportunities to enhance decision-making processes for both policymaking and guiding business transformation. Consumers lack full information to guide their dietary transition, and the broader TCA research field faces challenges in providing critical information necessary for driving impactful transformation.

POLICY CONSEQUENCES

Enhancing the data available for TCA of diets would enable a more comprehensive understanding of the true costs associated with different dietary patterns and could inform and bolster policy-making efforts aimed at promoting sustainable dietary practices. However, policymakers should not delay implementing evidence-based interventions to promote sustainable and healthy diets already now and take actionable steps to reduce environmental impacts, mitigate climate change, and improve social and public health outcomes.

The European Green Deal and Farm to Fork Strategy aim to make food systems more sustainable. However,without accurate data on interconnected impacts such as carbon emissions or impacts on biodiversity, these goals may be challenging to achieve simultaniously. TCA can serve as a valuable tool for navigating and addressing these interconnected impacts, providing policymakers with a comprehensive understanding of the true costs associated with different aspects of the food system.

Detailed health-related data can support effective health policies. For instance, specific data on the links between diet and chronic diseases, can support the design of policies aimed at reducing obesity rates and improving public health. But current data, modelling and unit gaps on the health impacts of pesticide ingestion limit the ability to accurately evaluate the health-related costs and benefits associated with pesticide ingestion of different dietary patterns. This impedes efforts to design targeted interventions to address diet-related diseases and improve public health outcomes. Accurate impact assessments are crucial for developing evidence-based strategies to promote healthier diets and prevent chronic diseases.

Data gaps in social impact data bear the risk of neglecting the social dimension when developing policy for sustainable food system. Data on social capital can support policies to address labour and ethical issues in the food supply chain and support European goals for fair and ethical food systems. For instance, the European Pillar of Social Rights emphasizes fair working conditions, but without comprehensive data on labour practices along the supply chain, including in the exporting countries outside of Europe, it is difficult to assess where we are on track to reach this goal.

MISSED OPPORTUNITIES FOR BUSINESS TRANSFORMATION

Impact assessments and TCA of food supply chains and products provide valuable insights that can drive innovation and collaboration across the food system. Data gaps restrict identifying opportunities for sustainable production and consumption practices, technological advancements, and the development of new business models. Bridging the data gaps can unlock innovative solutions and facilitate collaborations among stakeholders to achieve a more sustainable and resilient food system.

Incomplete environmental data and lack of transparency pose risks to sustainable business transformation and investment decisions. The Corporate Sustainability Reporting Directive seeks to align corporate reporting with sustainability goals, but businesses and investors may struggle to accurately assess their environmental impact without comprehensive data. EU nutrition and health claims regulations aim to protect consumers and encourage healthier choices, but data gaps can hinder the opportunity of institutions, e.g. consumer advice centres to monitor the implementation (or lack therof) by businessess. When companies do not monitor their production and supply chains for social issue, they run the risk of neglecting theses in their due diligence strategy. The monitoring of EU's commitment to responsible business conduct within the UN's 2030 Agenda can be hampered by incomplete data on social impacts.

It is in this context that TCA can function as a tool to monitor the environmental, social and health impacts of current business practices and support businesses and governments to identify pathways towards sustainable business models that support sustsianbale, healthy and just dietary patterns.

LIMITED CONSUMER GUIDANCE

Accurate TCA assessments are essential for providing consumers with reliable guidance to make informed dietary choices. Data gaps restrict the ability to communicate the true costs of different dietary patterns to the public. Without a comprehensive understanding of the environmental, social, and health impacts of their food choices, consumers may be misled or have limited information to support sustainable and healthy decision-making. Closing the data gaps can empower consumers with the knowledge needed to align their diets with sustainability goals.

Environmental impact data gaps can misinform consumers about the environmental impact of their choices. The proposed sustainable labelling framework as part of the legislative framework for sustainable food systems (FSFS) seeks to empower consumers with information and shape consumer choices towards transition to a sustainable food system. However, without data on the hidden costs of the food system consumers may lack crucial information for sustainable choices. Lack of clear diet-related health data can hinder consumers from making informed choices. The EU's commitment to promoting healthy and sustainable diets is challenged by data gaps linking diet to health outcomes. Consumers may unintentionally support products with questionable social responsibility records due to social impact data gaps. The lack of information on labour conditions can obstruct consumers' ability to make socially responsible choices.

TCA can support the provision of consumer information, e.g. through true pricing, i.e. the display of a second price tag displaying the true price of a food product, but can also support the design of policies aiming to nudge consumer to eat more healthy and sustainably (e.g. sugar tax).

LIMITED TCA RESEARCH

The existing data gaps have significant consequences on the ability of researchers and TCA practitioners to conduct comprehensive TCA case studies of diets. These data gaps not only impede the progress of TCA research but also demand substantial investments in terms of time and resources. As a result, the limited availability of data hinders researchers from offering policymakers and other stakeholders vital information required for informed decision-making and transformative actions. Without a robust data foundation, the potential for driving substantial change and fostering sustainable practices remains limited, underscoring the urgent need to address these data gaps to advance the field of TCA research effectively.

6. Recommendations on bridging the data gaps

TCA of European diets seeks to comprehensively evaluate the environmental, social and health impacts of our consumption choices. The previous chapters have shown that data and robust methodologies for environmental assessments are more evolved, but still not fully developed. Impact data for human and social capital is scarce, in some cases behind expensive paywalls while methodologies are not robustly defined. The scientific research addressing all the pillars of the dietary sustainability holistically requires further development. This chapter, therefore, first outlines recommendations on how to enhance data availability, accessibility and quality for TCA of European diets. Second, we propose how to improve data governance in this context. Lastly, we propose concrete priorities for bridging current data gaps.

6.1 Enhancing data availability, accessibility, usability and quality

To address the critical issue of enhancing data availability, accessibility, usability, and quality for TCA assessment of European diets, a set of comprehensive recommendations is being proposed. These recommendations are designed to create a standardized and collaborative framework, ensuring that data collection, reporting, and measurement techniques align to provide a holistic understanding of the impacts of European diets across multiple dimensions.

6.1.1 ENHANCING DATA AVAILABILITY AND QUALITY

R1: Standardized data collection frameworks: Encourage the harmonization of methodologies for data collection and impact measurement to ensure consistency and comparability across studies. A framework for LCI should cover the entire food supply chain, including production, processing, distribution, and consumption stages, as well as all four capitals (produced, social, human, and natural). These frameworks should specify data requirements, data documentation, and data-sharing mechanisms to ensure consistency and comparability across studies. This can be achieved through alliances of TCA practitioners and researchers or by building on existing initiatives for environmental impacts data – such as the Global Guidance for Life Cycle Impact Assessment Indicators and Methods (GLAM) or Global LCA Data Access Network (GLAD) under UNEP– and extend these for social and human capital impact data.

Promoting the harmonization of data collection can support the use of data, for instance, those collected during social audits, certifications, or other statistics, for multiple use cases. This will minimize the need to repeatedly collect the same data for various audits and purposes, hence, achieving a scenario where data is collected once and can be efficiently employed for diverse purposes. This can be achieved through the standardization of assessment protocols, data quality control procedures, and calculation methodologies, reducing redundancy.

R2: Data collection mandates: Establish policy frameworks that mandate the collection of relevant data for TCA assessments of European diets. This can include requirements for reporting and disclosing environmental, social, and health-related data by food producers, processors, and retailers. For example, this could become an integral part of current EU legislation initiatives, such as the Corporate Sustainability Due Diligence Directive.

R3: Standardised methodology and reporting: Develop standardized methodology and reporting guidelines and frameworks for TCA assessments, ensuring consistent reporting of data and results across studies. This will enhance the transparency, comparability, and reliability of TCA assessments. The harmonization of impact assessment methods, akin to the ongoing efforts at the European level by the JRC within Environmental Footprint 3.1, will fortify the availability of consistent LCIA data for TCA. Furthermore, efforts are necessary to advance the development of integrated reporting frameworks that incorporate sustainability information into financial reporting. For example, this could become part of the set 2 sector-specific reporting requirement for the agriculture and food sector of the European Sustainability Reporting Standards, which are to be developed by 2026.

R4: Funding support: Allocate dedicated funding for research and data collection efforts to bridge the data gaps. Government agencies, research institutions, and international organizations should provide financial support for comprehensive data collection, quality control, and modelling research in the field of TCA assessment.

6.1.2 ENHANCING DATA ACCESSIBILITY

R5: Public access: Improve data accessibility by establishing publicly accessible databases or repositories that house relevant data on the environmental, social, and health impacts of European diets. These repositories should adhere to data privacy and security regulations while promoting transparency and open access to support future research and policymaking. Encourage EU governing bodies, international organizations, national governments, and research institutions to adopt open data policies.

R6: Data sharing: Foster collaboration among stakeholders, including researchers, policymakers, industry actors, and consumer groups, to encourage data sharing and collaboration in data collection efforts. This collaboration can facilitate the pooling of resources and expertise, leading to more comprehensive and reliable datasets and overcoming current data silos.

6.2 Strengthening data governance

The effective governance of data in the context of TCA is vital for ensuring the integrity, accessibility, and harmonization of TCA data at the EU level. To address this, a series of recommendations are outlined here, aiming to create a robust data governance framework.

R7: Data governance framework: Establish a data governance framework for TCA data defining the roles and responsibilities of data collection, maintenance and dissemination for TCA of diets and food systems in accordance with the EU's Data Governance Act.

R8: Data harmonization: Align the TCA data harmonization with existing EU initiatives such as Product Environmental Footprint (PEF) as a standard LCA method and the Organization Environmental Footprint (OEF) for environmental data. TCA data should follow similar standardized methodologies expanded to social and human capital impacts, making it easier to integrate TCA into broader sustainability assessments.

R9: Make TCA data part of EU data exchange platform: Incorporate TCA data into the European Data Portal, ensuring compliance with established rules and data creation processes. Member states can contribute their national data to this integrated platform, transforming it into a comprehensive repository for TCA-related data, thereby enhancing accessibility and visibility for stakeholders and researchers. Inclusion of the TCA data into this kind of platform will also encourage cross-border collaboration among EU member states for data sharing and collaborative TCA-related projects, as well as facilitate data initiatives to achieve a harmonized TCA approach at the EU level.

