True cost accounting applied on cultured meat: an economic analysis, issues, and challenges

Master thesis
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Preface

Dear reader,

After a few months, the moment of handing in this thesis is finally there. When you asked me a few months ago what I would like to achieve in writing this thesis that I would like to learn something about a new topic and that I wouldn't stress out too much. After these months, I can say proudly that I achieved both and that I am proud of this thesis. Firstly, the decision about the topic. Cultured meat is something I hadn't heard of when Justus suggested the topic. To be honest, I still had to search for what cultured meat was after the first meeting. During the summer, I read the book ''Clean Meat'' and I finally had an idea about the product, how the development process has been going, and its societal importance. That was the starting point for finding the research gap and starting the thesis. Somehow, I started combining true pricing and cultured meat in my head and the topic of my thesis was born. In the beginning, I had a very idealized or even romanticized image of true pricing and the model I would be using. After a few weeks or even days of researching and gathering data the pitfalls and problems started to show and the idealized image vanished. It can be said that I am a bit more skeptical about the economic and societal relevance and impacts and the problems that arise with true pricing products, diets, or even whole systems.

Justus, thank you for the supervision, and advice, and for teaching me that in essence, all models are wrong. In addition, I would like my family to try to understand what I am doing all these months. Furthermore, Hugo for promising that he would read all the pages of my thesis when it is finished. Specifically, I would like to thank Claire for all the coffee breaks, but also for giving feedback on my draft! Finally, everyone with whom I had coffee and lunch breaks. They helped a lot with energizing and clearing my mind.

Abstract

Cultured meat is vivo-produced meat which is considered to be an environmentally and ethically friendly alternative to conventional-produced cattle beef. True cost accounting (TCA) is a methodology that aims to measure and valuate the positive and negative environmental, social, and health externalities a product has using monetary values. Externalities have been extensively described in economic literature over the past 100 years resulting in revolutionary papers such as the problem of social costs and important concepts such as the Pigouvian tax. Two main problems can be found: there is no standardization of TCA frameworks and the available frameworks are not strengthened enough which implies that a critical view should be maintained when applying such framework. The TCA method that has been used is the True Cost Accounting Agri-food Handbook. It is aimed to answer the following research question: *to what extent can TCA serve as a conclusive measure in assessing the sustainability of cultured meat as an alternative to conventional meat production, within the context of welfare economics and with a critical examination of TCA?* The results suggest that cultured meat is a sustainable alternative to conventional meat as the true costs are lower. The true price of cultured meat is higher as the private costs of cultured meat are nowhere near price competitive with conventional meat. However, when applying the TCA handbook, many issues were found to diminish the value that can be attached to the sustainability conclusion. In a broader context, TCA can be seen as a method that needs considerable system changes related to how we collect data globally. This change in the system and the costs associated with this system change are currently neglected. Furthermore, it can be debated whether it is desirable to internalize externalities as the potential for a decrease in economic efficiency exists.

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Abbreviations

Abbreviation	*Definition*
f.u.	Functional unit
GHG	Greenhouse gas
LCA	Life cycle assessment
OHS	Occupational health and safety
SOC	Soil organic carbon
TCA	True cost accounting

Definitions

In true cost accounting multiple definitions can be found related to this method. To avoid any misunderstandings, an overview will be provided of the different definitions. There is no consensus yet on several of the definitions, an example is true price, value, and costs. Consequently, the definitions are at risk of being used without giving a clear meaning to them.

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'' (FAO, 2023, p. xi).

- **Human**

''The knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being'' (FAO, 2023, p. xi).

- **Social**

''Networks, including institutions, together with shared norms, values and understandings that facilitate cooperation within or among groups'' (FAO, 2023, p. xi).

- **Natural**

''The stock of renewable and non-renewable natural resources that combine to yield a flow of benefits to people'' (FAO, 2023, p. xi).

- **Produced**

''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 and so on)'' (FAO, 2023, p. xi).

Conventional meat

In vivo produced animal meat.

Cultured meat

In vitro produced genuine animal meat or seafood by cultivating animal cells directly via modern biotechnological methods (Sinke et al., 2023).

External costs

''A cost incurred by individuals or a community as a result of an economic transaction in which they are not directly involved. The difference between private costs and the total cost to society of a product, service or activity is called an external cost'' (FAO, 2023, p. xi).

Hidden cost

''Any cost to individuals or society that is not reflected in the market price of a product or service. It refers to external costs (that is, a negative externality) or economic losses triggered by other market, institutional or policy failures'' (FAO, 2023, p. xi).

Private costs

''Any cost paid by a consumer to purchase a good or by a firm to purchase capital equipment, hire labour or buy materials or other inputs. These costs are included in production and consumption decisions'' (FAO, 2023, p. xi).

Remediation costs

''The remediation cost of a right violation is the cost that should be incurred to remediate the harm caused'' (Galgani et al., 2021, p. 14).

Social costs

The sum of the private costs and the net external costs or benefits.

True cost accounting

’’Evolving methodology to measure and value the positive and negative environmental, social, and health externalities in order to allow analyzing the costs and benefits of business and/or policy decisions’’ (Global Alliance for the Future of Food, 2020, p. 7).

True price

Market price plus the true costs expressed in a monetary unit (Splinter, 2022).

True price gap/ true cost

Difference between the true price and market price of a product (Oosterkamp et al., 2023).

True value

Market price plus the net external benefits and costs expressed in a monetary unit (Splinter, 2022).

In this thesis, conventional meat is used to refer to in vivo-produced beef cattle meat. Cultured meat is used to refer to in vitro-produced beef meat. It has been decided to use true price instead of true value as positive externalities are not included in this thesis. Furthermore, a term is needed that illustrates a decrease in the external costs, true price gap, true costs, or hidden costs. It has been decided to use true costs as a term because it relates to true cost accounting. If papers are cited, the other terms will be used if applicable.

1. Introduction

In 2050, it is expected to have 10 billion people living on our earth, 3 billion more than in 2010 (Ranganathan et al., n.d.). To feed all these people, we need to produce 56% more calories than we did in 2010 (Searchinger et al., 2018). At the same time, the average per capita income is expected to increase. If the average income of an individual changes, the diet of that individual will change as well. There will be a larger share of animal protein, fats, and oils in their diet (Valin et al., 2013). To illustrate this: in 2013, meat consumption in high-income countries was almost six times higher than in low-income countries (Sahlin et al., 2020). This can be explained according to the special status that meat-eating has in many cultures. It appears that people can have a higher social status if they consume, for example, more meat, specific portions of the animal, or young animals (De Boer & Aiking, 2011). In 2050, there is expected to be an over 76% increase in meat consumption worldwide compared to 2005. This equals 455 million tons of annual meat consumption in 2050 (Alexandratos & Bruinsma, 2012). The ruminant meat is expected to have the largest increase with 88% between 2010 and 2050 (Searchinger et al., 2018).

This increase in food consumption and shift in diet come with considerable consequences. The global food system is responsible for approximately 13.7Gt CO_{2}-eq emissions per year, accounting for 26% of anthropogenic greenhouse gas (GHG) emissions (Sun et al., 2022). In 2050, it is predicted that agricultural emissions account for 70% of allowable emissions for all sectors (Searchinger et al., 2018). Within the global food system, meat production shares a large fraction of the environmental impact. Meat production uses 30% of ice-free terrestrial land and 8% of freshwater while producing 18% of GHG emissions globally. The environmental impacts of beef are in general the highest whereas poultry has the lowest environmental impact (Tuomisto & De Mattos, 2011). Besides this large environmental impact, meat production is also associated with a debate on whether eating meat is ethically defendable (Croney & Swanson, 2023).

To overcome these environmental and ethical problems associated with meat, cultured meat has been proposed as a solution. Cultured meat is the growing of animal tissue, more specifically muscle tissue, in vitro instead of growing a whole animal (Tuomisto & De Mattos, 2011). The first real attention to the possibility of growing in vitro meat was drawn from an essay by Winston Churchill in 1931. In the essay, he mentioned: ''We shall escape the absurdity of growing a whole chicken in order to eat the breast or wing, by growing these parts separately under a suitable medium’’ (Eschner, 2017). In 1995, the first tangible projects emerged related to this idea. From 2004 onwards, the focus shifted towards refining technology to make the product suitable for mass production (Kumar et al., 2021). In 2022, 156 cultured meat companies exist globally of which 61 are founded in 2021 and 2022 combined. In addition, the policy field is changing to approve labeling, testing, or selling of cultured meat. Cultured meat could already be sold in Singapore, but in June 2023, regulation also approved the sale of cultured meat in the United States (Good Food Institute, 2023).

With the rapidly increased interest in cultured meat, research has been executed regarding the environmental impact of the product. It is suggested that cultured meat is an environmentally friendly alternative compared to conventional meat in terms of climate change measured in CO_2 equivalents, land use, fine particulate matter, and acidification (Tuomisto & De Mattos, 2011; Sinke et al., 2023).

True Cost Accounting (TCA) is a method that aims to provide transparency about the sustainability of a product to different stakeholders such as individuals, organizations, or governments. TCA tries to assess the total economic costs and benefits associated with the production of a good. It depends on the method in which impact capitals are included, e.g. social, human, produced, or natural capital. TCA includes not only the private costs and benefits but also the external costs and benefits of a product. From a TCA point of view, the sustainability of a product increases when there is a decrease in the net external costs of a product. The concept of externalities was first introduced by Pigou and Marshall in the 1920s (De Adelhart Toorop et al., 2021). Externalities, social costs, internalization of externalities, and related policies have been described extensively in literature over the past 100 years resulting in revolutionary papers such as *the problem of social costs* or important concepts such as the Pigouvian tax (Coase, 1960). In case of the cultured meat, the increased sustainability relative to conventional meat should be reflected in the lower true costs of cultured meat according to TCA theory.

However, TCA is a method that is in development. Over thirty distinct methodologies can be found, of which a few specialize in agri-food. There is a lack of a general TCA framework implying that there is no standardization. In addition, the existing methods are not strengthened enough (De Adelhart Toorop et al., 2021). This implies that when one of these methods is used, a critical view should be maintained.

From this description, the following thesis objective can be formulated: *the application of TCA on cultured meat to reveal whether it is a sustainable alternative to conventional meat production while addressing challenges and issues associated with TCA and providing insights from a welfare economics perspective.*

The main objective can be divided into three sub-objectives:

1) Providing an overview of TCA in literature, with a specific focus on TCA from a welfare economic perspective.
2) Application of TCA on cultured and conventional meat to analyze whether cultured meat can be viewed as a sustainable alternative to conventional meat.
3) Identify and address the challenges or issues that were found during the TCA application to provide insight into potential improvements of future TCA analysis.

From the objective, the following main research question can be formulated:
The main research question derived from the objective is: *to what extent can TCA serve as a conclusive measure in assessing the sustainability of cultured meat as an alternative to conventional meat production, within the context of welfare economics and with a critical examination of TCA?*

The TCA method that will be used to answer this research question is the True Cost Accounting Agri-food Handbook (True Cost Initiative, 2022). This TCA method was one of the recommended methods in the recently published paper ‘’True cost accounting applications for agri-food systems policymakers'' with as main benefits the usage of monetary values, the pre-made micro-decisions, and covering almost all impacts that are relevant for policymakers (De Adelhart Toorop et al., 2023).

The following thesis outline can be defined. The first chapter contains four theoretical frameworks. The first framework focuses on a general description of TCA in literature whereafter the focus shifts to the specific TCA method that is used in this thesis. The second framework provides an overview of welfare economics after which the overview will be used to analyze TCA. The third and fourth frameworks contain all the data that is needed to apply TCA on cultured and conventional meat respectively. The second chapter presents the results of TCA applied to conventional and cultured meat, including both a baseline scenario and a scenario analysis. In addition, the issues and challenges related to the TCA application will be mentioned. Finally, the results and the theoretical framework will be discussed and a conclusion will be given.

2. Theoretical Framework

2.1.True cost accounting

2.1.1.General information

TCA can be defined as an ''evolving methodology to measure and value the positive and negative environmental, social, and health externalities in order to allow analyzing the costs and benefits of business and/or policy decisions'' (Global Alliance for the Future of Food, 2020, p. 7). TCA enables the internalization of externalities of a product, organization, investment, geographical location, diet, or system (De Adelhart Toorop et al., 2021). In this chapter, an overview will be provided of what TCA is, its relevance for the agri-food industry, its implications for society, and a description of the TCA framework used in this thesis.

The production and consumption of goods or services are associated with negative or positive impacts that are not included in the market price. These impacts are referred to as externalities (Splinter, 2022). Externalities have benefits or costs for our society. The sum of these costs and benefits is referred to as the external costs. TCA aims to quantify these externalities and to express them in a monetary unit. A difference can be found between the true price and value. The true price of a product is the private costs plus the negative external costs. On the contrary, the true value of a product also includes the benefits gained by a positive externality (Splinter, 2022). The difference between the market price and the true price or value is the true price gap (Oosterkamp et al., 2023). Besides the true price gap, the terms true costs and hidden costs can be found. It is frequently unclear what the differences are between those three terms and it depends on the paper which one is used. Hidden costs can be defined as ''any cost to individuals or society that is not reflected in the market price of a product or service. It refers to external costs (that is, a negative externality) or economic losses triggered by other market, institutional or policy failures'' (FAO, 2023, p. xi). For true costs, a general definition could not be found. Therefore, it has been decided to define true costs as the sum of the costs and benefits that are not reflected in the market price of a product or service. In the case of hidden costs, the focus lies only on the costs for society while also benefits can be distinguished linked to positive externalities. Positive externalities can only be included in the true price if they offset negative externalities for 1) the same indicator or 2) the same affected group or environmental compartment (Galgani et al., 2023).