R10: Establish JRC as TCA data governing body: Recognizing the imperative for a robust governance structure in managing TCA data, we recommend designate the EU's JRC the role as TCA data governing body. Given their pivotal role in data management, quality assurance and standardization, it emerges as an invaluable institution for TCA data governance at EU level. A cooperation between JRC and UNEP could be considered to align and reduce data efforts, for example, by exploring together the explansion of the Global LCA Data Access Network (GLAD)

R11: **Scale up of Agribalyse on European level**: Following the example of the Agribalyse database, which is currently limited to French food consumption, set up an LCI database for food and agriculture encompassing the entirety of the European Union. This expansion would involve active participation from all EU member states, who would contribute valuable data and insights to enrich the database's content. The goal of this expansion is to establish a harmonized LCI at the EU level, ensuring consistency and standardization in data collection and analysis across the region that would support wide impact and TCA assessment of food consumption in Europe.

6.3 Future research direction

The literature that links dietary patterns to human and environmental health has expanded substantially in the past decade. Recent scientific efforts have also attempted to include further pillars into sustainability assessments by addressing the social and economic impacts of our diets. While European and Western countries are widely covered in recent studies, the research looking on the rest of the world is more scarce.

R12: Holistic, systems assessments: More research should focus on the interplay of environmental, human, social and produced capital impacts. The lack of holistic, systems assessments can be partially attributed to a deficiency in metrics and data gaps across various domains, especially social and health, but also environmental aspects such as biodiversity. As highlighted in the previous section, the absence of data and metrics related to social capital poses a specific challenge in incorporating social aspects into assessments of dietary sustainability. To attain a more holistic grasp of the trade-offs entailed in dietary shifts, it is imperative to direct research efforts towards embracing all three dimensions of sustainability.

R13: Scope and boundary: Currently, there is a scarcity of research that establishes links between consumption and production-related impacts, considering a comprehensive cradle-to-grave system boundary. This leaves a significant knowledge gap in our understanding of the entire lifecycle of food products and their associated environmental, health, and social impacts.

R14: Scenario Analysis: Conduct scenario-based modelling to explore different future pathways and assess the potential impacts of policy interventions and consumer behaviour changes on the true costs of European diets. This can help identify the most effective strategies for achieving sustainability goals and inform policy decision-making.

These EU-specific recommendations have global implications. The EU's reliance on food imports, particularly for calorie consumption, underscores the interconnectedness of global food systems. By promoting open data, harmonization, and international collaboration, the EU's efforts to enhance data quality and accessibility can have far-reaching effects. They encourage a global shift toward more responsible and sustainable food production and consumption practices, contributing to the worldwide efforts of transitioning towards healthier, fairer, and more sustainable diets. The recommendations outlined here, based on the EU's specific challenges, can lay the foundation for a global TCA approach. Additionally, TCA and the TCA database can serve as valuable tools for companies to align with the emerging EU sustainability and supply chain regulations, such as the Corporate Sustainability Due Diligence Directive .

In conclusion, while data gaps and challenges may pose hurdles, it is important to recognize that TCA can be a powerful policy tool to derive healthy, sustainable, and fair diets, within Europe and globally. By implementing these recommendations and fostering international collaboration, the EU can harness the potential of TCA to drive informed decision-making, address the complexities of global supply chains, and ultimately contribute to a more sustainable and equitable future for food systems worldwide. TCA has the capacity to navigate these challenges and emerge as a valuable instrument in achieving a more responsible and sustainable approach to food production and consumption.

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Appendix 1: Glossary

Term	Definition	Source
Capital	The economic framing of the various stocks in which each type of capital embodies future streams of benefits that contribute to human well-being.	TEEB (2018)
Consumption	The final stage in the value chain, including purchases of food for consumption within the household.	TEEB (2018)
Data	Collection of information on observations or measurements - often in the form of counts or numbers - for the True Cost Accounting of food and diets.	Author's own elaboration
Disability adjusted life years (DALY)	One DALY represents the loss of the equivalent of one year of full health. DALYs for a disease or health condition are the sum of the years of life lost to due to premature mortality and the years lived with a disability due to prevalent cases of the disease or health condition in a population.	WHO (2021)
Distribution and retail	The step in the value chain including the activities associated with the transport and sale of goods, for example to retailers or consumers.	TEEB (2018)
Environmental impacts	Environmental impact refers to negative effects caused by human activities on the areas of ecosystem and natural resources.	Author's own elaboration
Externality	A positive or negative consequence of an economic activity or transaction that affects other parties without this being reflected in the price of the goods or services transacted.	TEEB (2018)
Human capital	The knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being.	TEEB (2018)
Human impacts	The diverse effects on human lives resulting from different production and consumption related activities and practices.	Author's own elaboration
Impact	A positive or negative contribution to one or more dimensions (environmental, economic, health or social) of human well-being.	TEEB (2018)
Indicator	Something that shows what a situation is like by depicting a value or a change.	True Cost Initiative (2022)
Living wage	Remuneration received for a standard work week by a worker in a particular place sufficient to afford a decent standard of living for the worker and her or his family.	Global Living Wage Coalition (2018)
Manufacturing and processing	The second of four stages in the value chain, including the operations involved in converting raw materials into finished products.	TEEB (2018)
Monetization	The process of converting a metric or an impact into monetary terms.	True Cost Initiative (2022)

Natural capital	The limited stocks of physical and biological resources found on earth, and of the limited capacity of ecosystems to provide ecosystem services.	TEEB (2018)
Primary data	Raw data or original data that are directly obtained during an observation, a measurement or a data collection specifically undertaken for the True Cost Accounting assessment.	True Cost Initiative (2022)
Produced capital	All manufactured capital, such as buildings, factories, machinery, physical infrastructure (roads, water systems), as well as all financial capital and intellectual capital (technology, software, patents, brands, etc.).	TEEB (2018)
Product	Agricultural raw material (e.g. apple) and processed materials (e.g. apple puree).	True Cost Initiative (2022)
Production	The first stage in the value chain, including activities and processes occurring within farm gate boundaries.	TEEB (2018)
Secondary data	Data that were originally collected and published for another purpose or a different assessment.	True Cost Initiative (2022)
Social capital	Encompasses networks including institutions, together with shared norms, values and understandings that facilitate cooperation within or among groups.	TEEB (2018)
Social Impacts	The diverse effect on communities and individuals resulting from various factors such as economic activities, policies and cultural practices.	Author’s own elaboration
Sustainable healthy diet	Dietary patterns that promote all dimensions of individuals' health and wellbeing, have low environmental pressure and impact, are accessible, affordable, safe and equitable, and are culturally acceptable	FAO and WHO (2019)
True Cost Accounting	Evolving methodology to measure and value the positive and negative environmental, social, and health externalities to analyse the costs and benefits of business and/or policy decisions.	True Cost Initiative (2022)
Valuation	The process of determining the financial worth or estimated value of a metric or impact.	Author’s own elaboration
Value chain	The full range of processes and activities that characterize the lifecycle of a product from production, to manufacturing and processing, to distribution, marketing, and retail, and finally to consumption. This sequence is also referred to as supply chain.	TEEB (2018)

Appendix 2: Supply chain data

Appendix 2 includes the detailed results of a data mapping exercise for supply chain data and natural, social, and human capital impact data relevant to the TCA of food and diet. Table 1 provides an overview of the data mapping results, including resources identified, data types, geographic scope, time frames, and direct access links. Further in the appendix, we provide in-depth information about each data source, addressing availability, accessibility, usability and quality.

Table 1: Overview of supply chain and impact data mapping results

Database	Category	Data Type	Geographic scope	Time frame	Access	Link
FAOSTAT	Measurement	Supply chain data	Global coverage	From 1961 to 2021/2022	Open	https://www.fao.org/faostat/en/#data
IFASTAT	Measurement	Supply chain data	Global coverage	2017-2018	Open	https://doi.org/10.5061/dryad.2rbnzs7gh https://www.ifastat.org/consumption/fertilizer-use-by-crop
AQUASTAT	Measurement	Supply chain data	Global coverage	1961-2020	Open	https://data.apps.fao.org/aquastat/?lang=en
EUROSTAT	Measurement	Supply chain data	European countries	1960s-2022	Open	https://ec.europa.eu/eurostat/data/database
JRC Science and Policy Report Energy use in the EU food sector: State of play and opportunities for improvement	Measurement	Supply chain data	European countries	2015	Open	https://publications.jrc.ec.europa.eu/repository/handle/JRC96121
JRC Technical Report Building a balancing system for food waste accounting at National Level	Measurement	Supply chain data	European countries	2000-2017	Open	https://publications.jrc.ec.europa.eu/repository/handle/JRC124446

Ladha-Sabur et al (2019). Mapping energy consumption in food manufacturing	Measurement	Supply chain data	Global coverage (limited countries)	1980-2015	Open	https://doi.org/10.1016/j.tifs.2019.02.034
Agrifootprint database	Measurement	Supply chain data, Natural capital impact data	Global coverage	2023	Paid	https://blonksustainability.nl/tools-and-databases/agri-footprint
Ecoinvent	Measurement	Supply chain data, Natural capital impact data, Human impact data	Global coverage	2022	Paid	https://ecoinvent.org/offerings/licences/
World Food LCA by ESU Services	Measurement	Supply chain data, Natural capital impact data	Global coverage	Last update unclear	Paid	https://esu-services.ch/data/fooddata/
Agribalyse	Measurement	Natural capital impact data, Human impact data	France	2022	Open access	https://doc.agribalyse.fr/documentation-en/agribalyse-data/data-access
Poore and Nemecek Reducing food's environmental impacts through producers and consumers (2018)	Measurement	Natural capital impact data	Global coverage	2018	Open access	https://www.science.org/doi/10.1126/science.aaq0216
Idemat	Measurement	Natural capital impact data, Human impact data	Global coverage	2023	Open access	https://www.ecocostsvalue.com/data-tools-books/
RIVM database	Measurement	Natural capital impact data	Netherlands	2021	Open access	https://www.rivm.nl/voedsel-en-voeding/duurzaam-voedsel/database-milieubelasting-voedingsmiddelen
FAOSTAT Climate change domain	Measurement	Natural capital impact data	Global coverage	1961-2020	Open access	https://www.fao.org/faostat/en/#data

Estimating the environmental impacts of 57,000 food products Clark et al (2022)	Measurement	Natural capital impact data	UK and Ireland	2022	Open access	https://www.pnas.org/doi/suppl/10.1073/pnas.2120584119
PSILCA	Measurement	Social impact data	Global coverage	2023	Paid	https://psilca.net/
SHDB	Measurement	Social impact data	Global coverage	2019	Paid	http://www.socialhotspot.org/
USEtox	Measurement	Human impact data		2023	Open access	https://usetox.org/model/download
The Global Burden of Disease Study (2019)	Measurement	Human impact data	Global coverage	2019	Open access	https://vizhub.healthdata.org/gbd-results/
TCA Agrifood Handbook (2022)	Valuation	Monetization factor	Globally applied	2022	Open access	https://tca2f.org/wp-content/uploads/2022/03/TCA_Agrifood_Handbook.pdf
Monetization factors for true pricing (2023)	Valuation	Monetization factor	Globally applied	2023	Open access	https://trueprice.org/monetisation-factors-for-true-pricing/
The True Cost of Food report by The Rockefeller Foundation (2021)	Valuation	Monetization factor	US	2021	Open access	https://www.rockefellerfoundation.org/wp-content/uploads/2021/07/True-Cost-of-Food-Report-Technical-Appendix-Final.pdf
Ecocosts Value – Sustainability Impact Metrics	Valuation	Monetization factor	Globally applied	2022	Open access	https://www.ecocostsvalue.com/social/natural-and-social-capital/

SUPPLY CHAIN DATA

In this section, we offer comprehensive insights into the mapping of supply chain data and associated data sources. This section is organized into three sub-chapters:

Data Availability: This sub-chapter delves into the availability of supply chain data across various databases. It provides details about the format, time span, and geographical scope of the data, as comprehensively as possible.

Data Accessibility: Here, we inform the reader about whether the data sources are open access or require payment. Additionally, we provide links for online access.

Data Usability and Quality: This final sub-chapter offers insights into the quality of the data within the databases. It discusses quality assessments and informs the reader if the data is suitable for TCA of diet purposes.

DATA AVAILABILITY

FAOSTAT

Crops and Livestock: FAOSTAT provides a comprehensive and up-to-date collection of data related to global food and agriculture. Crops data includes data on more than 140 individual crops (primary and processed) from over 245 countries and territories including EU-27 countries. It covers crop production (in tonnes), yield (100 g/ha), and area harvested (ha), production quantity for each crop. Similar to crop data, livestock data includes data on more than 20 individual livestock items (primary and processed) from over 245 countries and territories including EU-27 countries. It includes data on livestock numbers (head or 1000 head), raised and slaughtered animal population, production of products such as meat (tonnes), milk (tonnes), eggs (tonnes), and honey (tonnes). FAOSTAT crop and livestock database section covers most of the input in production stage except food loss at the farm.

Energy used in Agriculture: The Energy Use section of FAOSTAT includes information on the energy consumed in agricultural, aquaculture, and fisheries operations. This encompasses energy used for operating machinery, heating stables, and running fishing vessels, as well as electricity and heat used on farms but generated off-site. It covers over 245 countries and territories including EU-27 countries. The statistics cover 10 different energy types including natural gas, electricity, heat, coal, motor gasoline.

Land use: The Land Use section in FAOSTAT encompasses data across 44 different land use categories, irrigation and farming practices, and five key indicators for tracking activities in agriculture, and fisheries on a national, regional, and global scale. The data is updated annually and covers over 245 countries and territories including EU-27 countries. The data is accessible by country and year.

Fertilizers by nutrient: The dataset on Fertilizers by Nutrient includes data on the aggregate amounts of nutrients involved in the Production, Trade, and Agricultural Use of inorganic (chemical or mineral) fertilizers (total fertilizer use and application rate), spanning from 1961 to the present for over 245 countries and territories including EU-27 countries. The data is accessible by country and year. The data covers the three main plant nutrients: nitrogen (N), phosphorus (expressed as P_2O_5), and potassium (expressed as K_2O), and includes both straight and compound fertilizers.

Fertilizers by product: The Fertilizers by Product dataset encompasses data on the Production, Trade, and Agricultural Use of inorganic (chemical or mineral) fertilizer products from 2002 to the present. This dataset includes statistics for 23 different product categories and covers both straight and compound fertilizers present for over 245 countries and territories including EU-27 countries.

Livestock Manure: The FAOSTAT domain on Livestock Manure includes estimated nitrogen (N) contributions to agricultural soils from animal waste. It also shares data on nitrogen losses to air and water. These estimates are created using official FAOSTAT animal stock statistics and applying the globally accepted Intergovernmental Panel on Climate Change (IPCC) Guidelines. The data, updated annually and covering 1961-2020, is accessible by country and has global coverage It includes the following aspects: 1) Stocks; 2) Amount excreted in manure (N content); 3) Manure left on pasture (N content); 4) Manure left on pasture that volatilises (N content); 5) Manure left on pasture that leaches (N content); 6) Manure treated (N content); 7) Losses from manure treated (N content); 8) Manure applied to soils (N content); 9) Manure applied to soils that volatilises (N content); 10) Manure applied to soils that leaches (N content).

Pesticide use: The Pesticides Use database encompasses information on the application of principal pesticide categories (Insecticides, Herbicides, Fungicides, Plant growth regulators, and Rodenticides) as well as significant chemical families. The data outlines the amounts used, measured in tonnes of active ingredients. The data, updated annually and covering countries worldwide (over 245 countries and territories including EU-27 countries), is accessible by country and year, latest data coming from 2021.

Agricultural Machinery: The FAOSTAT database on Agricultural Machinery, which provided statistical series on items such as tractors, harvesters, threshers, irrigation pumps, milking machines, hand tools, and soil machines, as well as estimates of agricultural machinery in use and the value of import and export of agricultural machinery, is currently inactive. The most recent data available in this database refers to the year 2009, highlighting a significant gap in the availability of up-to-date data on the usage of agricultural machinery per hectare of cropland.

Agricultural employment: FAOSTAT annually refreshes its employment indicators, utilizing data from the International Labour Organization (ILO) database, which encompasses a comprehensive array of indicators spanning various labour statistics topics. The focus of the FAOSTAT Employment Indicators Domain is on metrics related to agricultural and rural employment. Specifically, the agricultural area indicators offer insights into employment status, agricultural sectors, and hours worked by individuals employed in agriculture, and fishing, broken down by gender and age when feasible. The data, updated annually and covering countries worldwide, over 245 countries and territories including EU-27 countries. It is accessible by country and year, the latest data coming from 2022.

FAOSTAT data does not generally include agricultural input per commodity per country. It provides more general data on the total amount of various types of inputs used in a country, usually measured in metric tons or kilograms per hectare of arable land.

Country of origin of food products: The FAOSTAT trade matrix provides trade data on agricultural and food products. The database contains export quantity, export value, import quantity, and import value. It also features a trade matrix, a table illustrating the trade exchanges between countries for food goods. The FAOSTAT trade matrix encompasses more than 245 countries and regions, with data spanning from 1961 to the latest year accessible. The FAO gathers, refines, and shares this information following the standard International Merchandise Trade Statistics. The trade matrix is useful for identifying trade dynamics and country of origin of food product imported to/within EU. However, it is oftentimes difficult to identify the primary source of imports. In many cases, European countries are importing foodstuffs outside of the region and then (re)exporting within the region. Countries tend to re-export, especially those which have large port or terminal facilities. For instance, when examining banana imports to Germany, a significant quantity appears to be imported from the Netherlands and Belgium. However, the climate conditions in both countries are not suitable for banana production. Thus, even though the declared country of origin for the imported bananas may be these European nations, the matrix doesn't indicate where the product was initially grown. This raises concerns about the re-exporting of various products consumed in the EU, an issue that the matrix does not capture.

IFASTAT

Fertiliser by crop: While it is challenging to gather and verify details on fertilizer usage for crops (FUBC), the FAO, IFDC, and IFA took initiative and jointly conducted the first global survey on FUBC in 1992, covering the 1990/1991 period. This marked the beginning of similar surveys, conducted and published every two to four years in major fertilizer-consuming nations. IFA has spearheaded these initiatives since 2008, and, as far as we are aware, it remains the sole global data source on fertilizer usage by both crops and countries.

The latest FUBC report, released in May 2022, covers the periods 2016-2016/17 and 2018-2018/19, though the majority of the data is from 2017-2018. The latest FUBC report covers 64 countries including the majority of EU-27 countries, and crops and food groups such as Wheat, Rice, Barley, Sorghum, Maize, Soybeans. Oil crops, vegetables, fruits, tea, coffee, pulses, beans and more. For the countries and agricultural products and product categories. IFASTAT provides data on the planted area, metric tonnes of nutrients applied, the rate of nutrient application, and the percentage of total nutrient use attributed to each crop.

AQUASTAT

Water use: AQUASTAT is FAO's global information system on water and agriculture. It provides free access to food and agriculture data for over 245 countries and territories and covers all FAO regional groupings from 1961 to the most recent year (2020) available. The database provides a range of information on agrifood systems, including parameters for water footprint such as harvested irrigated permanent and temporary crop area for several crops surveyed at FAOSTAT, total harvested area irrigated, water use for irrigation, % of water used for irrigation from different water sources, total agricultural water withdrawal and water withdrawal for livestock. The latest data available is from 2020.

EUROSTAT

Agricultural production (area of cultivation, harvest amounts, yields, livestock): Eurostat provides statistics on agricultural production in the European Union (EU) for over 100 different crop products. The data is collected under Regulation (EC) No 543/2009 and obtained by sample surveys, supplemented by administrative data and estimates based on expert observations. The sources vary from one EU Member State to another because of national conditions and statistical practices. National statistical institutes or Ministries of Agriculture are responsible for data collection in accordance with EU regulations. The finalised data sent to Eurostat are as harmonised as possible. The earliest data are available from 1955 for cereals and from the early 1960s for fruits and vegetables. Eurostat is responsible for establishing EU aggregates. The statistics that are collected on agricultural products relate to the area under cultivation, the quantity harvested, and the yield. The statistics that are collected on animal production relate to the number of farms and heads of animals by livestock units (LSU) of farm. The data includes information on the livestock population, including pigs, bovine animals, sheep, and goats, and their evolution over time. Also provides information annual livestock, poultry, and fishery products production.