Calculating the true price gives insight into the true costs. It shows organizations or policymakers where possible improvements lie to increase sustainability. Three problems are suggested to be solved when using TCA. Firstly, it provides information on the size and scope of the hidden costs. Secondly, TCA enables a remediation market to remediate them. Finally, producers are incentivized to lower their impact (True Price, 2019). It has been claimed that a large part of the true price can be reduced by innovation and cost-effective measures. In this case, sustainability is being referred to as a decrease in the hidden costs (Oosterkamp et al., 2023). This can be on different capitals: produced, social, environmental, and human (FAO, 2023).

What the definition of sustainability is, depends on who you ask the question. Different views on sustainability can be found, influencing how to measure sustainability. Perman et al. (2003) distinguished 6 different concepts of sustainability:

1. A sustainable state is one in which utility (or consumption) is non-declining through time.
2. A sustainable state is one in which resources are managed so as to maintain production opportunities for the future.
3. A sustainable state is one in which the natural capital stock is non-declining through time.
4. A sustainable state is one in which resources are managed so as to maintain a sustainable yield of resource services.
5. A sustainable state is one which satisfies minimum conditions for ecosystem resilience through time.
6. Sustainable development as consensus-building and institutional development.

2.1.2.Agri-food relevance

In the case of agri-food, TCA is of great relevance. Agri-food has impacts and dependency on both people and nature, often larger than other sectors (Notarnicola et al., 2017). A recently published report showed that the global quantified hidden costs of the agri-food system equaled 12.7 trillion 2020 PPP dollars in 2020. These hidden costs arise dominantly from dietary patterns leading to diseases and lower labour productivity. Environmental costs consist only of over 20% of the hidden costs (FAO, 2023).

2.1.3.TCA frameworks

No generalized TCA framework can be found. Methods differ on several properties such as capital selection and corresponding impact categories, welfare dimension, qualitative or quantitative research, or the functional unit (f.u.). From the scientific community, there is an urge to harmonize the frameworks for TCA (De Adelhart Toorop et al., 2021; Galgani et al., 2023; De Adelhart Toorop et al., 2023). However, this is not the case yet.

With a wide variety of methods, it is crucial to select an appropriate TCA framework. FAO published the paper ''the state of food and agriculture: revealing the true cost of food to transform agri-food systems'' (November 2023). The paper focuses on assessing the true cost of food at a national level, which is out of the scope of this thesis. However, the background paper provided useful examples of how to perform TCA, literature examples, and insights in the benefits and limitations (De Aldelhart Toorop et al., 2023). In this paper, seven leading approaches of TCA that apply to agri-food were identified that were deemed most relevant for policymakers (De Adelhart Toorop et al., 2023). All these approaches use TEEBAgriFood’s Scientific as a reference framework and build upon it (TEEB, 2018). However, still, differences can be found between those seven approaches. Again, it is urged that these methodologies should be harmonized (De Adelhart Toorop et al., 2023). However, as no harmonized method can be found yet, it is necessary to select one of the seven approaches.

2.1.4.Selected TCA framework

The approach (method and framework) that has been selected is the True Cost Accounting Agri-food Handbook (True Cost Initiative, 2022). The method has been selected using four criteria: firstly, it includes three capitals: human, social, and natural. Furthermore, the scope used is a product scope. In addition, quantitively monetized values are used. Finally, the micro-decisions have already been made. The following benefits and disadvantages are mentioned:

Benefits:

- ''Lists material issues in the agri-food systems including the rationale;
- Relatively few micro decisions are needed;
- Provides monetization factors for a list of impacts;
- Provides guidance on reporting and presentation of results;
- List of impacts categories and indicators with guidance provided, covering almost all impacts relevant to policymakers.'' (De Adelhart Toorop et al., 2023, p. 74-75).

Disadvantages:

- ''Method does not include positive impacts
- Limited focus (plant-based systems)'' (De Adelhart Toorop et al., 2023, p. 74-75).

The limited (plant-based) focus of the handbook is a problem for some impact categories and therefore the true price calculation. The handbook is intended for all agricultural processes except livestock farming, fisheries, and aquaculture. In the case of some impact categories, problems emerge when using the framework for livestock. The main problem that can be found is that the true price calculation is incomplete for some impact categories or impact categories are missing (True Cost Initiative, 2022). However, the used impact categories are also of relevance for livestock meat production and more importantly, cultured meat production as both products largely depend on crops as input material. In addition, the handbook is constructed in such a manner that it should be compatible with Life Cycle Assessment (LCA) software and its results. This raises the question of why this handbook cannot be used if the scope is broader, but the results are presented in the same manner. Especially because the input ingredients of cultured meat are crops. Finally, the other 6 leading approaches are not realistic to use. Per leading approach, it is described why it has been decided not to use it:

- **TEEBAgriFood Evaluation Framework:** impact pathways are not described and many micro-decisions need to be made. This means it is not realistic in the given timeframe (TEEB, 2018).
- **System of Environmental Economic Accounting: Ecosystem accounting:** the functional unit of this TCA framework is geography and system, not a product (United Nations, 2021).
- **True price:** not detailed, only a general description is given of the TCA method and proposed impact categories. Many methodologies of the impact categories are not publicly available yet which means that the true price calculation is incomplete if this method is used (True Price, 2019).
- **Food System Impact Valuation Initiative (FoodSIVI)**: not very practical yet as a substantial number of micro-decisions is needed. Therefore, not realistic in the given timeframe (Lord, 2020).
- **Natural Capital Protocol:** only focuses on natural capital, while research shows that human and social capital are of great importance in the case of agri-food. In addition, no monetization factors are given (Natural Capital Coalition, 2018).
- **Social and Human Capital Protocol:** only focuses on social and human capital. It can be combined with the natural capital protocol. However, it would require monetization factors. In addition, impact categories still need to be selected, how data needs to be collected, and how to valuate them (monetization). This is not possible in the given time frame of this thesis (Social & Human Capital Coalition, 2019).

The used arguments are based upon De Adelhart Toorop et al. (2023) and critically researching the different methods. Based on these arguments, the decision has been made to use the TCA handbook with the substantial remark that this handbook is not intended for livestock and that therefore the true price calculation is likely to be incomplete.

The TCA Handbook provides a method to calculate the true costs over three capitals: natural, social, and human capital. To every capital, several impact categories are assigned. Table 1 provides an overview of the impact categories, metrics, and monetization factors.

Table 1

Impact categories per capital, metrics, and the monetization factor.

Impact Category	Metrics	Monetization factor	Unit
Natural Capital			
GHG emissions	tonne CO_2-eq	116	EUR_{2017}/tonne CO_2-eq
Carbon stock	Tonne carbon	116	EUR_{2017}/tonne CO_2-eq
Soil erosion	tonnes/ha/year	27,38	USD_{2014}/kg soil lost
Soil organic matter build up	Ton Carbon	100	EUR_{2014}/tonne SOC emission
Water stress	m^3	1	EUR_{2017}/m^3
Water pollution	kg	4.7	EUR_{2017}/kg PO_4-eq
Acidification	kg SO_2-eq	8.75	EUR_{2017}/ kg SO_2-eq
Eutrophication	kg PO_4-eq/ unit	4.7	EUR_{2017}/ kg PO_4-eq
Eco-toxicity	kg Cu-eq	340	EUR_{2017}/kg Cu-eq
Human Capital			
Human toxicity	DALY	80000	EUR_{2017}/DALY
Living wage gap	EUR	-	EUR
Occupational health and safety	DALY	80000	EUR_{2017}/DALY
Excessive working hours	DALY	80000	EUR_{2017}/DALY
Social Capital			
Gender pay gap	DALY	-	EUR
Forced labour	DALY	80000	EUR_{2017}/DALY
Child labour	EUR	80000	EUR_{2017}/DALY

Per impact category the following information is provided by the handbook:

- Materiality;
- Definition;
- Impact drivers;
- Performance reference point;
- Metrics on how to calculate the true price;
- Required data;
- Recommended tool;
- Monetization and monetization factor;
- How to verify data;
- And to which sustainable development goal it is linked.

The monetization factors are suggested to be globally applicable. Two arguments are given for this: not feasible to find monetization factors for each local situation. In addition, a global level playing field is preferable from a business perspective.

2.1.5. Impact categories

GHG emissions

GHGs are gasses that are emitted into our atmosphere and that cause an increase in global temperature and ultimately climate change. The impact of those gases is generally expressed in CO_2 equivalents using the 100-year Global Warming Potentials (GWP_{100}) (Del Prado et al., 2023). GWP can interpreted as: "an index of the total energy added to the climate system by a component in question relative to that added by CO_2" (Myhre et al., 2013, p. 711). Every GHG has its own lifespan and warming impact throughout its lifespan (Del Prado et al., 2023).

The true cost of GHG emissions can be calculated using the following metric:

$$TC_{GHG} = U_{GHG} * MF_{GHG} \qquad (1)$$

Where TC_{GHG}= true cost GHG emissions, U_{GHG}= total GHG emissions [tonne CO_2-eq], and MF_{GHG}= monetization factor GHG emissions [116 EUR_{2017}/ tonne CO_2-eq].

The recommended tool to use is the Cool Farm tool (Cool Farm, n.d.).

Carbon stock

The impact category carbon stock ''considers the emission and global warming potential of carbon stored in soil and tree biomass'' (True Cost Initiative, 2022, p. 25). It considers both benefits and costs as there is a potential that carbon can be stored in the soil or tree biomass creating a net uptake of carbon. This is of great relevance because of the possible mitigating effect of climate change (Hendriks et al., 2023). However, during the transformation from natural ecosystems towards arable land, carbon is emitted from tree biomass and the soil. This contributes to the emission of GHG and therefore climate change. If the best management practices are used, at least a bit of the soil's organic carbon content can be restored (Smith et al., 2019).

The true cost of carbon stock can be calculated using the following metrics:

$$TC_{CS} = (C_{soil} + C_{tree\ biomass)} * 3.67 * MF_{CS} \tag{2}$$

Where TC_{CS}= true cost of carbon stock

C_{soil}= carbon emissions from the soil [tonne C], C_{tree} biomass= carbon emissions from tree biomass [tonne C], MF_{CS}= monetization factor carbon stock emissions [116 EUR_{2017}/ kg CO_2-eq], and 3.67 is the conversion factor carbon to carbon dioxide.

C_{soil} can be derived by:

$$\Delta C_{20} = SOC_t - SOC_{t-20},$$
$$SOC_{t-20} = RC * BF * TF * IF * LA \tag{3}$$

Where RC= reference carbon stock [tonne C], BF= base factor (relative carbon storage compared to the native system), TF= tillage factor, IF= input factor, and LA= land area for a particular land use and management system.

The recommended tool to use is the Cool Farm tool (Cool Farm, n.d.).

Soil erosion

The soil erosion impact category considers: ''the erosion of soil due to precipitation (True Cost Initiative, 2022, p. 25). Multiple factors can be found that influence the soil erosion rate such as slope, land use practices, or deforestation (De La Paix et al., 2011; Guerra et al., 2017).

The metrics to calculate the true cost of soil erosion are the following:

$$TC_{SE} = A * MF_{SE} \tag{4}$$

Where TC_{SE}= the true cost of soil erosion per ha per year, A= soil loss in tonnes per ha per year, and MF_{SE}= monetization factor soil erosion by water [27.38 USD_{2014}/ tonne soil loss]

With:

$$A = R * K * LS * C * P \tag{5}$$

Where R= rainfall-runoff erosity factor, K= soil erodibility factor, LS= slope length and steepness factor, C= cover-management factor and P= support-practice factor

The parameter A can be calculated or found using one of the two recommended tools:

1. Based upon farm management data: RUSLE model (Ganasri & Ramesh, 2016).
2. Based upon location: Global soil erosion map (Borrelli et al., 2017).

Soil organic carbon build up

Soil organic carbon (SOC) build up impact category considers the composition and decomposition of SOC. The SOC reference point is a situation where there is no increase or decrease in SOC.

The following metrics are defined to calculate the true costs of SOC:

$$TC_{CS} = C_{soil} * MF_{SOC} \tag{6}$$

Where TC_{CS}= true costs of carbon stock, C_{soil}= carbon emissions from the soil [tonne C] and MF_{CS}= monetization factor SOC [100 EUR_{2014}/ kg CO_2-eq]

C_{soil} can be derived by:

$$\Delta C_{20} = SOC_t - SOC_{t-20},$$
$$SOC_{t-20} = RC * BF * TF * IF * LA \quad (7)$$

Where RC= reference carbon stock [tonne C], BF= base factor (relative carbon storage compared to the native system), TF= tillage factor, IF= input factor, and LA= land area for a particular land use and management system.

The recommended tool to use is the Cool Farm tool (Cool Farm, n.d.).

Based on the information provided, the impact categories SOC and carbon stock differ on the following points:

- In the case of carbon stock, carbon emissions from tree biomass are included. This is not the case in SOC build up.
- In the case of carbon stock, a conversion factor from carbon to CO_2 is used.

Despite these differences, the metric to calculate C_{soil} is the same. This implies that there is a double counting of the same problem in both metrics. Therefore, it has been decided to leave the impact category SOC build up out of further true cost calculations.

Water stress

Water stress can be defined as: ''the withdrawal of fresh ground- and surface water compared to its availability '' (True Cost Initiative, 2022, p. 25). It is estimated that 10% of the global population lives in an area with high or critical water stress. Globally, water use is increasing by 1% per year over the last 40 years. In the case of agri-food production, water is crucial to irrigate crops. If less water is available for crops, it reduces global food security and farmers' livelihood incomes (United Nations, 2023).

The following metric can be used to calculate the true costs of water stress:

$$TC_{WS} = MF_{WS} * B_{WS} * (Irri\ req + W_P) \quad (8)$$

Where TC_{WS}= true costs of water stress, MF_{WS}= monetization factor water stress [1 EUR_{2017}/ m^3], B_{WS}= Aqueduct baseline water stress factor, Irri req= CropWat irrigation requirements [m^3] and W_P= water demand processing fase [m^3]

The recommended tools to use are the Aqueduct water stress atlas, Cropwat, and Climatwat for Cropwat.

Water pollution

Water pollution can be defined as: ''the leaching and run-off of nitrogen and phosphorous and their eutrophication potential in ground and surface water'' (True Cost Initiative, 2022, p. 25). Eutrophication (of the water) causes excessive growth of algae and plants from increased availability of limiting growth factor. In case of water pollution, nitrogen and phosphorous become excessively available. This causes problems for drinking water, ecosystems, and recreational purposes (Akinnawo, 2023; United Nations, 2023).

In the TCA handbook, both water pollution and eutrophication are included. To differentiate between both impact categories, the origin of the nitrogen and phosphorous is of importance. Water pollution focuses on the application of fertilizers and the runoff and leaching of the fertilizer into ground and surface water. Eutrophication focuses on energy use, combustion, production of fertilizers, and the nitrogen oxides that are emitted during these processes. These nitrogen oxides cause terrestrial eutrophication. These nitrogen oxides form $HN0_3$ in several atmospheric process pathways. HNO_3 is susceptible to both dry and wet deposition. The H^+ causes consequently acidification of the soil and NO_3^- causes eutrophication. If the NO_3^- is not used by plants, it is susceptible to leaching towards the groundwater (Smith et al., 1999).

Based on this description, it is crucial to differentiate between water pollution and eutrophication as both processes are linked. The only way to do this is to know primary processes such as fuel use and applied fertilizer as described in the impact category description.

The metric to calculate the true cost of water pollution is the following:

$$TC_{WP} = N_{appl} * MF_{neu} * an + P_{appl} * MF_{peu} * ap \tag{9}$$

Where TC_{WP}= true costs of water pollution, N_{appl}= amount of N applied [kg], an= leaching-runoff fraction of N, MF_{neu}= monetization factor of N eutrophication in EUR/kg pollution [1.75 EUR_{2017}/ kg N], P_{appl}= amount of P applied [kg], ap= leaching-runoff fraction of P and MF_{peu}= monetization factor of P eutrophication in EUR/kg pollution [12.76 EUR_{2017}/ kg P]

The recommended tool to calculate water pollution is greywater footprint accounting (Franke et al., 2013).

Acidification

The impact category acidification ''considers the emissions of nitrogen oxides (NO_x), sulphur dioxide (SO_2) and ammonia (NH_3), their atmospheric deposition and acidifying potential on water and soil systems by hydrogen ion concentration'' (True Cost Initiative, 2022, p. 25). The deposition of acids causes severe problems for ecosystems. Acidification has a negative impact on soil chemistry, water quality, and biodiversity. In addition, acidification makes the ecosystem less resistant to storms, diseases, or drought (Buijsman et al., 2010). Policies in the 1980s caused a significant decrease in emissions of acidifying substances. However, ongoing acidification is still taking place (De Vries et al., 2019).

Acidification of the soil can be caused by several substances such as nitrogen oxides, sulphur dioxide, and ammonia. Nitrogen oxides have also a terrestrial eutrophication potential. This causes potential double counting of the emission of the same substance in different impact indicators. This will be further discussed in chapter 4.6.2.
The following metric can be used to calculate the true costs of acidification:

$$TC_{AC} = U_i * A_i * MF_{AC} \tag{10}$$

Where TC_{AC}= true cost of acidification, U_i= use of substance i [unit], A_i= acidification potential of substance i [kg SO_2-eq/unit] and MF_{AC}= monetization factor acidification [8.75 EUR_{2017}/ kg SO_2^-eq]

The recommended tool the calculate the true costs of acidification is LCA software.

Eutrophication

Eutrophication considers: ‘’energy use, diesel combustion and production of non-organic fertilizers and their terrestrial eutrophication potential’’ (True Cost Initiative, 2022, p. 25). The process of eutrophication is already explained in the chapter on water pollution. The consequence of eutrophication is different in this impact category as it entails terrestrial eutrophication instead of eutrophication of water systems. Consequently, the main consequence can be found in change in the biodiversity of the terrestrial ecosystems; species that flourish in the dominance of nutrients will increase in number, while other species decrease in number (Smith et al., 1999).

The true cost of eutrophication of terrestrial ecosystems can be calculated according to the following metric:

$$TC_{eu} = U_i * A_i * MF_{eu} \tag{11}$$

Where TC_{eu}= true cost of eutrophication, U_i= use of substance i (unit) , A_i= eutrophication potential of substance I [kg PO_4-eq/unit] and MF_{eu}= monetization factor eutrophication [4.7 EUR_{2017}/ kg PO_4-eq]

The recommended tool to calculate the true costs of eutrophication is LCA software.

Eco-toxicity

Eco-toxicity is the potential ecological risk to species by chemicals emitted into the environment (mainly water) (True Cost Initiative, 2022). During the production process of a good, chemicals can be emitted that have a potential health risk for different species living on our earth. When emitted, different factors influence the damage or impact such a chemical has. Factors that have an impact are how long it stays in the environment, whether is it available for uptake by organisms, and what the effect is caused by the exposure (Huijbregts et al., 2016). In the past, different chemicals were identified that cause a risk to the environment, and of which emissions are now banned. However, new possible problematic chemical emissions are emerging such as (micro) plastics, hormones, or antibiotics (Mishra et al., 2023).

The metric to calculate eco-toxicity is the following:

$$TC_{ET} = U_i * T_i * MF_{ET} \tag{12}$$

Where TC_{ET}= true cost of eco-toxicity, U_i= use of substance i [kg], T_i= toxicity impact of substance i [kg Cu-eq /kg], and MF_{ET}= monetization factor eco-toxicity [340 EUR_{2017}/ kg cu-eq]

The recommended tool to calculate the true costs of eco-toxicity is USEtox 2.1 or LCA software.

Human toxicity

Human toxicity can be defined as: ‘’the potential health risk of cancerous and non-cancerous effects of chemicals emitted to the environment (mainly soil and air)’’ (True Cost Initiative, 2022, p. 26). Emitted chemicals can have an impact on ecosystems, human health, or both. Different pathways can be identified through which the chemicals end up in the human body such as inhalation, ingestion, or direct contact. In LCAs, a differentiation is made between the cancerous and non-cancerous effects of these emitted substances.

The production process of conventional meat took thousands of years to develop and to become safe and affordable. On the contrary, this process of cultured meat is just starting. Little research has been performed on the health effects of eating cultured meat. It can be argued that it is safer because it is a fully controlled environment, but arguments can also be raised that not everything can be controlled resulting in for example cancerous cells (Chriki & Hocquette, 2020). A total of 53 hazards are defined during the different production stages of cultured meat. These hazards differ from potential novel substances during the production process, the usage of hazardous food additives, or the presence of food allergens. Some of these hazards can also occur during the production of conventional meat (FAO & WHO, 2023). Limiting these hazards and providing a safe environment limits the impact on human toxicity and/or eco-toxicity.

The metric to calculate the true cost of human toxicity is the following:

$$TC_{HT} = U_i * T_i * MF_{HT} \tag{13}$$

Where TC_{HT}= true costs of human toxicity, U_i= use of substance i [kg], T_i= toxicity impact of substance i [diseases cases per kg], and MF_{HT}= monetization factor of human toxicity [80000 EUR_{2017}/DALY]

The recommended tool to find the true costs of human toxicity is USEtox 2 or LCA software.

Living wage

A living wage gap can be defined as: ''the gap between the national (or regional) estimated living wage and what is being paid to the worker'' (True Cost Initiative, 2023, p. 26). A living wage aims at having a salary that satisfies and provides a sufficient standard of living for the worker and their family (Anker, 2011). Internationally, earning a living wage is seen as a human right. However, this is not necessarily always followed as still people earn less than a living wage, even in Western countries (Social Justice Ireland, 2023).

The true costs of the living wage gap can be defined according to the following metrics:

$$TC_{LWG} = LWG * CER \tag{14}$$

Where LWG is the living wage gap in local currency and CER is the currency exchange rate into euro.

$$LWG = \sum_{i=1}^{n}(WG_i * H) \tag{15}$$

With:

$$WG_i = LW - W_i \; for \; W_i < LW \tag{16}$$

$$WG_i = 0 \; for \; W_i \geq LW \tag{17}$$

Where n= number of workers, WG_i= wage gap of worker I [local currency], LW= local or national monthly living wage [local currency], W_i= monthly net paid to worker i [local currency], and H= standard working hours of worker i per year (1840 inside Europe, 2240 outside Europe).

Excessive working hours

Excessive working hours can be defined as: ‘’overtime which is all hours worked in excess of the normal hours’’ (True Cost Initiative, 2022, p. 26). It is assumed that overtime occurs when an individual works more than 48 hours (True Cost Initiative, 2022). These excessive working hours are associated with increased risks of diseases. Individuals who work more than the standard working hours have a higher risk of having a stroke: by 10% for 41–48 hours per week, 27% for 49–54 hours, and 33% for 55 hours and above (Kivimäki et al., 2015). In addition to the higher chances of having a stroke, excessive working hours may trigger the onset of a cerebro-cardiovascular disease (Shin et al., 2017).

The following metrics can be used to calculate the true costs of excessive working hours:

$$TC_{EWH} = EWH * MF_{EWH} \tag{18}$$

With the following formula for EWH:

$$EWH = \sum_{i=1}^{m} \sum_{j=1}^{n} (H_{EWH}^{j} - 48)/48 * 0.5DALY \ if \ H_{EWH} > 48 \ hours \ \ per \ week$$

$$EWH = 0 \ if \ H_{EWH} \ \leq 48 \ hours \ per \ week \tag{19}$$

Where TC_{EWH}= true cost of excessive working hours, MF_{EWH}= monetization factor excessive working hours [80000 EUR_{2017}/ DALY], m= number of working weeks, n= number of workers and H_{EWH}= working hours of worker j per week

The 0.5 is based on the idea that EWH is half the cost of treating a kidney patient per year (True Cost Initiative, 2022). The value of DALY is not given and no tool is provided to find this value.

Occupational health and safety

Occupational health and safety (OHS) can be referred to as: ''the health impact from work-related injuries, (long-term or chronic) illness and death of workers'' (True Cost Initiative, 2022, p. 26). To different injuries and illnesses, a specific disability weight can be linked (Salomon et al., 2015). This is a severe problem worldwide as 295 million workers experienced a non-fatal injury and 2.93 million workers died because of work-related factors in 2019 (International Labour Organization, 2023).

The following metrics can be used to calculate the true costs of OHS:

$$TC_{OHS} = OHS * MF_{OHS} \tag{20}$$

With TC_{OHS}= true cost of occupational health and safety, OHS= work-related illnesses, injuries, and deaths [DALY], and MF_{OHS}= monetization factor occupational health and safety [80000 EUR_{2017}/DALY]

With:

$$OHS = [\textstyle\sum_{j=0}^{q} (F_j * DW_j)(LE - A_j)] + [\textstyle\sum_{K=o}^{n} (LN_L * DW_K)(LE - A_K)] + \textstyle\sum_{l=0}^{m} (IL_l * DW_l) /365 \tag{21}$$

With q= number of fatal accidents per year

F= number of fatalities per killed worker j (equals 1)

DW_j= disability weight of death worker j (equals 1)

LE= national life expectancy [years]

A= age of worker j or worker j [years]

n= number of injuries per year

LN= number of injuries per injury type K per year

DW_k= Disability weight of injury type K

m= number of illnesses per year

IL= number of days with illness type l per year

DW_l= disability weights of illness type l

235 unique health states have been defined with all having their own disability weight (Salomon et al., 2015). Per type of injury or illness, it should be defined to which disability weight it belongs.

Gender pay gap

A gender pay gap can be defined as: ''the difference between male and female net earnings'' (True Cost Initiative, 2022, p. 26). The gender pay gap is still present to date in many countries all over the world, including European countries. In 2021, women earned on average 12.7% less than males in Europe. This is an unadjusted average; it depends per type of job, company, and other factors on whether this percentage is higher or lower when a man and woman perform the same work (Eurostat, 2023b). The global average is even higher with an average of 22% in terms of median monthly wages.

The following metrics can be used to calculate the true costs of the gender pay gap:

$$TC_{GPG} = GPG * CER \tag{22}$$

With TC_{GPG}= the true costs of the gender pay gap, GPG= the gender pay gap [local currency], and CER= Currency exchange rate into euro

If the wages of both men and women are above the local living wage then the GPG is the following:

$$GPG = \sum_{i=1}^{n}[(S_H - S_L) * H] \; if \; S_L > LW \tag{23}$$

If one of the wages is below the local living wage and the other above, the GPG is the following:

$$GPG = \sum_{i=1}^{n}[(S_H - S_L) * H] \; if \; S_H > LW \; and \; S_L \leq LW \tag{24}$$

If both wages are below the local living wage then the formula is the following:

$$GPG = 0 \; if \; S_H \leq LW \tag{25}$$

With:

$$S_H = (j_1 + j_2 + \cdots + j_m)/m$$
$$S_L = (i_1 + i_2 + \cdots + i_n)/n \tag{26}$$

With S_H= average salary of the sex with the higher salary per hour [local currency/hour], S_L= average salary of the sex with the lower salary per hour [local currency/hour], LW= local living wage [local currency], H= standard working hours per year (1840 per year inside Europe and 2240 outside Europe), n= number of workers of the sex with the lower salary and m= number of workers of the sex with the higher salary j

Forced labour

Forced labour can be defined as: ''any work that is performed involuntarily and under the threat of punishment'' (True Cost Initiative, 2022, p. 26). Nowadays forced labour is still a significant problem as 5.4 out of the thousand people in the world (including children) experience forced labour (International Labour Office, 2017). 71% of the people that experience forced labour are children and women.