JRC Science and Policy Report Energy use in the EU food sector: State of play and opportunities for improvement

Accurately quantifying the energy used in food production is highly complex. Food is a diverse commodity, and the energy required to take it 'from farm to fork' can vary significantly between different products. Even for the same type of product, the energy 'cost' can vary widely, influenced by factors such as the cultivation area, farming practices, efficiency of processing and storage, season of production or consumption, and transportation needs. The food supply chain involves several consecutive stages, each requiring energy for its specific processes. This report aims to outline the energy consumption in the agricultural chain at the EU level, providing detailed insights into the energy consumption in agriculture at the EU level for different stages of agricultural production, for 17 products identified as the most representative for the nutrition basket created by JRC. They provided data on energy embedded in the production steps and products making up the JRC food basket. However, it does not provide energy consumption values at the individual country and process level.

JRC Technical Report Building a balancing system for food waste accounting at National Level

As per the Waste Framework Directive (2008/98/EC), Member States (MS) are required to report food waste data for the reference year 2020 by June 30, 2022. However, EU countries are not at the same level when reporting national food waste quantification. This model introduces a model to address this gap. The model's primary objective is to quantify food waste at different stages of the food supply chain, including primary production, processing, retail, food services, and household consumption. The food groups covered by the model include sugar beet, cereals, fruits, vegetables, potatoes, oilseeds, meat, fish, eggs, and dairy. This model enables the estimation of food waste generated by each EU member state for the years 2000 to 2017. The results are broken down by stages of the food supply chain, allowing for the identification of key areas of concern in both stages and across various food groups.

Ladha-Sabur et al (2019). Mapping energy consumption in food manufacturing

To obtain a clearer insight into the energy used in the production and distribution of food, both within the UK and worldwide, energy consumption data in the food sector has been gathered from various literature and categorized based on the product, processing method, and mode of transportation. Food products were then clustered into seven categories: grains and oilseed milling, sugar and confectionary, fruit and vegetable, dairy, bakery, meat, and others. A literature review was conducted to collect data on energy consumption in the food manufacturing sector from 1980 to 2015. The review used specific energy consumption (SEC) data for products, processes, and food distribution based on product-based energy intensity (PEI) metrics. The dataset included the study's date and location, product details, involved processes, energy sources, and bibliographic references.

The Agri-footprint by Blonk Sustainability

The Agri-footprint database covers data on agricultural inputs, including feed, food, and biomass. The database provides a comprehensive life cycle inventory (LCI) of agricultural products and processes, including specific energy consumption (SEC) data for products, processes, and food distribution. The data includes information on product-based energy intensity (PEI) metrics, where the energy input in megajoules (MJ) was divided by the product output in kilograms (kg). The dataset includes information on the study's date and location, product details, involved processes, energy sources, and references. Some examples on of country specific products and processes included are: Fertilizer products, vegetable oil and protein meal products, sugar products, animal products, starch products, marine ingredients. The accessibility of the complete list of products and processes is restricted due to the paywall. Agri-footprint is constructed using a combination of statistics, scientific literature, other databases, and industry data, all integrated with expert modelling by Blonk.

Ecoinvent

The ecoinvent database contains information on the supply chains, covering a range of sectors, including agriculture and animal husbandry. The Agriculture & Animal Husbandry sector in the ecoinvent database comprises more than 2,400 datasets. covering the growing of perennial and non-perennial crops, raising of cattle and buffaloes, raising of pigs and hogs, and other activities within the agriculture and animal husbandry sector. The database includes information on the industrial or agricultural process they model, measuring the natural resources withdrawn from the environment, the emissions released to the water, soil and air, the products demanded from other processes (electricity), and of course, the products, co-products, and wastes produced. Ecoinvent database does not specifically focus on food but includes process data from other industries such as transportation, energy and packaging.

World Food LCA by ESU Services

The ESU World Food LCA database comprises over 2500 clear life cycle inventories (LCI) associated with agricultural, food processing, and consumption endeavors. This information is recorded in the EcoSpold v1 electronic format. The database provides:

- Complete and consistent balancing of all food products relevant to the Swiss market
- The whole chain from field to household is covered for many products
- Most data include information on food waste and water use

The database covers among other things following areas relevant to agriculture and food production systems:

Agricultural production services (application of fertilizers, machinery hours), Vegetable production, Fruits, Animal products, Fish, Dairy products, Meat alternatives, Staple food, Drinks, Sweets, Household appliances, Food consumption (packages, transports, cooking, consumption patterns, food waste), and Pets and pet food.

DATA ACCESSIBILITY

FAOSTAT

FAOSTAT offers wide range of data on agricultural supply chain The data can be accessed for free, without the need for a subscription or special access. The datasets can be downloaded for selected countries and parameters in excel or csv format or viewed directly in a table on the FAOSTAT Database website.

IFASTAT

The complete dataset, including historical data from all FUBC reports since 1992, is made publicly accessible. IFASTAT has 2 different access options to their dataset. Public access provides free access without a subscription to: Fertilizer Use by Crop: Datasets, Reports and Crop Calendars and Nutrient Use Efficiency: IFA NUE Backgrounder and NUE Removal & BND Coefficients.

Member Access option grants more detailed information to: Fertilizer Use by Crop: Country Profiles, Nutrient Use Efficiency: Dataset and Presentations, Special Products: Datasets, Reports and Presentations and Other Reports: Sulphur Nutrient Consumption Assessment.

Global data on fertilizer use by crop and by country can be download from the publication link in a zip file including all relevant data files. The excel named country tables presents fertilizer use by crop and country for the periods 2016-2016/17 and 2018-2018/19.

AQUASTAT

The data is accessible through the AQUASTAT database, free of charge and without a need for a subscription. The datasets can be downloaded for selected countries and parameters in excel or csv format or viewed directly in a table on the AQUASTAT Database website.

EUROSTAT

The data is accessible through the Eurostat Agriculture database, which covers topics such as the structure of farms, orchards, and vineyards, economic accounts for agriculture, agricultural production, organic farming, and agriculture and environment. The data is available from 2010 onwards and is updated regularly. Eurostat is committed to ensuring the quality, accuracy, and accessibility of its data. The data is available to the public through the Eurostat website, free access and without subscription. The datasets can be downloaded for selected countries and parameters in excel or csv format or viewed directly in a table on EUROSTAT Database website.

JRC Science and Policy Report Energy use in the EU food sector: State of play and opportunities for improvement

The JRC report, accessible through the JRC repository, is designed to offer scientifically grounded evidence to assist in the European decision-making process. The data on energy use in the EU food sector is either incorporated within the text or displayed in graphs throughout the report. Unfortunately, there is no direct access to the compiled data via the report. If access to the data is required, it is recommended to contact the authors directly.

Ladha-Sabur et al (2019). Mapping energy consumption in food manufacturing

The publication is openly accessible through ScienceDirect. Detailed metadata on energy consumption in food manufacturing can be found in the supplementary files.

The Agri-footprint by Blonk Sustainability

The Agri-footprint database is accessible through various formats, including XLSX, CSV, JSON, SimaPro CSV, and openLCA.zolca. The database is available for commercial use, and it is widely accepted by the food industry, LCA community, scientific community, and governments worldwide. Access to the database is available through an annual paid subscription and is governed by different licensing agreements for its use.

Ecoinvent

Ecoinvent offers paid access to detailed data regarding the environmental effects of numerous activities and products spanning all industrial fields. They have a variety of licensing options for individual commercial users, academic groups, developers, and large corporations.

World Food LCA by ESU Services

ESU Services offers paid access to the database. If desired, they collect and analyze detailed LCI-data for your studies and can provide it in various data formats.

DATA USABILITY AND QUALITY

FAOSTAT

The Food and Agriculture Organization of the United Nations (FAO) has developed a Statistics and Data Quality Assurance Framework (SDQAF) to ensure the quality of its statistical outputs and the soundness of processes and governance mechanisms put in place. The SDQAF includes 14 principles that cover the entire statistical process, from data collection to dissemination. FAO also works continuously to ensure that its data and statistical production processes and outputs are of the highest possible quality. Direct use of FAOSTAT data is not possible to estimate TCA of diets in its current format. FAOSTAT does not provide information on crop/food product level as desired to estimate TCA of diets.

IFASTAT

The present survey leveraged the agricultural knowledge of several specialists to provide and validate estimates, representing the best outcome that IFA could accomplish with the resources available. The data is collected through surveys and estimation methods based on county-level statistics published by the National Development and Reform Commission (NDRC) and other sources. It is advised, however, to be aware that the estimates provided for many countries are linked with significant uncertainties. Similarly, comparing with past reports should be done carefully as methodologies and information sources have evolved over time. Despite these caveats, this dataset represents the most accurate estimates of FUBC at a national level with worldwide coverage available up to now. Data can be used as supply chain input data for LCA and TCA of diets.

AQUASTAT

The data is collected through a questionnaire compiled by National Correspondents and validated through a data validation process. After the completion of the questionnaire, the data validation process begins, involving exchanges between the National Correspondents and the AQUASTAT team to clarify the collected data. The critical assessment of the compiled data prioritizes national sources and expert knowledge. The AQUASTAT team manually carries out five initial checks and validations which are; Cross-variable check, Time-series coherency, Comparison with neighbouring countries, Verification and validation of transboundary water data, considering all countries involved in the transboundary river basin, Verification of the metadata, especially the source of the proposed data. Following manual verification, the AQUASTAT database management system aids in the data validation and processing using nearly 200 validation rules. Similar to FAOSTAT data, AQUASTAT data is also limited to country level estimations.

EUROSTAT

The data is collected through surveys and estimation methods based on county-level statistics published by the National Development and Reform Commission (NDRC) and other sources. Eurostat monitors regularly the quality of crop statistics, and in general, the availability, completeness, and punctuality are good, particularly for the data on crop production. Similar to other statistics data, EUROSTAT data is also aggregated on country level and its use is limited in TCA applications.