11 indicators are defined that indicate forced labour:

- Deception
- Restriction of movement

- Isolation
- Physical and sexual violence
- Intimidation and threats
- Retention of identity documents
- Withholding of wages
- Debt bondage
- Abusive working and living conditions
- Abusive of vulnerability
- Excessive overtime

If an individual meets three or more of the eleven indicators it is classified as forced labour (True Cost Initiative, 2022). According to the ILO, sometimes if one indicator is met, it can already be classified as forced labour (International Labour Organization, 2012). However, for the used metrics, three indicators need to be met to identify forced labour.

$$TC_{FL} = FL * MF_{FL} \tag{27}$$

With TC_{FL}= true costs of forced labour, FL= forced labour [DALY] and MF_{FL}= monetization factor forced labour [80000 EUR_{2017}/DALY]

If less than three indicators apply:

$$FL = 0$$

If three or more indicators apply:

$$FL = h * 0.5DALY \; with \; h = \sum_{i=1}^{n} h_i \tag{28}$$

With h= total annual working hours of forced worker i.

The value of DALY is not known and not given. In addition, the 0.5 is based on the idea that forced labour is half the cost of treating a kidney patient per year (True Cost Initiative, 2022).

Child labour

Child labour can be defined as: ''work that deprives children of their childhood, their potential, and their dignity, and that is harmful to physical and mental development. It refers to work that:

- ''is mentally, physically, socially, or morally dangerous and harmful to children; and/or
- interferes with their schooling'' (International Labour Organization, n.d.-b)

It is estimated that at the beginning of 2020, 160 million children were in child labour. This accounts for almost one-tenth of all children worldwide. The relative number of children being in child labour is higher for boys compared to girls. Most of the child labour occurs in agriculture. In sub-Saharan Africa, the largest prevalence of child labour occurs. Almost half of all children in child labour are performing hazardous work (International Labour Office & United Nations Children's Fund, 2021).

The true costs of child labour can be calculated according to the following metrics:

$$TC_{CL} = SC_{CL} * MF_{CL} \tag{29}$$

With TC_{CL}= true costs of child labour, SC_{CL}= child labour [DALY] and MF_{CL}= monetization factor child labour [80000 EUR_{2017}/DALY]

$$SC_{CL} = \sum_{i=1}^{n} (H_{CL}^{i} - 560)/2240 * 0.5DALY \; if \; H_{CL}^{i} > 560 \; hours$$

$$SC_{CL} = 0 \; if \; H_{CL}^{i} \leq 560 \; hours \; per \; year \qquad (30)$$

With n= number of children working and H^{i}_{CL}= working hours per child i per year.

The value of DALY is not known and cannot be found in the provided tools. In addition, the 0.5 is again based on the idea that child labour is half the cost of treating a kidney patient per year (True Cost Initiative, 2022).

2.2. Welfare economics and true cost accounting

In this chapter, firstly a welfare economics framework be provided. Thereafter, TCA will be analyzed from a welfare economic perspective using different views such as the government, businesses, and individuals. In addition, several levers will be described that can be used with TCA as a decision instrument.

2.2.1. Utility and individual preferences

Assume an economy where consumers have access to a certain amount of produced goods. The individuals have certain preferences related to those goods. Allocation of resources occurs that determines which quantities of goods are produced, which combination of resources is used to produce those goods, and how these produced goods are distributed among consumers. This allocation of goods is associated with a certain amount of utility. The concept of utility will be explained according to a highly simplified model. In addition, two assumptions are made in this simplified model. The assumptions will be explained and assessed later in this chapter in more depth.

1) No externalities exist in both consumption and production.
2) The produced goods are private goods.

Assume an economy that consists of two persons: A and B. In addition, two goods are produced: X and Y. The inputs to produce those goods consist of Kapital (K) and Labour (L). From the consumption of those goods individual A or B enjoys a certain amount of utility. In other words, the total utility individual A (or B) enjoys depends on the quantity he/she consumes of goods X and Y.

$$U^{A} = U^{A}(X^{A}, Y^{A}) \qquad (31)$$

$$U^{B} = U^{B}(X^{B}, Y^{B}) \qquad (32)$$

The output level of X or Y depends on the input and K and L. This implies that no K and L are wasted in production.

$$X = X(K^{X}, L^{X}) \qquad (33)$$

$$Y = Y(K^{Y}, L^{Y}) \qquad (34)$$

When considering the utility of the consumers, the following two marginal functions can be found that relate to formulas 31 and 32. Firstly, the marginal utility for both products from the consumption of one good X or one good Y can be derived. Secondly, the marginal rate of substitution can be derived meaning the rate at which X can be substituted for Y or vice versa, keeping the total utility of individual A (or B) constant.

When examining the output of production, the following two marginal functions can be found that relate to formulas 33 and 34. Firstly, the marginal rate of technical substitution is the rate at which K can be substituted for L and vice versa, keeping X (or Y) constant. In addition, the marginal rate of transformation indicates the rate at which one good X or Y should be given up producing one additional unit of the other good.

These notations provide the basis for an explanation of the efficient and optimal allocation of resources in society under the specified assumptions (Perman et al., 2003).

The mathematical explanation is an attempt to quantify utility, but it should be noted there is a debate around the utility concept which contains topics such as the definition, whether utility is something you can measure, how you can measure it, and the rationality of the consumer. The concept of utility of Utilitarianism dates to the concept of hedonism, first described by the ancient Greeks. Hedonism can be described as individuals trying to maximize their total happiness (Brue & Grant, 2012). This concept of utilitarianism was further elaborated by Bentham et al. (1789). He also was the first to introduce the concept of diminishing marginal utility. By publishing the first papers on utilitarianism, the first critiques arose. The first critique that can be found is that happiness is subjective and it differs per person. Everyone values things differently and it is difficult to compare and measure these valuations (Brue & Grant, 2012).

If it can be measured, the second debate starts about how it can be measured. Bentham used money as his unit of cardinal measurement (Brue & Grant, 2012). The concept of cardinal utility was supported by Léon Walras in the 19th century (Walras, 1954). Ordinal utility allows precise comparisons of preferences and choices. On the contrary, Carl Menger (19th century) was a supporter of ordinal utility case of ordinal utility, only ranking of utility and no numeric numbers are linked to utility (Stigler, 1937). Over time, the definition of utility changed. Bentham defined utility in his paper in 1780 utility as happiness, benefit, or pleasure and preventing the happening of pain, evil, or unhappiness. All these words can be summarized in attempting to maximize happiness. Later economic theories shifted from happiness to preferences and choices of individuals (Walras, 1954; Stigler, 1937).

The final point of discussion can be found in how rational consumers are. The classical utility theories assume that consumers think rationally and that individuals aim to maximize utility. However, the prospect theory has proven that individuals tend to make risk-averse decisions. It has been observed that individuals feel losses more than that of an equivalent gain (Kahneman & Tversky, 1979). This is in contradiction with the rationality assumption in the utility theory.

2.2.2. Social welfare function

A social welfare function seeks to aggregate individual preferences and utilities into a measure of overall social welfare, a measure of the overall welfare of the society. The main aim of a social welfare function is to compare different policies and to compare their impact on overall welfare. Many different views on social welfare functions can be found. The most common ones will be described in more depth.

1) Utilitarianism

Utilitarianism aims to have the greatest overall welfare of society. This implies that the social welfare function aims that the social welfare function should maximize the sum of individual utilities. It is assumed that the utility of every individual has an equal weight (Bentham et al., 1789).

2) Rawlsian

Rawlsian aims to increase the utility of the worst-off members of society. It allows inequalities between members of society as long as the members that are the worst off gain an increase in utility (Rawls, 1971).

3) Libertarian

The libertarian view is about limiting government interventions and that individuals have their rights. Libertarians limit the distribution of income even if it gains an increase in social welfare (Smith & Rogers, 1776).

The critiques related to the usage of utility can also be found in the discussion around the social welfare function. It is argued how private-sector real-world outcomes can be compared to social utility norms. Brennan and Buchanan (1988) defined two lines of arguments. Firstly, utility can only be known individually, no one can discern a social welfare function. Individuals are even not aware of their utility preferences until they are presented with real-world choices. Secondly, even if social welfare choices were known, the private sector is not a reliable sector for achieving this. Therefore, it is difficult to align the individual interests of companies with social beliefs (Brennan & Buchanan, 1988).

2.2.3. Pareto efficiency

If the utility of one person cannot be improved without making another person worse off, a Pareto efficient state is reached. In this state, individuals are satisfied as much as possible. In addition, there is no waste or inefficiency as resources are allocated optimally. If one's utility can be improved without decreasing the utility of another, the resources are allocated inefficiently. To be Pareto efficient, the marginal rate of substitution should be the same for all consumers. In addition, the marginal rate of technical substitution should be equal for all commodities. Finally, the marginal rate of substitution and the marginal rate of technical substitution should be the same for all products and all consumers. If that is the case, the situation is Pareto efficient (Perman et al., 2003). The example of two consumers and two goods, as described in chapter 2.2.1, can be extended to more consumers and more goods.

This Pareto efficient state works under two conditions:

1) All producers and consumers are perfect competitors: no one has any market power.
2) A market exists for every commodity.

2.2.4. First welfare theorem

The first welfare theorem states that a competitive market equilibrium is an efficient allocation. This entails that there is an equilibrium when no one can be better off without making the other worse off. In other words, a pareto-efficient situation (Perman et al., 2003). This can be realized if all players in the economy are maximizers. The consumers try to do the best for themselves in the situation they are in. Producers try to maximize profit. In addition, certain conditions need to be met:

1) Markets consist for all products and services produced and consumed.
2) All markets are perfectly competitive.

3) All actors on the market have perfect information.
4) Private property rights are assigned to all resources and commodities.
5) No externalities exist.
6) Alle goods are private goods.
7) All utility and production functions are well-behaved meaning the utility functions are continuous and are bowed shaped towards the origin. In the case of production, it means that increasing returns of scale are ruled out.

2.2.5. Market equilibrium

In a market, two curves can be found: the demand and supply of a product. The demand curve represents how many products the consumer demands at a certain price. The supply curve represents how many products a producer is willing to produce for a certain price. Where these curves intersect, an equilibrium price and quantity can be found. These demand and supply curves may shift because of changing consumer preferences or technological innovations. If the market price is not equal to the equilibrium price, there is a shortage or surplus of a product. It is a signal that the market is suboptimal and not efficient.

2.2.6. Second welfare theorem

The second welfare theorem deviates from the first welfare theorem in that the first welfare theorem assumes that the initial allocation of resources is efficient. In addition, if certain conditions are met it is assumed that a Pareto efficient state is reached with a competitive equilibrium. The second welfare is in some terms the same, but the major difference can be found in that the second welfare theorem also indicates that despite inefficient initial allocation, a Pareto efficient equilibrium can be reached in the future through a competitive market. The same conditions need to be met as in the first welfare theorem (Perman et al., 2003).

2.2.7. Market failures

The Pareto efficient state can be reached under the conditions that no market failures occur. However, these conditions do not hold in an actual economy. If these conditions are not met, they are being referred to as market failures. In this chapter, per market failure, it will be explained what happens if the market fails.

1) **Markets consist for all products and services produced and consumed.**

If no market consists for a good or a service, resources can per definition not be allocated efficiently.

2) **All markets are perfectly competitive.**

A perfect competitive market can be defined according to four main characteristics:

- *The producers and consumers of a good are price takers. Both cannot influence the price of a good and therefore accept the market price.*

  If producers or consumers influence the market price, they can be considered price-makers. Imperfect markets where this is the case are monopolistic or oligopoly markets. There are only respectively one or a few producers of a good or service.

- *The product that is offered on the market is homogenous.*

In general, two kinds of goods can be distinguished: homogenous and heterogenous. If a good or service is heterogeneous, the producer tries to differentiate the product or service from its competitors by changing the attributes. Consumers view a good or service with the same function in a different matter. These differences in consumer preferences make thar reaching a Pareto-efficient state is more difficult.

- *Free entry and exit of the market. No costs are associated with entering or exiting a market.*

When producers cannot enter the market freely, it can be assumed that fewer producers enter the market causing limited competition. This implies that suboptimal outcomes will be reached. In addition, the few competitors that are present have more market power which causes a monopoly or oligopoly will occur instead of a market with perfect competition.

- *Every actor in the market has perfect information.*

If these characteristics are met, the market is perfectly competitive. If one of these characteristics is not met, the market is not perfectly competitive.

3) All actors on the market have perfect information.

Perfect information entails that all actors in making a transaction have the same amount of information. On the contrary, asymmetric information refers to a situation where one actor in a transaction has more information about the product or service than the other actor or actors. If there is asymmetric information, market failures can occur for several reasons:

- Adverse selection. One actor on the market has more information about a product, service, or risks than another actor. For example, assume that not all products are the same: there are low- and high-quality products. The consumer does not have the information on which one is the low-quality product and which one is the high quality. The consumers are not willing to pay more than the price they are willing to pay for the product than the low-quality price. After all, the consumers do not have all the information. For the producers with high-quality products, this price is too low. Hence, they will no longer sell these products. This leads to market inefficiencies and therefore suboptimal allocation of resources.

- Moral Hazard occurs when individuals are taking extra risks because they do not bear the potential financial consequences. These individuals have more information about the risks they are taking than the actor who bears the consequences.

- Market Segmentation occurs when some groups (both producers and consumers) have different information than other groups. These can hinder efficient allocation and create inefficiencies.

- If there is a lack of information and uncertainty about investments, investors can ask for higher interest rates or returns to compensate leading to inefficiencies.

4) **Private property rights are assigned to all resources and commodities.**

Property rights can be described as: ''a bundle of characteristics that convey certain powers to the owner of that right'' (Perman et al., 2003). Property rights are necessary to hold condition 1. Without property rights, no market can exist for a resource or commodity (Perman et al., 2003).

5) **No externalities exist.**

An externality can be referred to as an external effect that occurs when the production or consumption decisions of one agent have an impact on the utility or profit of another agent in an unintended way. No compensation or payment is made by the generator of the effect to the affected party. Important to know is that both producers and consumers can cause externalities and that these externalities can be inflicted on producers and/or consumers (Rosen & Gayer, 2009).

Negative externality

In case of a negative externality, too much of a good is produced than socially optimal. This leads to an inefficient situation. The negative externality comes at a certain cost: the marginal external cost. This marginal external cost can be added to the marginal private cost to give the marginal social costs (Perman et al., 2003).

Positive externality

A positive externality means that too little of a good is produced than socially optimal. This leads again to an inefficient situation. The marginal external benefit that is gained from a positive externality can be added to the marginal private benefit giving the marginal social benefit. As per produced product, the benefits are higher, the production of the good or service will increase in a social optimum (Perman et al., 2003).

Different types of externalities can be found such as pollution, music that your neighbor produces or health benefits a certain type of food has. However, it can be hard to determine what the cause of the externality is, the specific effect it has, and the value of this specific effect. A widely mentioned example of a negative externality is pollution. Differentiation can be made between stock and flow pollutants. Stock pollutants accumulate in the environment and only some have degradation. Depending on the lifetime, they tend to accumulate in the environment (Perman et al., 2003). Once a pollutant has been identified, it is needed to identify what activity (or activities) produces the pollutant. Determining which specific activity causes a specific amount of pollution can be hard as many factors may influence the specific amount of pollution. For example, acid rain depends on local weather conditions and other chemicals in the atmosphere. In addition, volcanic eruptions and plant decay also cause a fraction of the acid rain. It is known that acid rain is a pollutant with impacts on the environment, but how much is caused by a specific fabric is hard to determine (Rosen & Gayer, 2009).

Assume that it is known how much damage is done by a specific activity. Then the willingness to pay for not having that pollutant needs to be determined. This can again be a hard step as people are unaware of for example the health impact of pollutants and hence will underestimate the value of being willing to reduce it (Rosen & Gayer, 2009).

It is not necessarily that zero pollution is optimal. Again, the efficient amount of pollution needs to be calculated. This is the point where the net benefits of pollution are maximized. The net benefits equal the benefits minus the damages of the pollution. Policy objectives play a part in how to reach this or which emission targets need to be met to maximize net benefits (Perman et al., 2003).

Bargaining and the Coase theorem

Assume there are two actors: A and B. Both actors own a certain amount of land and they both own property rights of that land. A has an economic activity on his land that causes unintended pollution of the land of B. Actors A and B start to bargain with each other about how much B is willing to pay A to reduce the pollution of A. The situation is illustrated in Figure 1. The quantity that A produces will be reduced from Q_1 to Q*. This comes at a certain cost for A which equals triangle *BCD.* Actor B gains from the decreasing the pollution *ABCD*. Therefore, the amount B pays A is between BCD and ABCD. The specific amount is reached through bargaining. Again, an efficient situation is reached (Rosen & Gayer, 2009). This described situation is referred to as the Coase theorem. The Coase theorem describes that provided that the transaction costs are neglectable, an efficient situation can be reached as long as property rights are assigned, independent of who is assigned property rights. It implies that no government interventions are required in case of externalities (Coase, 1960).

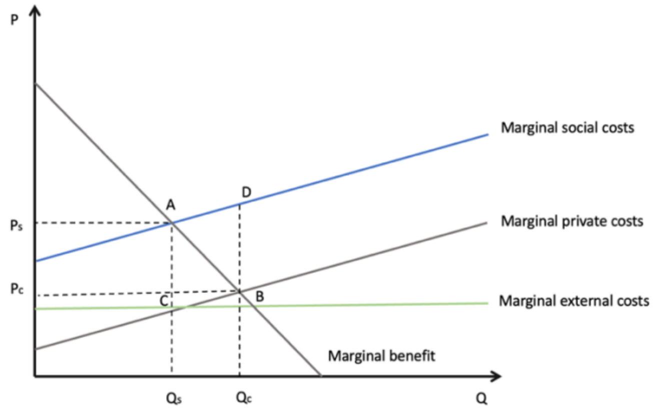
Two main critiques can be found on the Coase theorem. The first one and the most prominent one is that pollution involves many people. If it involves many people, it is impossible not to have transaction costs. It is said that the Coase theorem presents a situation that cannot be reached in the real world (Fox, 2007). It can be argued that this is not the message that Coase tries to give. In essence, transaction costs are present because of imperfect information. If every actor in the market has the same perfect information, no transaction costs would be present and an artificial world of perfect competition would arise (Coase, 1960). This is simply not realistic and therefore transaction costs are present. The second critique is that it is difficult to assign property rights to, for example, air. If property rights are assigned to an airspace, it is hard to determine which of the many polluters is responsible for the pollution in their airspace (Rosen & Gayer, 2009).

These critiques miss the mark of what Coase really meant with the essay ''The Problem of Social Costs''. The first message that Coase tries to give is the reciprocal nature of externalities. Traditionally, the following relation can be described: the polluter (A) imposes harm on the victim (B) and the A should be restrained from harming B. However, the more important question to ask is whether A should be allowed to harm B or should B be allowed to harm A. It should be decided whether the gain from preventing the harm is higher than the loss elsewhere from stopping the harm (Coase, 1960).

The second message Coase aims to give is that in case of significant transaction costs, governmental policies may potentially increase efficiency. Governments can reduce or eliminate some transaction costs when policies are rightly implemented (Coase, 1960). This second message should be handled with care as policy interference can make efficiency worse instead of increasing it (Fox, 2007).

Figure 1

Marginal social and private costs and marginal benefit



6) Alle goods are private goods.

Whether a good is a private good, can be defined according to two characteristics: rivalry and excludability. Rivalry means whether one's agent's consumption is at the expense of another agent's consumption. Excludability means whether agents can be excluded from consumption. These two characterization factors induce that goods or services can be subdivided into four types as shown in table 2.

Public goods or services can therefore be defined as non-rivalrous and non-excludable. To allocate public goods efficiently, the provision of a public good should be expanded until the point at which the sum of each person's marginal benefit equals the marginal costs. However, in the case of a public good, the good must be consumed in equal amounts. Therefore, the willingness to pay by society for a certain amount of public good is calculated by adding the prices each individual is willing to pay for a certain amount of public good. The price one individual is willing to pay equals the marginal rate of substitution. Therefore, the sum of the prices individuals want to pay equals the sum of the marginal rates of substitution. This sum should equal the total incremental costs of society providing the public good. Which equals the marginal rate of transformation (Rosen & Gayer, 2009).

Table 2

Different types of goods

	Excludable	*Non-excludable*
Rivalous	**Pure private good**	**Open-access resource**
	Ice cream	Ocean fishery
Non-rivalrous	**Congestible resource**	**Pure public good**
	Wilderness area	Defence

Different factors can be found that make it difficult to reach this efficiency. Firstly, the consumers have to be honest about the price they are willing to pay for the public good. A problem that is related to the true preferences of individuals is the free rider problem. Individuals may say that are not willing to pay anything for the good, while still enjoying the benefits of the good.

7) **All utility and production functions are well-behaved meaning the utility functions are continuous and are bowed shaped towards the origin. In the case of production, it means that increasing returns of scale are ruled out.** If this is not the case, it is not possible to reach a pareto-efficient situation (Perman et al., 2003).

2.2.8. Externalities

In the case of cultured or conventional meat, many externalities can be identified of which a part is included in the used TCA method. Examples of externalities that are not included are the cultural value meat has, the ethical side of the debate, or the health risks eating meat imposes on individuals (besides the emissions of toxic substances). Currently, the approach on how to select the impact categories is rights-based. Worldwide, rights are defined such as labour, environmental, or human rights. If none of these rights is violated a product, investment or even a system can be described as sustainable (Galgani et al., 2021). The chosen impact categories are impact categories in which rights are violated and are therefore defined as unsustainable. In the future, it is aimed that all possible costs and benefits are included, including those that cannot be expressed in monetary terms. This induces all possible costs and benefits and goes beyond the right-based selection approach (FAO, 2023).

The externalities can be divided into four different capitals: produced, natural, social, and human. In every TCA framework, one or more of these capitals are included. In many cases, the costs of the produced capital are already reflected in the market price of a product and are therefore not further included in TCA (True Cost Initiative, 2022). In TCA, the externalities need to be internalized to help different actors in their decision-making process regarding a certain product, investment, or system changes. It is aimed that internalizing these externalities increases the sustainability of a product, investment, business, system, or diet. TCA can be done qualitatively, quantitatively, and, preferably, using monetary values (De Adelhart Toorop et al., 2023). To be able to use monetary values for an externality, three things have to be known: what is the impact of the externality which monetary value needs to be assigned, and who has to pay who.

2.2.9. Impact and monetary values

How the impact of the externality is measured depends on the TCA framework used. In addition, it depends on the micro-decisions that are taken. Eventually, an outcome can be found to which a monetary value needs to be assigned. In TCA, the remediation costs are taken as guidance to find the monetary value per unit of an externality. The definition of remediation costs is the following: ‘’the remediation cost of a right violation is the cost that should be incurred to remediate the harm caused’’ (Galgani et al., 2021). The remediation costs can be defined according to four types of costs: restoration, compensation, prevention of re-occurrence, and retribution costs (Galgani et al., 2021). Firstly, the decision between restoring and compensating has to be made. Restoration costs are preferred as long as the costs are lower than the costs compensating. In addition to restoring or compensating costs, it is essential to prevent the re-occurrence of severe or irreversible damage using so-called re-occurrence costs. Damages done by violating rights or obligations also need to be compensated using estimations of the legal costs. Table 3 presents the different possibilities to estimate the different costs to eventually find the restoration costs.

Reviewing the method on how to define the monetary value also indicates who has to pay whom. In the case of TCA, the polluter pays the victim. Who the victim is, depends on the assigned property rights. The principle of using remediation costs ignores the first message Coase aims to give in the essay ''the problem of social costs''. TCA states that the polluter pays the victim. However, no research has been performed to compare the effect of government action on overall wealth compared to a situation with no government action. (Fox, 2007). When the polluter pays the victim, the net losses for society might be greater than the net gains leading to an inefficient situation. This also relates to the second message Coase aims to give. Policy interference that aims to increase overall welfare should be carefully implemented as one policy could also decrease overall welfare (Coase, 1970).

2.2.10. Property rights

Not for all impact category property rights are clearly defined. In the case of impact categories that belong to the natural capital, the goods that are affected are pure public goods, open-access resources, or congestible resources. For these goods or resources, it can be difficult to assign property rights. For example, GHG emissions affect the quality of clean air. Clean air is a public good. An agent cannot be excluded from having clean air and the good is non-rivalrous. GHG emissions are a global problem and hence, the entire global population is affected by GHG emissions. Another example is water stress. Water is rivalrous as the water use of one agent affects the water use of another agent, especially in areas with water scarcity. In principle, water is non-excludable. However, in the case of clean tap water is excludable; if the bills are not paid, you cannot receive water. However, as the impact category does not entail clean water, but water use in general, it is assumed that it is non-excludable. Therefore,

Table 3

Composition of remediation costs (adapted from Galgani et al., 2021).

	Environmental costs	**Social costs**
Restoration costs	Abatement or restoration costs	Healthcare costs, reintegration, and education costs
Compensation costs	Damage costs (stated/observed or revealed preference)	Damage costs (stated/observed or revealed preference)
Prevention of re-occurrence costs	Cost of averting measures	Cost of averting measures
Retribution costs	E.g. legal sanctions	E.g. legal sanctions

water use is a congestible resource. The difficulty is how to define the property rights of water as it travels through large distances. Consequently, the water use in one area can affect the water use in another area.