JRC Science and Policy Report Energy use in the EU food sector: State of play and opportunities for improvement

The Joint Research Centre (JRC) of the European Commission is committed to making its data available for use under the conditions of free, full, open, and timely access, subject to the conditions and exceptions laid down in their data policy. Particular attention was dedicated to evaluating the quality of the data used in the study by considering the following parameters and creating a 'pedigree' data matrix:

Time-related coverage: the age of the data

Geographical coverage: the geographical area from which data for unit processes were collected.

Technology coverage: the specific technology or mix of technologies.

Completeness: the type of flow provided.

Consistency: the alignment of data with the methodology and assumptions of the study.

In its current format in the report, energy consumption data is aggregated for EU level and can be suitable for high level EU average TCA of diets.

Ladha-Sabur et al. Mapping energy consumption in food manufacturing

Numerous energy studies were carried out in the 1970s and 1980s. Average energy consumption values for processes and products were calculated only when more than two duplicates were found in the literature. Although the accuracy of the data reported could not be ascertained, as error measurements or uncertainties are seldom mentioned in energy accounting studies, general trends in processing as well as critical areas can be identified. There is a shortage of comprehensive and current data, and many recent sources still cite outdated figures. The estimation and reporting of energy consumption data did not adhere to a uniform methodology, resulting in significant differences in the energy usage estimates for identical food products or processes. . Energy consumption data can be used as proxies for LCA and TCA of diets.

The Agri-footprint by Blonk Sustainability

The Agri-footprint database is considered to be a high-quality and reliable LCI database focused on the agriculture and food sector. The data quality and coverage of Agri-footprint are improved with each release, and the database now contains approximately 5,000 products and processes. The database includes a comprehensive data quality check and rating method. Moreover, it has been externally reviewed for ILCD requirements by the Centre for Design and Society at RMIT University, Melbourne, Australia. The external reviewers assessed the consistency and transparency of the applied methodology as well as the completeness and transparency of data documentation. The main purpose of Agrifootprint database is providing inventory data for agricultural production systems to conducting LCAs and other analysis. Data can be useful for TCA of food and diets.

Ecoinvent

The ecoinvent database has a thorough data quality evaluation method to guarantee data reliability and precision. Its processes are clear and traceable, with detailed documentation covering every aspect of the database. Each year, the Ecoinvent Association releases reports detailing updates to the database, which also gives in-depth insights into the basis of the calculated environmental impacts. The "Data Quality Guideline for ecoinvent Database Version 3" offers insights into the used Life Cycle Assessment (LCA) techniques, the overarching structure of the database, criteria for submitting data, an overview of the review mechanism, and more. The main purpose of the Ecoinvent database is to use for LCAs and it is suitable for conducting food LCAs. The ecoinvent database is integrated into all leading LCA software tools such as SimaPro, OpenLCA. Ecoinvent database can be used for TCA of food and diets.

World Food LCA by ESU Services

At the website of World Food LCA by ESU Services detailed information or documentation on data quality assessment is not provided. They provide that the ESU-services initially constructed their food production and consumption databases from a doctoral study that examined meat and vegetable purchases (Jungbluth et al. 2000; Jungbluth 2000). These databases have been regularly updated and expanded to reflect current agricultural practices. Further information was sourced from multiple consulting projects. While the majority of the data is relevant to Switzerland and derived from published sources, some information also comes directly from producers and the food sector. The inventory database providing detailed information on agricultural supply chains can be used to conduct LCAs, and can be used for TCA of food and diets.

Appendix 3: Impact and monetization data

Appendix 3

Appendix 3 provides comprehensive details regarding the availability, accessibility, usability, and quality of impact and monetization data for natural, social, and human capitals.NATURAL CAPITAL

In this section, we delve deeply into the mapping of natural capital impact data, the valuation of impact indicators, and their corresponding data sources. We have structured this section into three sub-chapters:

Data Availability: This portion highlights natural capital impact indicators relevant to agriculture and food products, detailing their presence in various LCA databases and peer-reviewed studies. Additionally, it sheds light on the availability of monetization factors for these natural capital impact indicators.

Data Accessibility: In this sub-chapter, we guide the reader on the accessibility of data sources, specifying if they are freely available or require payment. We also provide online access links.

Data Usability and Quality: This sub-chapter provides insights into the quality of data from the mapped data sources. It provides insights on quality evaluations and informs the reader if the impact data are suitable for TCA of diets use.

DATA AVAILABILITY

IMPACT INDICATORS

Agrifootprint

As mentioned in the chapter 4.2.1 under supply chain data, the latest version of the database, Agri-footprint 6.3, covers a wide range of agricultural products, including feed, food, and biomass. The database contains calculated environmental impacts of all products and processes for cradle to farm gate system boundaries. It is a useful tool for experts working on environmental assessment of the agricultural value chain. Agrifootprint provides impact assessment data for 19 impact indicators.

Ecoinvent

As mentioned under supply chain data, the latest version of the Ecoinvent database v3.9.1, includes various data from the agriculture and animal husbandry sector. For each dataset in the ecoinvent database, Life Cycle Impact Assessment scores for several impact assessment methods and corresponding impact categories are available. These impact categories include climate change, human toxicity, land use, and water use, among others. Ecoinvent provides implementation of LCA for different system boundaries such as cradle to gate or cradle to grave.

World LCA by ESU Services

As mentioned in detail under the chapter 4.2.3 supply chain data availability, ESU services provide data on food and agricultural services. Besides the inventory data on food systems they also provide Environmental intensity data for products (e.g. carbon footprint (CO_2-eq per kg). The details on impact categories and environmental intensities are not provided on their website. Since the data is behind a paywall it is advisable to contact the ESU services directly to get more information on the impact assessment data.

Agribalyse

Agribalyse is a French database that offers an in-depth Life Cycle Assessment (LCA) detailing the environmental footprint of agricultural and food products specific to the country. This comprehensive resource has environmental metrics for each of its 2,500 listed food items.

From the cultivation to the consumption of food, Agribalyse covers every aspect, including its production, processing, packaging, transportation, and distribution stages. The data within this database reflects over a decade of research and expertise, aiming to accurately represent the environmental consequences of agricultural and food items. The data was built for the French food market and context. However, while it might be a suitable first approach proxy for European nations, it's not recommended to use for southern countries. The creators of Agribalyse have recognized the demand for more comprehensive data and the inclusion of other national datasets.

Throughout the supply chain, balances of materials, energy, and emissions are documented and summarized under 14 environmental indicators for each product. These indicators are in line with the guidelines set by the European Commission's Product Environmental Footprint project. Additionally, a single score termed the "single EF score", is provided for each product. However, Agribalyse acknowledges certain limitations, emphasizing that existing LCA metrics don't fully reflect every environmental concern. Some of the critical areas that need refining within the LCA indicators for the food sector include:

- Water usage in agriculture
- Carbon storage and release in soils
- Effects of plant protection products on human and ecosystem health
- Biodiversity

Reducing food's environmental impacts through producers and consumers J. Poore and T. Nemecek (2018)

In this study Poore and Nemecek combined data covering five environmental indicators, encompassing 38700 farms in 119 countries, and 1600 processors, packaging types and retailers. They built a multi indicator global dataset derived from a compherensive meta-analysis. The database cover 40 products and five environmental impact indicators which are; land use, freshwater withdrawals weighted by local water scarcity, greenhouse gas emissions, acidifying and eutrophying emissions. They collected data throught out food production chain with input at the farm and ends at retail. For each study, they documented the list of inventory inputs and outputs, such as the amount and kind of fertilizer, irrigation practices, soil, and weather conditions. When certain information was missing, they utilized study coordinates and spatial datasets to bridge the gaps.They recorded all relevant environmetal impact at each stage of supply chain. They also categorize products based on their main nutritional purpose and present impacts on a per-unit basis of their primary nutritional advantage.

Idemat

The IDEMAT database, an abbreviation for Industrial Design & Engineering materials, is a collection of Life Cycle Inventory data curated by the Sustainable Impact Metrics Foundation (SIMF). This database offers insights into the environmental consequences of various materials such as metals, plastics, wood, and even electricity for cradle to grave boundaries. among others. It serves as a tool for evaluating eco-costs, carbon emissions, and midpoint impact indicators. Although its primary emphasis isn't on food, IDEMAT incorporates some agricultural data sourced from the Agri footprint database.

RIVM

The RIVM conducted an analysis of the environmental impact of around 250 foods commonly consumed in the Netherlands. These selected foods span various categories, including meat, dairy, bread, vegetables, beverages, and spreads. Their selection was based on their representation of the significant daily environmental consequences of food intake. Commissioned by the Ministry of Agriculture, Nature and Food Quality, RIVM has consolidated data to assess the lifecycle environmental footprint of Dutch food consumption and aims to track this continuously in upcoming years. The data in the database are constructed using the Life Cycle Analysis (LCA) methodology for cradle to grave system boundaries, Blonk Consultants performed this comprehensive assessment for RIVM. The LCA has been used to map the environmental impact for the following environmental indicators: greenhouse gas emissions eutrophication of freshwater and marine, acidification of the soil land use blue water consumption (irrigation water).

FAOSTAT Climate change domain

FAOSTAT Climate Change Agrifood Systems Emissions provides global, regional, and country-level statistics on absolute emissions and their shares over time. The domain presents results of the database and disseminates statistics over the period 2000–2020. FAOSTAT Climate Change Agrifood Systems Emissions also includes a new statistical domain dedicated to greenhouse gas emissions from pre- and post-agricultural production activities.

The Climate Change domain within FAOSTAT provides data on GHG emissions from agrifood systems, offering detailed insights into various emission sources. The key components of this domain are:

Agriculture: Emissions derived directly from agricultural activities, such as:

Enteric Fermentation: Methane emissions from the digestive processes in ruminant animals.

Manure Management: GHG emissions from the storage and treatment of animal manure.

Rice Cultivation: Methane emissions from anaerobic decomposition in flooded rice fields.

Agricultural Soil Management: Emissions (mainly nitrous oxide) from the soil due to fertilizer application, organic soil amendments, tillage, crop residues, etc.

Burning of Agricultural Residues: Emissions from open burning of crop residues.

Energy Use in Agriculture: Emissions from the use of fossil fuels in agricultural operations.

Land Use, Land-Use Change, and Forestry (LULUCF): Emissions and removals resulting from changes in the use of land (e.g., deforestation, reforestation) and from processes happening in forests, wetlands, and other land uses.