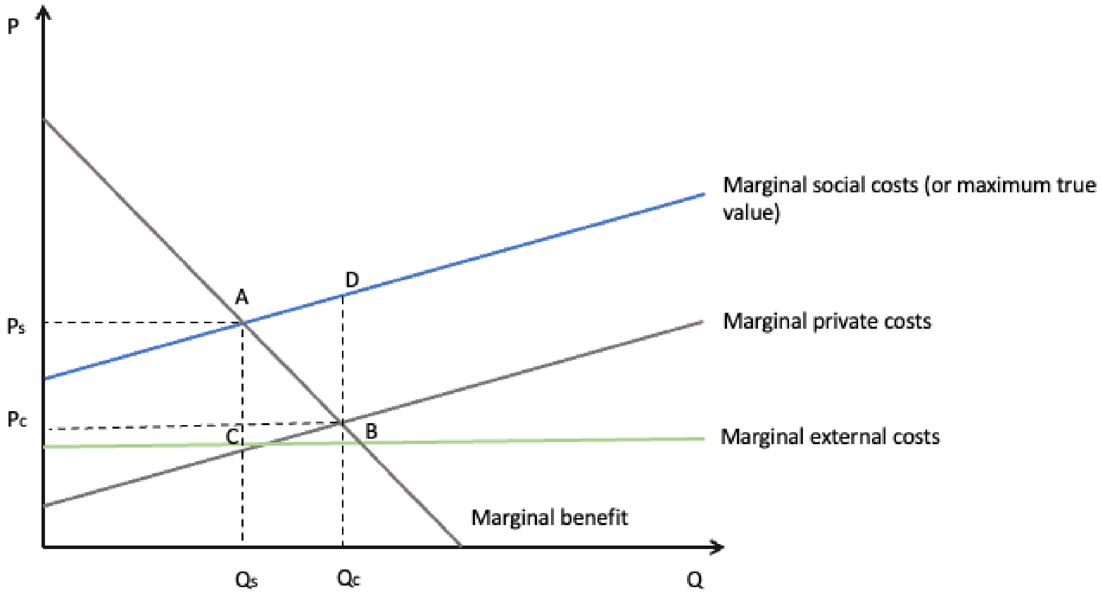
In the case of human and social capital, property rights are more easily to define as it entails laborers that are affected during the production of a good and whose rights are violated. An exception is the impact category human toxicity which entails all individuals who are affected by the emission of toxic substances during the production process. In that case, more people are likely to be affected than the laborers.

In TCA, the true value of a product equals ideally the marginal social costs. However, it is not realistic to include all possible externalities in the true value of a product. Therefore, the true value of a product is the value between the marginal social costs and marginal private costs. True value is used instead of true price because the marginal social costs present an equilibrium situation between the marginal social benefits and costs. Therefore, this equals the maximum true value because the true value entails both the benefits and costs associated with a product or service.

In the case of a competitive equilibrium without externalities or other market failures, Q_c is produced and consumed for an equilibrium price of P_c (figure 2). This can be described as the ideal situation with perfect competition, information, and no transaction costs. If externalities are present, the optimal produced quantity is Q_s for the socially optimal price of P_s. In a socially desirable situation, the price of the per produced quantity is higher while the produced quantity is lower. Figure 2 assumes that the external costs are higher than the benefits resulting in net marginal external costs > 0. The quantity that would be produced using the true value will be between the Q_c and Q_s.

Figure 2

Maximum true value and the marginal social costs



2.2.11. TCA and consumers

Two options can be considered: the first option for TCA is to let the consumers pay the true price or value of a product. The second option is to have TCA as an informative instrument for consumers to inform them about the impact a certain product has.

The first option gives two possibilities: the company itself decides to let the consumer pay the true price or a policy is implemented that ensures that consumers need to pay a true price or value. Enabling consumers to pay the true price is not among the primary objectives of TCA. It is an option that eventually in the future may or may not happen (De Adelhart Toorop et al., 2021). The consequence of letting a consumer pay the true price can be defined according to the following steps. The price the consumers need to pay is set by a company, the government, or another party, and it is based on the TCA framework. The whole process of bargaining between the actor that causes the externality, and the affected agent is not happening anymore; it is decided upon a framework. The consumers pay a higher price for a good and consequently, the consumers will consume less of the good. This drives incentive for companies to lower their true price or products will be eliminated from the market if the true price is too high. Again, it should be urged that the losses in societal welfare might be higher than the gains in societal welfare when the consumers pay a true price as the broader picture is neglected in the TCA frameworks.

The revenue by implementing the true price; the true price minus the private costs multiplied by the amount of goods sold, can be used for different purposes. For example, revenue can be used to improve the sustainability of the supply chain and therefore to reduce the true price of a product. The increase in sustainability can be reached through technical innovations or by improving the working conditions by having more supervision having more tools to ensure safety. Compensating, the affected actors in the supply chain is another example. The affected actors can be referred to as victims. Compensating all victims will likely cause high transaction costs as it will involve many individuals. Businesses may need to compensate workers in the supply chain whose labour rights are violated or the global population for the GHG emissions that are emitted. This also causes an increase in administration costs as it needs to be registered which agents are affected.

Letting a consumer pay the true price of a product is not one of the TCA goals, but informing the consumer in their decision-making process is. Presenting the true price of a product in addition to the market price, can help the consumer in deciding between different products. Consumers aim to maximize their utility which results in the quantity of the consumed goods. However, following the assumption of maximizing utility would imply that consumers base their preferences between goods on the market price. Using the true price as an informative tool would suggest that the decision between different goods is not necessarily rational. An individual can have the unrevealed preference to consume fewer goods with a higher market price but with a lower true price.

2.2.12. TCA and businesses

From a business perspective, three different TCA scopes are of interest: product, investment, or organization. TCA accounting can give insight into the true price and costs of a product that a business produces and how this product performs in terms of true price compared to a similar product. In addition, it can give insight into how the organization performs in terms of true price besides classical instruments such as market share, profit, or revenue. Finally, it can contribute to the decision-making on whether to make a certain investment or not or to compare different investment possibilities.

A few cases can be identified in which TCA has contributed to the decision-making process of businesses. Simmons & Boone (2022) formulated the following examples. Firstly, ProRail included the social costs in the decision-making process of investments as they are vulnerable to the opinion of society and their reputation. Including the costs and benefits to society in their process shows transparency. In addition, Tony Chocolony increased their prices by 20% to compensate for the CO_2 during their production process. Finally, Ahold Delhaize uses 20% of the bonus the board receives for investments in healthier foods, less food waste, and CO_2 emissions. This example is not directly linked to TCA, but it is an example of companies using a part of their profit to meet their sustainability goals.

2.2.13. TCA and governmental policies

The government can avoid the market and influence the factors of production without the trouble of making market agreements. Again, the main goal is to inform the institutions in their decision-making. Different benefits can be distinguished by how TCA contributes.

Firstly, TCA using different scopes helps to prioritize. In other words, the impact indicator which contributes to the highest true costs should be the priority to reduce its impact using different policy instruments. Thereafter, the second highest, and so on.

Secondly, TCA can serve as a tool to analyze the effect of different (policy) scenarios (FAO, 2023). Policies are implemented to reach a certain goal or target. Scenarios can be defined according to different policy options to reach those goals and/or targets. Exploring different scenarios helps to give insight into how impact can be reduced and lead to improved outcomes. Including the true price in these scenarios gives insight into the true costs of these scenarios. From a welfare economics point of view, it is important to research the effect of total societal welfare effect of these policies. Implementing a policy that reduces the true price of a product, system, or diet might have benefits in terms of reducing true costs but might cause a decrease in overall societal welfare. The problem with policies is that in general, they must apply to a wide variety of cases, while in practice they are inappropriate for some of them (Coase, 1970). Consequently, there will be a decrease in efficiency. This implies that in some cases, governmental regulations might not give better results in terms of efficiency compared to letting the problem be solved by the market.

Finally, TCA can serve as a tool to give insights into trade-offs that have to be made when implementing policies. A policy may result in efficiently reaching a target but has unforeseen consequences related to the social, human, and environmental impact areas. TCA helps to unveil these consequences and to give insight into the true costs (FAO, 2023). It helps policymakers make a more informed decision (De Adelhart Toorop et al., 2023).

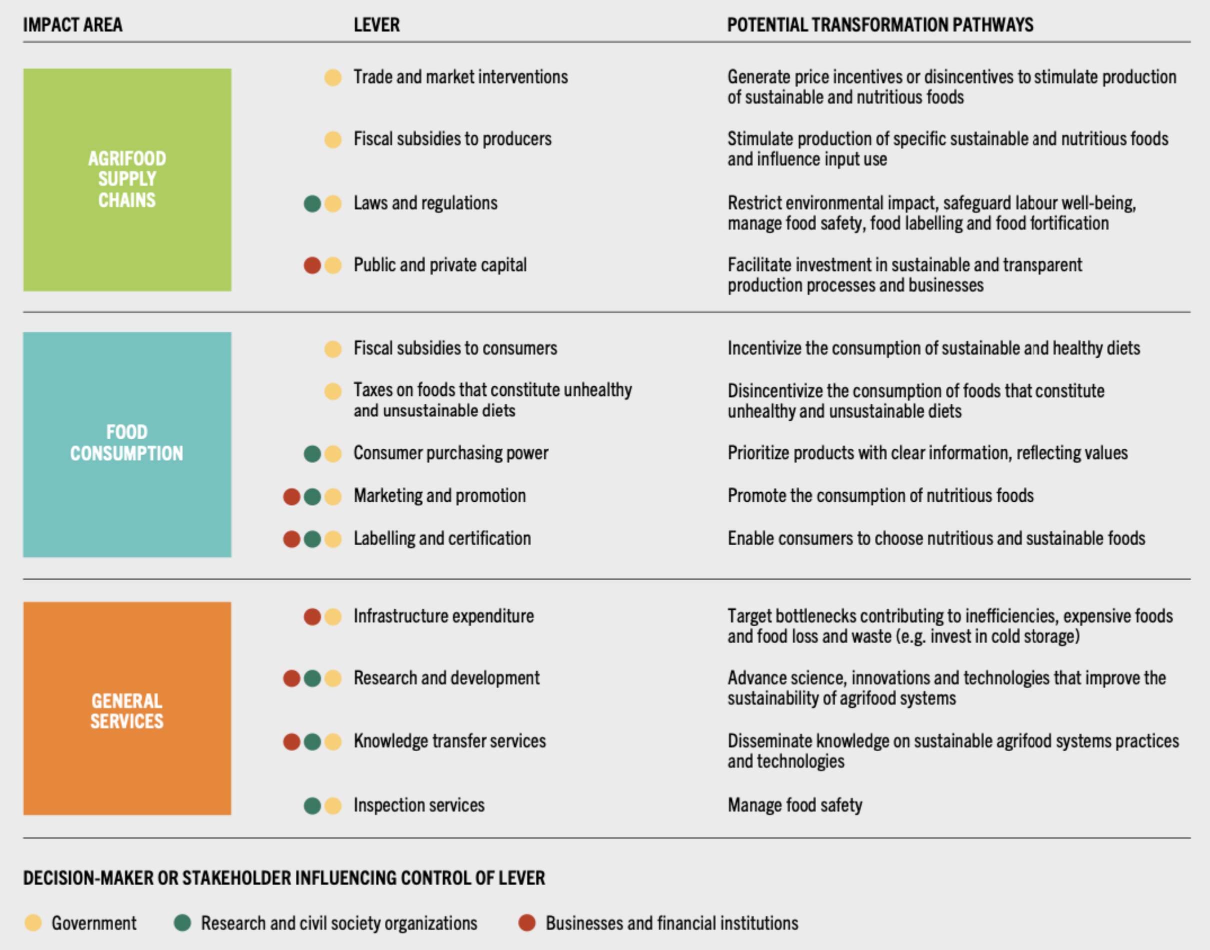
2.2.14. Market regulation instruments

The policies that are used to reach the targets or goals are not new: trade and market interventions, subsidies, laws, regulations, and all the other possible policies have been widely used. TCA is only a tool to help to decide between the different levers. These levers can be seen as a manner to guide the production process, consumption, or general processes in a certain direction (FAO, 2023).

In general, the different levers can be seen as an intervention in the liberal market. The agri-food products offered on the market need to have some kind of regulation to decrease their negative or increase their positive externalities and therefore increase the sustainability of the product (FAO, 2023). According to Table 4, the wide variety of policy tools related to agri-food can be subdivided among three impact areas: agri-food supply chain, food consumption, and general services. It depends on the type of market intervention what the impact is and what the effect on the economic efficiency is. Four examples will be described and their impact on societal welfare by decreasing the negative externalities and promoting the positive.

Table 4

Different types of levers related to several impact areas (FAO, 2023).



IMPACT AREA		LEVER	POTENTIAL TRANSFORMATION PATHWAYS
AGRIFOOD SUPPLY CHAINS	🟡	Trade and market interventions	Generate price incentives or disincentives to stimulate production of sustainable and nutritious foods
	🟡	Fiscal subsidies to producers	Stimulate production of specific sustainable and nutritious foods and influence input use
	🟢🟡	Laws and regulations	Restrict environmental impact, safeguard labour well-being, manage food safety, food labelling and food fortification
	🔴🟡	Public and private capital	Facilitate investment in sustainable and transparent production processes and businesses
FOOD CONSUMPTION	🟡	Fiscal subsidies to consumers	Incentivize the consumption of sustainable and healthy diets
	🟡	Taxes on foods that constitute unhealthy and unsustainable diets	Disincentivize the consumption of foods that constitute unhealthy and unsustainable diets
	🟢🟡	Consumer purchasing power	Prioritize products with clear information, reflecting values
	🔴🟢🟡	Marketing and promotion	Promote the consumption of nutritious foods
	🔴🟢🟡	Labelling and certification	Enable consumers to choose nutritious and sustainable foods
GENERAL SERVICES	🔴🟡	Infrastructure expenditure	Target bottlenecks contributing to inefficiencies, expensive foods and food loss and waste (e.g. invest in cold storage)
	🔴🟢🟡	Research and development	Advance science, innovations and technologies that improve the sustainability of agrifood systems
	🔴🟢🟡	Knowledge transfer services	Disseminate knowledge on sustainable agrifood systems practices and technologies
	🟢🟡	Inspection services	Manage food safety

DECISION-MAKER OR STAKEHOLDER INFLUENCING CONTROL OF LEVER

🟡 Government 🟢 Research and civil society organizations 🔴 Businesses and financial institutions

Taxes

Firstly, taxation with no externalities present will be discussed. If a tax is implemented, the quantity of the bought product decreases (figure 3a). The producers receive a price that is lower than the price it would receive in an equilibrium. The implementation of the tax causes a dead weight loss to society which is caused by an inefficiency in the market. This inefficiency is presented in Figure 4a with triangle ACB (red colour).

Secondly, a tax can be implemented to internalize the externalities into the price (figure 3b). This tax example is the so-called Pigouvian tax. The tax is linked to a specific externality. It is aimed that the producers decrease the impact of the externality or that individuals buy less of that product. Consequently, the impact of the externality will decrease. The tax per unit of externality should equal the marginal external damage of that externality. Consequently, the optimum amount of taxation is reached (Sandmo, 2008). Including all marginal external benefits and costs in the price of a product through a tax implies that individuals pay the marginal social costs or the maximum true price/value for a product. Again, it can be discussed on whether this is desirable as a tax will be applied to a wide variety of cases, in some cases there might be a loss of societal welfare as the tax is not the right approach (Coase, 1970).

From a social perspective support might be lacking for including all these taxes. It depends on who you ask the question on whether the support is there as it interferes with the free market. In the Netherlands, a debate has been started about the sugar tax as people view it as patronizing of society (De Gelderlander, 2023). In addition, a discussion has been started as the sugar tax also applies to non-alcoholic beer and oat milk. Both products are viewed as healthier or more sustainable alternatives to alcohol-containing beer and cow milk. Finally, internalizing all externalities using a tax results in the same as letting the consumer pay the true price of a product. As already described, this is not one of the main goals of TCA and is not desirable.

Subsidy

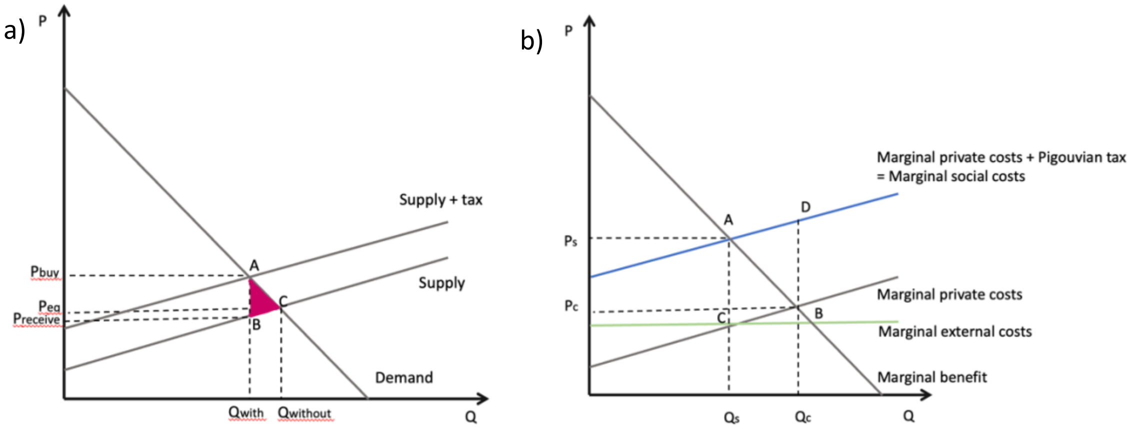
The second example is the implementation of a subsidy to stimulate the production of sustainable goods. If a subsidy is implemented, the price buyers pay is lower than the price producers receive. The produced quantity increases towards a social optimum. For positive externalities, the subsidy is levied per unit of externality. In case of negative externalities, the subsidy is levied per unit of abatement of the negative externality. Consequently, a social optimum produced quantity is aimed to be reached.

Laws and regulation

The third example is laws and regulations. An example of a regulation is that there is maximum amount of GHG emissions or that a specific toxic substance cannot be used anymore. The regulations on how to reach this decrease will differ. For example, the usage of a toxic substance can be completely banned or a maximum number of emissions can be allowed, depending on the impact a toxic substance has. GHG emissions can be controlled using tradable permits. Firstly, the companies with the lowest marginal abatement costs will lower their GHG emissions and sell a part of their permits to companies with higher marginal abatement costs. Thereafter the companies with the second lowest marginal abatement costs and so on.

Figure 3

Two types of taxes. Figure a shows a situation with a tax when there are no externalities present. Figure b shows a situation with a Pigouvian tax when there are externalities present.



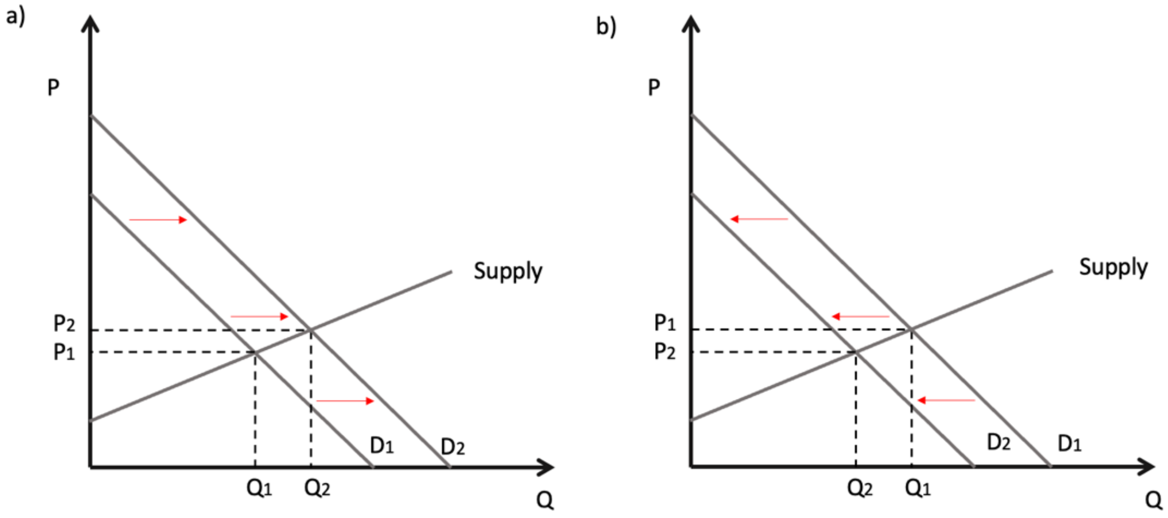
This way, the GHG emissions can be reduced in a cost-effective manner (European Commission, 2021). Laws and regulations can also have unintended effects as they apply to a wide variety of cases and not all costs and benefits for the society are taken into account. Consequently, there will likely be losses in overall wealth for the society (Coase, 1960).

Information provision

The fourth, and final example, is to provide information to consumers to change their preferences. This can be reached in different ways: marketing and promotion of sustainable products or using labeling and certification to indicate which products are sustainable. These methods aim to change consumer preferences towards sustainable products. This implies that the demand for less sustainable products increases and the demand for more sustainable products increases (figure 4).

Figure 4

Two figures representing a change in consumer demand. In both figures, D1 is the old demand and D2 is the new demand. Figure a presents an increase in demand. Figure b shows a decrease in demand.



For all these market regulation instruments, it can be argued whether it increases overall societal welfare or whether it is a better option to let the market solve the impact of externalities. Ideally, for every policy, all costs and benefits associated with that specific policy will be calculated. If what is gained by society is higher than what is lost, these policies are the right action to take. However, if only a fraction of these costs and benefits are considered and the broader system changes and consequently costs and benefits are not considered, a loss of economic efficiency is lurking.

2.3.Cultured meat production

Cultured meat can be seen as an alternative to conventional meat and different types of cultured and conventional meat can be found. In this thesis, the focus lies on (cattle) beef meat. The reason for this is that cattle beef meat is associated with a high environmental impact. Organizations, governments, and research institutions are searching for alternatives to conventional cattle such as plant-based or cultured meat (De Boer & Aiking, 2011). In the case of cultured meat, significant investments are being made and the policy field is changing to allow the labeling, testing, and selling of cultured meat. These investments and changes in policy are being made under the assumption that cultured meat is a sustainable alternative to conventional meat. According to the theory of TCA, the sustainability of cultured meat should be reflected in the true costs of the product when compared to conventional meat. A lower true cost of cultured meat should support the decision to make these investments and changes in policy.

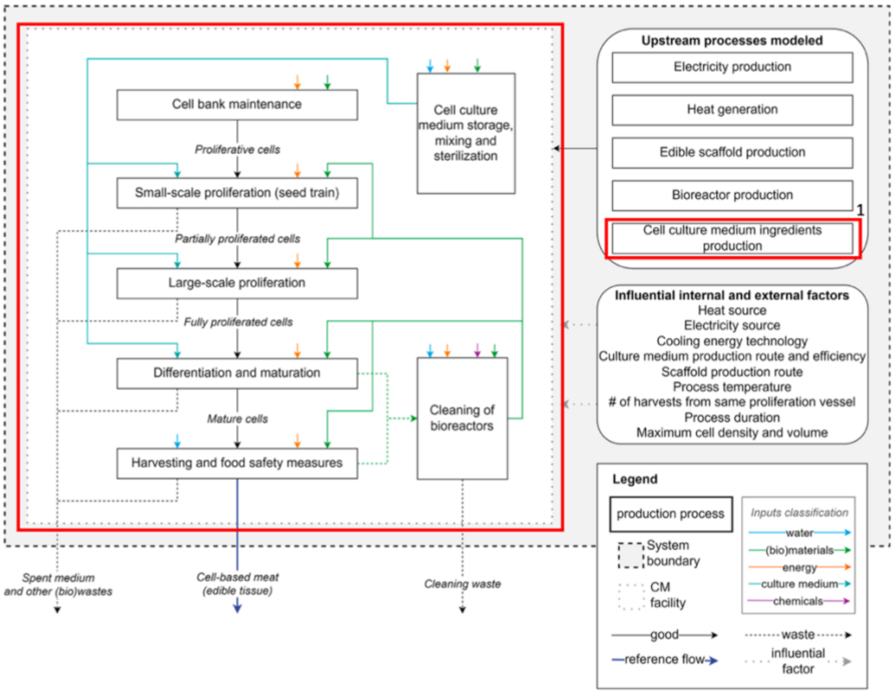
Sinke et al. (2023) and Odegard et al. (2021) researched and tried to visualize how a cultured meat production plant would operate in 2030. From this research, a techno-economic analysis and a LCA of cultured meat were conducted. The LCA focused on giving insight into the environmental impact of cultured meat (Sinke et al., 2023). The techno-economic analysis (TEA) focused on providing a model of the costs of the goods sold, based upon production technologies and costs for inputs. Thereafter, different scenarios were formulated and researched, based on the future, to examine the effect on the costs of cultured meat (Odegard et al., 2021). Both papers used 1 kilogram of cultured meat as a functional unit. The two papers are used as the basis to describe the cultured meat production chain and the TCA analysis.

2.3.1.System boundaries

Figure 5 provides the system boundaries used in the LCA (Sinke et al., 2023). Ideally, to calculate the true price of one f.u. of cultured meat, the true price should be calculated over the whole supply chain: from all upstream processes to the consumer. As in both the TEA and the LCA, the processes after creating edible tissue were left out of the scope, this same assumption will be followed in this thesis. In addition, including all five upstream processes in the true price of cultured meat, is not achievable in the given timeframe. Therefore, it has been decided to only model the true price of the cultured meat production facility and the production of cell culture medium ingredients.

Figure 5

Cultured meat production process flowchart representing the base for the TCA analysis (Sinke et al., 2023). For some TCA impact categories, only the steps outlined in red are included.



[1] The medium ingredients that are included weigh> 30 grams per kilogram of cultured meat.

Whenever possible, in the true price analysis of cultured meat, the LCA of Sinke et al. (2023) will be used. This implies that if the results of this LCA are used, all processes within the system boundary will be included instead of only the production of cell culture medium and the cultured meat production facility (figure 5). Whenever this LCA is used, the results are based on an ambitious benchmark energy mix and a baseline medium ingredients, unless specified otherwise.

2.3.2.Functional unit

The chosen f.u. is 1 kg of cultured meat. Not every kg of cultured meat is the same, the protein and dry matter content differ per LCA. As Sinke et al. (2023) is chosen as a benchmark LCA, that f.u. will be followed: 1 kg cultured meat containing 20-30% dry matter and 18-25% protein. Table 5 shows the cell culture medium that is needed to produce one f.u. of cultured meat.

It has been decided to only include medium ingredients with a value >30 grams in the TCA analysis because of the limited availability of time. Therefore, all components < 30 grams are excluded from the true price model. In addition, water has been excluded. The reason for this is that both water pollution and water stress are already accounted for as impact categories in the true price model. The medium components in bold are included in the true price of cultured meat.

Table 5

The medium ingredients needed to produce 1 f.u. cultured meat. The ingredients in bold are included in the TCA analyses.

Medium ingredients	Baseline scenario (gram)
Amino acids	
Amino acids from hydrolysate	**283**
Amino acids from conventional production	**212**
Sugars	
Pyruvate	2
Glucose	**398**
Recombinant proteins	3
Salts	**224**
Buffering agents	26
Vitamins	2
Growth factors	<<1
Water	44
Total (gram)	46
Total (Liter)	47

2.3.3. Data

Sinke et al. (2023) interviewed people from the industry, both companies and research institutes to gather data and to make an estimate of how cultured meat production would look in 2030. A list is provided of all the companies interviewed. In addition to data acquired from these interviews, other research papers are used. In the supplementary materials, it has been cited which data sources they used for which step of the analysis and whether papers and/or data have been cross-checked. However, problems arise when trying to trace back information on where the different components are produced and which assumptions are made in the production process of these components. It only has been stated which papers have been used, not which data has been used from which paper and how this has been contributed to the final LCA (Sinke et al., 2023). Therefore, using the cited papers and own assumptions, supported by literature, reference frameworks have been developed that will be used throughout the TCA analysis.