Supply Chain: Emissions associated with the production and transport of agricultural inputs (like fertilizers and pesticides) and emissions from the processing, transport, retail, and consumption of food products.

Estimating the environmental impacts of 57,000 food products Clark et al. (2022)

Previous studies, such as the one by Poore and Nemecek (2018), examined the environmental impacts of individual food commodities like fruits, wheat, and beef. Yet, many food products consist of multiple ingredients. Clark et al. (2022) states that determining the environmental impact of these products has been challenging since the exact quantity of each ingredient is typically only known to the manufacturer. In this study, they introduce a method that uses prior knowledge from ingredient lists to infer the composition of each ingredient. This data is then combined with environmental databases (Poore and Nemecek, (2018) and Gephart et al.,(2021) to calculate a product's environmental footprint based on four indicators: greenhouse gas emissions, land usage, water stress, and potential for eutrophication. When applied to 57,000 products from the UK and Ireland, the results reveal varying environmental impacts, from low (like sugary drinks, fruits, breads) to medium (many desserts, pastries) and high (meats, fish, cheese). They evaluated the nutritional value of products using Nutri-Score. By integrating the algorithm with a nutritional quality metric, they found that across various retail categories, several of the most nutritious food categories (excluding beverages) align with being the most environmentally sustainable.

MONETIZATION FACTORS

TCA Agrifood Handbook (2022)

TMG Think Tank for Sustainability and partners developed Practical Guidelines for the Food and Farming Sector on Impact Measurement, Valuation and Reporting in order to facilitate implementation of TCA conceptual frameworks through detailed description of metrics and monetization of environmental, health and social impacts. The 9 natural capital indicators include:

- GHG emissions,
- Carbon Stock,
- Soil erosion,
- Soil organic matter build-up,
- Water stress,
- Water pollution,
- Acidification,
- Eutrophication,
- Eco-toxicity

Monetization factors for True pricing (2023)

True Price offers monetization factors to support the application of TCA, covering various true price effects with their respective footprint indicators and sub-indicators, complemented by insights into their interpretation and data sources. Additionally, Environmental impacts module, provides an in-depth rationale for the monetization factors and further guidance on their application, as well as a methodology for determining true prices. The true price methodology implements the principles of remediation by identifying the following four types of costs that, when appropriately combined, form the remediation cost for an impact: restoration costs, compensation (damage) costs, prevention of re-occurrence costs and retribution costs. The 10 environmental impact categories are provided with their respective impact indicators.

- Contribute to climate change
  - Greenhouse ga emissions
- Air pollution
  - Toxic emissions to air
  - Nitrogen deposition (NH3/NOx)
  - Particular matter formation
  - Photochemical oxidation formation
  - Acidification
  - Ozone layer depleting emissions
- Water pollution
  - Toxic emissions to water
  - Freshwater eutrophication
  - Marine eutrophication
- Soil pollution
  - Toxic emissions to soil
- Land occupation
  - Land occupation
- Land transformation
  - Land transformation
- Fossil fuel depletion
  - Fossil fuel depletion
- (Other) nonrenewable material depletion
  - (Other) nonrenewable material depletion
- Scarce water use
  - Scarce water use
- Soil degradation
  - Soil organic carbon loss
  - Soil loss from wind erosion
  - Soil loss from water erosion
  - Soil compaction

The True Cost of Food report by The Rockefeller Foundation (2021)

The report outlines the true cost of food in the United States, which includes the impacts on human health, the environment, biodiversity, livelihoods, and much more. The report examines 14 key metrics across the impact areas of human health, environment, biodiversity, livelihoods, and more to quantify the true cost of food. The environmental and biodiversity impacts that they monetize include Greenhouse gas emissions, Water use/depletion, Land use, Soil, water, air pollution. In this exercise, US-specific monetization factors were provided by True Price.

Ecocosts Value – Sustainability Impact Metrics

In Ecocosts Value True Cost Accounting, they calculate the costs of not damaging nature by using prevention costs approach in the eco-costs system. Eco-costs of natural capital includes; global warming (carbon footprint), acidification, eutrophication, photochemical oxidant formation, ecotoxicity. E-LCA addresses air pollution, while issues of water pollution are tackled through eco-toxicity, acidification, and eutrophication. Water scarcity is addressed by E-LCA concerns by comparing total water withdrawals to natural water resources available. The eco-cost of land use is also estimated related to the marginal costs of prevention of the negative environmental effects of change of land-use.

DATA ACCESSIBILITY

IMPACT INDICATORS

Agrifootprint

As previously noted in the Supply Chain Data Accessibility chapter, the Agrifootprint database is available through various licensing options behind a paywall.

Ecoinvent

As previously noted in the Supply Chain Data Accessibility chapter, Ecoinvent database is available through various licensing options behind a paywall.

World LCA by ESU Services

As previously noted in the Supply Chain Data Accessibility chapter, the World LCA database is available through various licensing options behind a paywall.

Agribalyse

The data from AGRIBALYSE® is provided for free in two formats:

A comprehensive version, which necessitates having and knowing how to use an LCA software for access. This version offers insights into every production phase and permits adjustments to production assumptions at each step.

A simplified version, open to all users.

- two spreadsheets for raw conventional agricultural products and organic products (at the farm gate)
- a spreadsheet for feed (available in INRAE website),
- a spreadsheet for ready-to-eat food products.

Reducing food's environmental impacts through producers and consumers J. Poore and T. Nemecek (2018)

Poore and Nemecek's publication is available online. All relevant data pertaining to food products can be found in the supplementary files of the publication.

Idemat

Idemat database is open access and can be downloaded in excel format at eoc-costs value website.

RIVM

The data on the environmental impact of foodstuffs is public and free to use.

FAOSTAT Climate change domain

As previously noted in the Supply Chain Data Accessibility chapter, FAOSTAT database is available free of charge.

Estimating the environmental impacts of 57,000 food products M. Clark et al., (2022)

The publication is available online open access. The algorithm along with its corresponding data inputs can be found at the Oxford Research Archives (https://ora.ox.ac.uk/objects/uuid:4ad0b594-3e81-4e61-aefc-5d869c799a87) (41). Due to legal reasons, the product-specific data on the mentioned link is made anonymous. A version of the product data that is not anonymized can be obtained under license by reaching out to R.H. and P.S. For those wanting to replicate the study results and need the non-anonymous version of the product-level data, they can contact foodDBaccess@ndph.ox.ac.uk.

MONETIZATION FACTORS

Table 2: Accessiblitiy of monetization factors for environmental impacts

Source	Accessibility
TCA Agrifood Handbook (2022)	The TCA Agrifood Handbook is open access and can be accessed through the link provided in Table 1.
Monetization factors for true pricing (2023)	Monetization factors for true pricing are available through True Price website. The document can be downloaded free of charge through a quick registration requesting name and contact details.
The True Cost of Food report by The Rockefeller Foundation (2021)	The True Cost of Food report is available free of charge through The Rockefeller Foundation website.
Ecocosts Value – Sustainability Impact Metrics	The Sustainability Impact Metrics foundation believes in free online access to all data, ensuring transparency and accessibility for all, from SMEs to students. Calculations should be rooted in peer-reviewed scientific papers.

DATA USABILITY AND QUALITY

IMPACT INDICATORS

Agrifootprint

As highlighted in the supply chain chapter, the Agrifootprint database undergoes rigorous data quality checks. This database is well-suited for conducting LCAs, and fits TCA of food and diets purpose. The agricultural impact data can be extracted from it.

Ecoinvent

As mentioned previously under Supply Chain Data Usability and Quality section, Ecoinvent has a compherensive data quality assessment. Ecoinvent can be used to perform LCAs on food products to understand their environmental impacts from production to consumption. The structure of the database allows users to trace the impacts of their products throughout the supply chain and understand their results. Ecoinvent impact data is suitable for TCA of food and diets use.

World LCA by ESU Services

Please refer to the 'Supply Chain' chapter for a detailed explanation on the usability and quality of the 'World LCA by ESU Services' data.

Agribalyse

Each agricultural and food product in the Agribalyse database comes with a Data Quality Ratio (DQR) ranking, which ranges from 1 (excellent quality) to 5 (lowest quality). The European Commission advises caution when using data with a DQR exceeding 3. Within the AGRIBALYSE system, 67% of the entries possess a DQR that's rated as either good or very good, falling within the 1 to 3 range. The Agribalyse database can be integrated into TCA of food products. Provided environmental impacts of various agricultural products can be used to assess the environmental costs associated with the product.

Reducing food's environmental impacts through producers and consumers J. Poore and T. Nemecek (2018)

Poore and Nemecek applied a comprehensive inclusion criteria for their meta-analysis. They verified the worldwide representativeness of their sample by comparing it to average and 90th-percentile yields from

FAO data. The results aligned within a margin of ±10% for the majority of crops. They then scaled their sample data using FAO food balance sheets. The overall arable land and freshwater withdrawal figures matched the FAO's estimates. Emission values from deforestation and agricultural methane aligned with the range provided by independent models. Their entire methodology and calculations are reported in the supplementary files of the publication. The environmental impacts results of their LCA meta-analysis of food products can be used for TCA of food and diets.

Idemat

According to IDEMAT Calculation Rules on the Sustainable Impact Metrics website, there are certain assumptions and uncertainties associated with the IDEMAT data. However, the Sustainable Impact Metrics Foundation (SIMF) aims to ensure the data's accuracy and strives to keep it up to date. Indicators from the idemat database can be used for TCA of food and diets.

RIVM

On the database website there is no information provided regarding data quality. The LCA research was conducted following the standards set by ISO14040 and 14044. Additionally, when relevant, they were adjusted to align with the Product Environmental Footprint Category Rules. RIVM database can be used to develop TCA of food and diets.

FAOSTAT Climate change domain

FAOSTAT's Climate Change domain, follows robust methodologies to ensure that the data presented is of high quality. The data are based on the FAOSTAT Emissions database, which is compiled using a Tier 2 approach of the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. For users who require detailed insights into the data quality of specific datasets, it's useful to refer to specific FAO methodological documents, guidelines, or accompanying documentation in the climate change domain.

Estimating the environmental impacts of 57,000 food products M. Clark et al., (2022)

They applied sensitivity analysis to test the robustness of their approach. Sensitivity analysis showed that their approach is robust and a lack of ingredient sourcing information is a potential limitation. Impact data can be used for TCA of food and diets.

MONETIZATION FACTORS

TCA Agrifood Handbook (2022)

Experts developing the TCA Agrifood Handbook applied an iterative process where they used the TEEB AgriFood Evaluation Framework as a starting point. They implemented pilot assessment on farm level and processing level to test the applicability of the TCA methodology and get feedback. The indicators and methodology of the handbook was developed based on the feedback and results. A simplified approach that incorporated checks for the credibility of both primary data and results was adopted. Furthermore, an internal assessment of the modeled data was carried out, and an audit readiness evaluation was conducted.

Monetization factors for true pricing (2023)

True Price work on monetization factors is still in progress and recognizes its limitations, such as: the coverage of the current impacts is rather complete for impacts related to environmental and worker rights but impacts related to rights of local and indigenous communities and society at large have not yet been covered; estimates of restoration, compensation, prevention and especially retribution costs are uncertain; not all impacts are modelled, leading to underestimates. It is acknowledged that when creating a method useful for various businesses and products, it's ideal to align with existing sustainability reporting and impact measurement standards. Efforts have been made towards this alignment, but it hasn't been fully achieved in the last version. The True Price Standard aims to consistently determine a product's true price, allowing for easy comparison across all products. The current method documents mainly offer data and steps for transparent assessments, but they can't guarantee accurate claims about a product's true price. Until a standard is issued, it's recommended to refer to costs calculated using this method as “social and environmental costs calculated with the true price method” instead of “true prices” to ensure consistency across different organizations.

The True Cost of Food report by The Rockefeller Foundation (2021)

The report does not specify the limitations regarding the data quality of monetization factors. However, it references True Price as the source for US-specific monetization factors. If needed, data quality information can be obtained directly from True Price.

Ecocosts Value – Sustainability Impact Metrics

The Ecocostvalue website does not explicitly provide a data quality assessment.

SOCIAL CAPITAL

In this section, we provide comprehensive information on social impact data and corresponding data sources. Similar to previous sections, we have structured this section into three distinct sub-chapters:

Data Availability: This sub-chapter covers 2 available S-LCA databases providing impact indicators for various sectors including agriculture and food. Additionally, it sheds light on the availability of monetization factors for social impact indicators.

Data Accessibility: In this sub-chapter, we guide the reader on the accessibility of data sources, specifying if they are freely available or require payment. We also provide online access links.

Data Usability and Quality: This sub-chapter provides insights into the quality of data from the provided sources. It provides information on quality assessment of databases and informs the reader about the usability of the data sources.

DATA AVAILABILITY

IMPACT INDICATORS

PSILCA database

The Product Social Impact Life Cycle Assessment (PSILCA) database can be used to assess the social impacts of food production. The PSILCA database is a comprehensive database for Social Life Cycle Assessment (S-LCA) developed by GreenDelta, which provides transparent and up-to-date information on social aspects of products over their life cycles. PSILCA database is based on EORA/MIRO Input-Output model and designed for visualizing value-chain actors and screening significant impacts in supply chains, can be applied to a product's system. It allows users to add desired social indicators, and highlights relevant high-risk indicators.

The latest version of the database, which is the third iteration, includes data on 69 qualitative and quantitative social elements that cover 19 subcategories. These subcategories are associated with four key stakeholders: workers, value chain actors, the local community, and society at large. It covers 189 countries, and provides information about the data sources of each indicator. These indicators are assessed on a risk scale, providing outputs of social flows with risk assessment results.

The primary sources of information of the database include statistical agencies such as the World Bank, the International Labour Organisation (ILO), the World Health Organization (WHO), and the United Nations (UN). Additionally, private or governmental databases were considered, for example, the Database on Institutional Characteristics of Trade Unions, Wage Setting, State Intervention and Social Pacts (ICTWSS 2013 by the Amsterdam Institute for Advanced Labour Studies (AIAS)), public records on Environmental Health and Safety violations, by company or industry (United States Department of Labor (2014a); Environmentally Harmful Subsidies Today (2015), etc. Besides, case studies and independent investigations were conducted, initially by GreenDelta, to gather site-specific information. The database documents all the sources used.

Each impact's significance is explained by the activity variable, which is the worker hours required for each USD output of each process. Social risk data is scaled from no/very low risk to extremely high risk, with a characterization factor (CF) expressed exponentially, representing the risk level in medium risk hours per worker hour. This method of quantification facilitates the consolidation of different country specific sectors (CSSs) in the supply chain by using the activity variable, worker hours. The worker hours signify the time necessary to generate 1 USD output in the sector. The social risk is calculated by multiplying the activity variable with the CF of the specified social indicator in the CSS and accumulating it throughout the supply chain. Medium risk hours define the noted indicator risk in worker hours, compared to its average risk to produce 1 USD output in the evaluated sector. Social databases help experts to examine the results more closely and determine the main sources of the most significant or most risky areas.

SHDB

The Social Hotspots Database (SHDB) is a global model that enables supply chain practitioners to perform a rapid social risk assessment using a life-cycle approach. It is a collection of secondary data that provides information on social and environmental risks associated with global supply chains. It can be used to assess the social and environmental impacts of products and services. It provides information on social risks and opportunities in product supply chains, covering 244 countries and regions and 57 economic sectors. SHDB is based on GTAP Input-Output model and uses a different methodology (than PSILCA) for calculating worker-hour model. The worker hours model in the SHDB is derived by dividing total wage payments by the average wage rate, allowing for the estimation of work intensity in different parts of the supply chain. The data sources used in the SHDB include international organizations such as the International Labor Organization and the World Health Organization, as well as government agencies and non-governmental organizations. The data comprehensively addresses social issues on human rights, working conditions, community impacts and governance issues, via a set of over 132 risk indicators grouped within 30 themes. Risks are expressed by country and sector, commodity or production activity. In the SHDB licenses 30 themes are included and some countries are grouped in regions because of the Global Trade model (140 countries and regions).

Soca

Soca, an extension designed by GreenDelta for ecoinvent LCI databases, enriches the database with information relevant to SLCA. Soca is developed based on the PSILCA database. The soca add-on comprehensively addresses social impacts on workers, local communities, entire societies, and value chain actors. It encompasses over 70 social indicators across 17 categories, including aspects such as Health and Safety, Fair Salary, Child and Forced Labor, Migration, Corruption, and Fair Competition.

MONETIZATION FACTORS

TCA Agrifood Handbook (2022)

TMG Think Tank for Sustainability and partners developed Practical Guidelines for the Food and Farming Sector on Impact Measurement, Valuation and Reporting in order to facilitate implementation of TCA conceptual frameworks through detailed description of metrics and monetization of environmental, health and social impacts. The 5 social capital indicators include:

- Social capital: gender pay gap, forced labour, child labour, living wage gap, excessive working hours
- These indicators focus on labour issues which presumes more attention to enterprise operations within legal requirements, and a relative ease to monetize impacts.

Monetization factors for true pricing (2023)

True Price offers monetization factors to support the application of TCA, covering 10 social true price effects with their respective footprint indicators and sub-indicators, complemented by insights into their interpretation and data sources. Additionally, Social Impact Modules are released, providing an in-depth rationale for the monetization factors and further guidance on their application, as well as a methodology for determining true prices. The true price methodology implements the principles of remediation by identifying the following four types of costs that, when appropriately combined, form the remediation cost for an impact: restoration costs, compensation (damage) costs, prevention of re-occurrence costs and retribution costs. The 10 social topics address negative consequences/costs such as: child labor, forced labor, discrimination, undervalued pay in the supply chain, absent social security, excessive and unpaid overtime, insufficient income, 97ccurrence of harassment, lack of freedom of association, and negative effects on employee health and safety.

The True Cost of Food report by The Rockefeller Foundation (2021)

The report outlines the true cost of food in the United States, which includes the impacts on human health, the environment, biodiversity, livelihoods, and much more. The report examines 14 key metrics across the impact areas of human health, environment, biodiversity, livelihoods, and more to quantify the true cost of food. The social impacts that they monetize include the impact on Labor, underpayment of wages, lack of benefits, occupational health, and safety issues. In this exercise, US-specific monetization factors were provided by True Price.

Ecocosts Value – Sustainability Impact Metrics

In Ecocosts Value True Cost Accounting, unfavorable labor conditions are addressed using s-eco-costs, similar to the approach in S-LCA. This includes; minimum acceptable wage, child labour, extreme poverty, excessive working hours,occupational health and safety.

DATA ACCESSIBILITY

IMPACT INDICATORS

Table 3 Accessibilitiy of social impact indicators

Source	Accessibilitiy
PSILCA	The PSILCA is a paid resource that can be accessed through various annual licensing options. PSILCA is available in three variants: Starter, Professional and Developer, all accessible via openLCA Nexus.
SHDB	SHDB is a paid database that can be accces through different licensing options. Similar to PSILCA, it can be used through different LCA sofwares like OpenLCA and SimaPro.
Soca	Soca is a paid database that can be accessed through different licencing options.

MONETIZATION FACTORS

Table 4: Accessibilitiy of monetization factors for social impact indicators

Source	Accessibilitiy
TCA Agrifood Handbook (2022)	The TCA Agrifood Handbook is open access and can be accessed through the link provided in Table 1 in the appendix.
Monetization factors for true pricing (2023)	Monetization factors for true pricing are available through True Price website. The document can be downloaded free of charge through a quick registrationrequesting name and contact details.
The True Cost of Food report by The Rockefeller Foundation (2021)	The True Cost of Food report is available free of charge through The Rockefeller Foundation website.
Ecocosts Value – Sustainability Impact Metrics	The Sustainability Impact Metrics foundation believes in free online access to all data, ensuring transparency and accessibility for all, from SMEs to students. Calculations should be rooted in peer-reviewed scientific papers.

DATA USABILITY AND QUALITY

IMPACT INDICATORS

PSILCA

The PSILCA database uses a pedigree matrix to assess the quality of each indicator, an approach adapted from the matrix introduced by Weidema and Wesnæs in 1996 for LCA quality assurance, but tailored for social LCA. One indicator evaluates the reliability of the sources, while four other indicators assess the dataset's conformity in terms of completeness, time, geography, and technology. These indicators are rated on a scale from 1 (indicating very good performance) to 5 (indicating very poor performance). Each dataset includes details about its origin, the year associated with a particular data point, and the general assessment framework. Consequently, PSILCA consistently aims to utilize the most up-to-date data accessible at the time of data gathering.

Since the PSILCA database is not open access, the precise application of the database for a diet LCA cannot be specified. This can be clarified upon obtaining a license for the database. However, the PSILCA database can be used to assess the social impacts of specific food products. The database provides transparent and up-to-date information on social aspects of products over their life cycles, considering global supply chains and services. Several studies have employed the PSILCA database for food LCA, including the "Social footprint of European food production and consumption" study. This study used the PSILCA database, along with other databases and methodologies, to offer a thorough analysis of the social impacts of food production and consumption in Europe.

SHDB

The data selection criteria encompass the comprehensiveness of the data, which includes the number of countries and sectors available; the legitimacy of the data source; the reliability of the methods used by the source to collect data; the presence of both quantitative and qualitative indicators; the relevance of the data to the theme being investigated; and the timeliness of the data, ensuring that it is current. SHDB also measures the data quality with a pedigree matrix adapted for S-LCA.

The SHDB data is not openly accessible, which means the exact usage of the database for a diet LCA cannot be detailed specifically. However, integrating SHDB data into a food LCA can lead to a more thorough and well-rounded evaluation of the social impacts linked to food production and consumption. Research studies have demonstrated the application of the SHDB in real cases of food LCA, including the social LCA of fertilizers.

Soca

Soca can be used as an add-on with ecoinvent database to estimate social impacts of food production. Since it is based on the PSILCA database, it is expected to have same level of data quality and usabilitiy.

MONETIZATION FACTORS

Table 5: Usabilitiy and Qualitiy of monetization factors for social impact indicators

Source	**Usabilitiy and Qualitiy**
TCA Agrifood Handbook (2022)	This information is the same as detailed under the Natural Capital Impact Data Usability and Quality.
Monetization factors for true pricing (2023)	This information is the same as detailed under the Natural Capital Impact Data Usability and Quality.
The True Cost of Food report by The Rockefeller Foundation (2021)	This information is the same as detailed under the Natural Capital Impact Data Usability and Quality.
Ecocosts Value – Sustainability Impact Metrics	This information is the same as detailed under the Natural Capital Impact Data Usability and Quality.

HUMAN CAPITAL

In this section, we provide insights on human capital impact data and corresponding data sources. Similar to previous sections, we have structured this section into three distinct sub-chapters:

Data Availability: This sub-chapter covers availability of impact indicators from different sources and it sheds light on the availability of monetization factors for human capital impact indicators.

Data Accessibility: In this sub-chapter, we guide the reader on the accessibility of data sources, specifying if they are freely available or require payment. We also provide online access links.

Data Usability and Quality: This sub-chapter provides insights into the quality of data from the provided sources. It provides information on quality assessment of databases and informs the reader about the usability of the data sources.

DATA AVAILABILITY

IMPACT INDICATORS

Agrifootprint

The Agri-footprint database includes effects related to human toxicity. This database addresses an extensive range of impact areas, including human health aspects like human carcinogenic and non-carcinogenic toxicity. The Agri-footprint 6 methodology report also mentions toxicological stress on human health as one of the evaluated environmental impacts.

Ecoinvent

As explained in the Supply Chain Data Availabilitiy chapter, Ecoinvent database is an extensive LCI database including relevant, transparent, and consistent data on wide range of products and activities. Ecoinvent database includes human health related impacts as part of its life cycle impact assessment which are human carcinogenic toxicity and human non-carcinogenic toxicity.

Agribalyse

Details on Agribalyse database were provided under the Natural Capital Impact Data Availabilitiy. As a French database offering detailed LCA on environmental footprint of agricultural and food products, Agribalyse also report impact assessment data on are human carcinogenic toxicity and human non-carcinogenic toxicity.

USEtox

USEtox is a consensus model established by UNEP/SETAC that seeks to enhance understanding and management of chemicals by measuring their exposure, risks, and effects in products the environment. The USEtox model, along with its database, contains details on environmental fate, exposure, and the potential harmful effects related to human toxicity. USEtox evaluates human toxicity impacts for numerous chemical emissions and product uses, laying the groundwork for a comparative study of chemicals. It also includes the interface for food contact material (FCM), which provides data on all materials meant to come in contact with food, like packaging, containers, and kitchen apparatus. The FCM interface is utilized to evaluate the human and ecotoxicological impacts of chemicals in these food contact materials. The interface displays outcomes related to exposure, detailing the average daily dose a user might encounter through different exposure pathways. It also provides the projected cancer risk for cancerous impacts and a hazard quotient for non-cancer impacts. Under cumulative impact results, the results for human toxicity including cancer and non-cancer characterization factors and damage in terms of disability-adjusted life years (DALYs) for 5 populations (user adult, user child, household adult, household child and the general population) are presented.

The Global Burden of Disease Study 2019

The Global Burden of Disease (GBD) study offers a detailed overview of death and disability across nations, timelines, ages, and genders. It measures health losses from a vast range of diseases, injuries, and risk factors to improve health systems. The study assesses mortality and disability from major diseases, injuries, and risk factors, and provides a systematic scientific assessment of published, publicly available, and other data sources. The study also provides dietary risk exposure estimates. Estimations related to 15 dietary risks and the associated burdens were generated for the period between 1990-2019. The provided records contain data on the daily consumption of the 15 GBD food categories (measured in grams or as a percentage of energy). This data is broken down by year, gender, and 5-year age groups for those aged 25 and older, including a combined group for ages 25 and above. The results, reported in DALYs, cover 204 countries up to the most recent year, 2019.

PSILCA database

The details on PSILCA database were explained under the Social Impact Data Availability. PSILCA database offers human capital impact indicators under health and safety.

SHDB database

The details on SHDB database were explained under the Social Impact Data Availability. SHDB database description mentions that it offers human capital impact indicators under health and safety.

Soca

The details on the soca add-on were explained under the Social Impact Data Availabilitiy.

MONETIZATION FACTORS

Table 6: Availabilitiy of monetization factors for human impacts

Source	Availabilitiy
TCA Agrifood Handbook (2022)	Under the TCA Agrifood Handbook occupational health and safety related valuation factor can be found. This indicator considers the health impact from work related injuries, illness and death of workers and expressed in DALYs.
Monetization factors for true pricing (2023)	True Price provides monetization factor for Human Toxicity impact, expressed in EUR/DALY.

DATA ACCESSIBILITY

IMPACT INDICATORS

Table 7: Accessiblitiy of human impact indicators

Source	Acessiblity
Agrifootprint	As mentioned earlier under Supply Chain data Accessibility, the Agrifootprint database is behind a paywall under different licencing options.
Ecoinvent	As mentioned earlier under Supply Chain data Accessibility, the Ecoinvent database is behind a paywall under different licencing options.
Agribalyse	As mentioned earlier in the Natural Capital Impact Data Accessibility, Agribalyse database is accessible free of charge through their website.

Usetox	Usetox is accessible free of charge at their website. The website also presents a detailed manual and how to instructions on use of the Usetox model.
The Global Burden of Disease Study 2019	The Global Burden of Disease study results are accessible online free of charge through the GBD Results tool.
PSILCA database	As mentioned earlier under Social Impact Data Accessibility, the PSILCA database is behind a paywall under different licencing options.
SHDB database	As mentioned earlier under Social Impact Data Accessibility, the SHDB database is behind a paywall under different licencing options.
Soca	As mentioned earlier under Social Impact Data Accessibility, soca is behind a paywall under different licencing options.

MONETIZATION FACTORS

Table 8: Accessiblity of monetization factors for human impact indicators

Source	Acessiblity
True Cost Initiative (2022)	As mentioned earlier under Natural Capital Impact Data Accessibility, monetization factors under the handbook are available free of charge.
True Price (2023)	As mentioned earlier under Natural Capital Impact Data Accessibility, True Price monetization factors are available free of charge.

DATA USABILITY AND QUALITY

IMPACT INDICATORS

Agrifootprint

The quality and usability of the data were explained earlier under the Supply Chain Data.

Ecoinvent

The quality and usability of the data were explained earlier under the Natural Capital Impact Data.

Agribalyse

The quality and usability of the data were explained earlier under the Natural Capital Impact Data.

Usetox

The USEtox team intends to release updated versions of the software regularly, along with updates to model inputs and outputs as frequently as needed, while trying to keep changes to a minimum. The Usetox model undergoes procedures for quality assurance, transparency, and peer review. This procedure is designed to maintain the quality, transparency, and reliability of the USEtox model, its input data, and its periodic updates. Usetox gains its credibility through continuous testing and evaluation of the model's performance. Both the algorithms of the model and its overall performance are subjected to tests. The USEtox model and database are commonly used for life cycle assessment (LCA) studies as well as other evaluations based in the life cycle methodology. Usetox data can be used for developing TCA of food and diets.

The Global Burden of Disease Study 2019

The Global Burden of Disease (GBD) study collects health data from hospitals, governments, surveys, and other databases worldwide. Research teams then clean and sort the data and use modelling tools to generate estimates for locations and years where data are not available. The GDB study reports in detail their methodology, covers key principles, assumptions, products, roles and responsibilities, processes. Burden of disease estimation is an iterative process, where new data and methodological innovations lead to the revision of estimates. This approach ensures that the study incorporates the latest information and improves over time. The Independent Advisory Committee for the Global Burden of Disease guides the Institute for Health Metrics and Evaluation on the study, ensuring scientific rigor, promoting dialogue with global health initiatives. The GBD data can be used to develop diet related indicators to use for TCA.

PSILCA database

The quality and usability of the data were explained earlier under tunder Social Impact Data.

SHDB database

The quality and usability of the data were explained earlier under tunder Social Impact Data.

Soca

The quality and usability of the data were explained earlier under tunder Social Impact Data.

MONETIZATION FACTORS

Table 9: Usabilitiy and quality of monetization factors for human impact indicators.

Source	Acessiblity
True Cost Initiative (2022)	The quality and usability of the data were explained earlier under the Natural Capital Impact Data.
True Price (2023)	The quality and usability of the data were explained earlier under the Natural Capital Impact Data.