2.3.4. Conversion rates

For both cultured meat and conventional meat, the following conversion rates will be used:

- From USD to euro: 0.92, 18 December 2023 (Wisselkoers, n.d.-a).
- From Brazilian Real to euro: 1 Brazilian real equals 0.19 euro, 18 December 2023 (Wisselkoers, n.d.-b).
- From Yuan to euro: 1 yuan equals 0.12 euro, 18 December 2023 (Wisselkoers, n.d.-c).

- From pounds to euro: 1 pound equals 1.16 euro, 4 January 2024 (Wise, n.d.).

2.3.5. Allocation

In the case of some impact categories, the calculated true costs for different production stages need to be allocated among the different outputs of the production stage. Two different types of allocation methods can be defined: physical allocation and economic allocation. In the case of physical allocation, the system and the assigned impact are divided among different co-products using the physical relation between the products such as mass or energy content (Michiels et al., 2021). In the case of economic allocation, a market value needs to be assigned to every product to calculate the economic value of every co-product. The system and calculated impact are divided using the economic value of every value (Cherubini et al., 2018). Allocation is a widely used method in LCAs. It has been shown that the allocation method has an impact on the results of a LCA as the value for one or more impact categories may alter when choosing another allocation method (Cherubini et al., 2018). This results in different outcomes and consequently conclusions for apparently the same system.

In the case of TCA, the proposed method is economic allocation (True Cost Initiative, 2022; Galgani et al., 2023). To illustrate this with an example: a farm that produces 1 ha of maize. This hectare of maize is x % of the total farm income. If the true costs of OHS of the farm equals y euro, x % of the y euros can be allocated to the 1 hectare of maize. If allocation needs to be applied on a certain production stage, it will be specified in the reference framework.

2.3.6. Salt production

Salt is assumed to be produced in China as they have the largest market share in salt production in 2022 (Statista, 2023f). In 2022, they produced 49.85 million mt salts (SMM, 2023). The salt production in China is a monopoly; there is only one company producing salt. This company employs approximately 48476 workers (IPP Journal, 2022). Based upon this data, it is estimated that every employer produces 1028 mton annually. It is assumed that no allocation is necessary.

2.3.7. Hydrolysate amino acids

Hydrolysate amino acids are produced using soy as a medium ingredient. It is assumed that soy is produced in Brazil, as Brazil was the largest producer of soy in 2022 (Statista, 2023a). It has been shown that soy flour contains 50% hydrolysate amino acids (Ernster, 1990). In addition, 780 kg of soil meal can be extracted per ton of seeds (Fine et al., 2015). Therefore, to produce 212-gram hydrolysate amino acids, 212*2*(1000/780) = 544-gram soy seeds is needed. The soybean yield in Brazil equals 3.5 tons per ha (Statista, 2023b). 262000 individuals work in the soy plantations in Brazil, producing 155,7 million tons of soy in 2021 (DIEESE, 2022; OEC, n.d.). To go from soy seeds to hydrolysate amino acids, additional production steps are needed. These additional steps are not included in the true costs model. It is assumed that no allocation is needed because it is assumed that the soy farmers only produce soy and no other agricultural outputs of the farm.

2.3.8. Conventional amino acids

Conventional amino acids are produced from wheat and maize (Mattick et al., 2015; Marinussen & Kool, 2010). It is assumed that wheat and maize are produced in the Netherlands. A 50% mass ratio is assumed, hence 50% of the mass of conventional amino acids comes from the wheat and 50% from the maize. To produce 71 grams of conventional amino acids, 35 grams of wheat and 36 grams of maize are needed. It is assumed that per ha, 3 people work on the production of maize and 3 people on the production of wheat. The maize yield equals 12.1 tons per ha. The yield of wheat equals 9.6 tons per ha (Centraal Bureau Statistiek, 2023). To go from maize and wheat to conventional amino acids, additional production steps are needed. These additional steps are not included in the true costs model.

The wheat and maize production (1 ha production each) are only a part of the expected farm outputs and therefore, income. It is assumed that 5% of the economic value of the farm can be allocated to 1 ha of maize and 5% to 1 ha of wheat.

2.3.9. Glucose

Maize is used as input material to produce glucose. To produce 398 grams of glucose, 398* 1,34= 533,32 grams of whole maize is needed. (Round table on responsible soy, 2022). It is assumed that the maize is produced in the Netherlands. In addition, it is assumed that the people (or farm) who produce the maize for conventional amino acid production also produce the maize for glucose production. The same holds for the production: the maize for the production of conventional amino acids is from the same hectare as the maize for glucose production. To go from maize to glucose, additional production steps are needed. These additional steps are not included in the true costs model.

2.3.10. Cultured meat production facility

The cultured meat production facility data is based on the facility described by Odegard et al. (2021). Based upon interviews with the industry, it is formulated how a production facility in 2030 would function. Below, the important data from this paper is listed that is used in the true costs model.

- Staff: 24/7 operation of the plant, 200 full-time equivalents.
- Salary: 100 dollars per hour
- Location: Utrecht, the Netherlands.
- Output per 42 days: 3080 kg of cultured meat. This gives the total output per year of 26766.7 kg per facility.

Figure 5 shows that there are different output flows: spent medium and other (bio) wastes, cell-based meat, and cleaning waste. It is not specified what spent medium, other bio, and cleaning wastes exactly are. Therefore, it is assumed that the economic value of those products equals 0. Therefore, the impacts can be fully allocated to the cultured meat production facility.

2.4. Conventional meat

In this thesis, conventional meat is cattle beef that is produced in vivo. The impacts of conventional meat have been researched many times. A review article published in 2015 has found 41 peer-reviewed LCAs on beef production (De Vries et al., 2015). These LCAs differ in functional unit, all of them used a kg of meat, but some of them focused on carcass weight, others on live weights or bone-free meat. Other differences between the LCAs are the origin of the calves, country of production, whether the cows received hormonal growth factors, organic vs non-organic systems, and type of diet. This consequently influenced the results of the LCA.

Because of the wide variety of LCAs in conventional beef meat, a reference model defined by Van Paassen et al. (2019) is used. This reference model is also used by Mattick et al. (2015) and Sinke et al. (2023) in their LCAs on cultured meat. The system is described as: ''Agri-footprint: Beef meat, at slaughterhouse Economic (Ireland)'' (Mattick et al., 2015). Sinke et al. (2023) adjusted this reference system in such a manner that it is predicted to fit a 2030 scenario using several ambitious benchmarks:

- Methane emissions from enteric fermentation: -15%, additional input is used: enzymes.
- Additional outdoor grazing resulted in ~5.4% lower NH_3 emissions.
- Sustainable energy (electricity and heat) at farm and in feed compound production and soybean production.

To match the 2030 scenario defined for cultured meat, this adjusted version of the reference model is used and consequently, the results from Sinke et al. (2023) are used.

2.4.1. Functional unit

The f.u. is 1 kg of beef cattle meat.

2.4.2. System boundaries

Utilizing a standardized reference model, the specified boundaries will be used in the TCA analysis for conventional meat. The boundaries are from cradle to gate, and all upstream production processes and transport are included in the scope (Sinke et al., 2023). To calculate the true costs of all these upstream processes in the given timeframe is not realistic. Therefore, the decision has been made to only calculate the true costs of feed production processes, on-farm growing of the cow, and the slaughterhouse.

The system produces 117000 kg of meat per year (van Paassen et al., 2019). The yearly feed input to produce this quantity is shown in Table 6. In addition, the feed input required per kg of meat is shown. In Appendix 3, the elaborate version is shown with intermediate calculations.

It is assumed that the feed input per kg of meat with a value <0.03 has an insignificant impact on the true costs of conventional meat and is therefore left out of the TCA analysis. Whenever possible, the results from the LCA of Sinke et al. (2023) will be used. This implies that if these results are used, all upstream processes and transport will be included instead of only selected feed production, and on-farm growing of the cow and the slaughterhouse. The ambitious benchmark energy mix is used during the production process of one f.u. of conventional meat.

The system that will used in the TCA analysis of conventional meat is shown in Figure 6. This system will be used if the LCA by Sinke et al. (2023) cannot be used. Figure 6 also shows in which country the production steps take place which is specified by Van Paassen et al. (2019).

Table 6

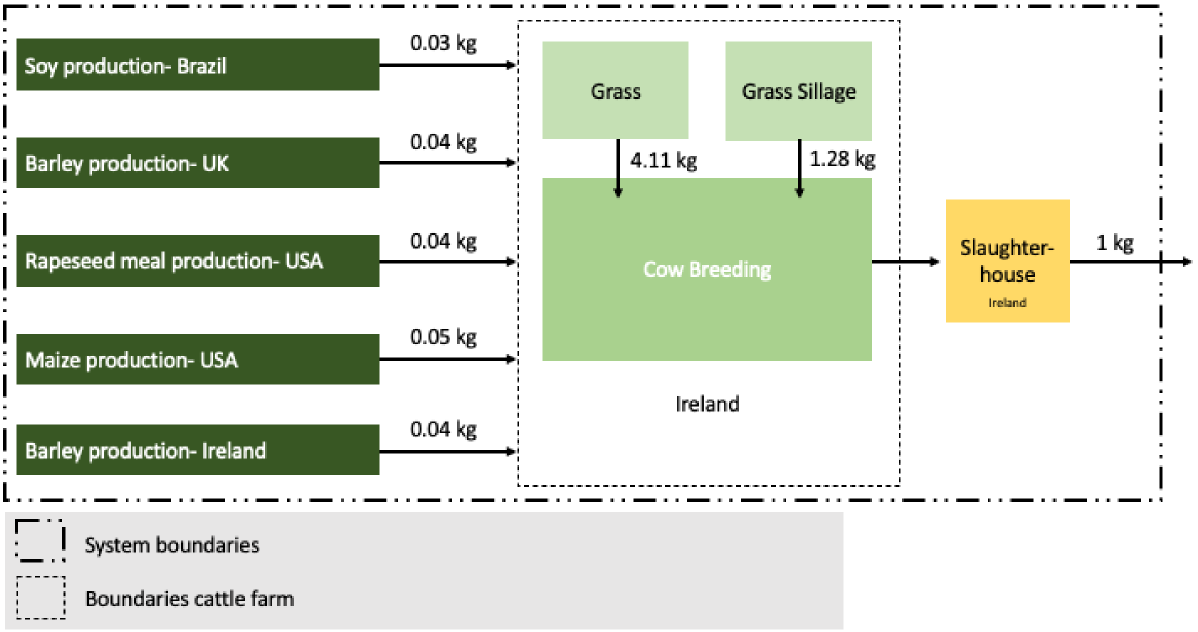
Feed input for a cattle farm with an annual output of 11700 kg of meat. In addition, feed is required to produce 1 f.u. of conventional meat.

Feed product	Feed farm input [kg]	Feed per f.u. conventional meat [kg]
Grass	480774	41.09
Grass silage	149490	12.78
Barley	8839	0.38
Wheat	2743	~~0.02~~
Molasses	1524	~~0.01~~
Rapeseed meal	4572	0.04
Oats	2743	~~0.02~~
Soy	3658	0.03
Maize	6401	0.06
Total	**660744**	**55.87 (excluding those with a value <0.03)**

It should be noted that this is a simplification of reality. It does not include waste streams, the steps between the feed production and the farm, or recycling practices.

Figure 6

The flow system used for the TCA model of conventional meat includes different outputs and producing countries.



2.4.3. Soy

Soy is produced in Brazil. 262000 individuals work in the soy plantations in Brazil, producing 155,7 million tons of soy in 2021 (DIEESE, 2022; OEC, n.d.).

2.4.4. Barley

Barley is produced in both the United Kingdom and Ireland (50/50 mass ratio). It is assumed that three people work on one-hectare barley production creating a yield between 5.8 for spring barley and 6.6 for winter barley (Strutt & Parker, 2020). It has not been defined on whether spring or winter barley is given to the cows. Therefore, an average of 6.2 tons per ha is taken. Barley production needs to be economically allocated among the farm the outputs. It is assumed that 1 ha of Barley production accounts for 5% of the farm income.

2.4.5. Rapeseed meal

Rapeseed meal is a byproduct of rapeseed oil production as both products are made from rapeseeds. Economic allocation has been chosen to define the fraction of the true costs that can be allocated to rapeseed meal production. Table 7 shows the quantities, prices, values, and allocation factors associated with rapeseed meal production. 1000 kg of rapeseed is used as input material. Other byproducts of rapeseed products are not included. Therefore, it is a simplification of reality.

It is assumed that three people work on the production of one hectare of rapeseed. The yield equals 1.46 tons per ha (Our World in Data, 2021). Rapeseed production needs to be economically allocated among the farm the outputs. It is assumed that 1 ha of Rapeseed production accounts for 5% of the farm income.

2.4.6. Maize

Maize is produced in the USA. It is assumed that three people work on the production of one hectare of maize. The yield equals 12 tons per ha (Langemeier & Zhou, 2022). Maize production needs to be economically allocated among the farm the outputs. It is assumed that 1 ha of maize production accounts for 5% of the farm income.

Table 7

Allocation factor of rapeseed meal

Product	**Quantity [kg]**[1]	**Economic value [euro/ton product]**	**Value [euro]**	**Allocation factor**
Rapeseed oil	549	439.50[2]	241.29	0.62
Rapeseed meal	419	339[3]	142.04	0.37
Sum				1.00

[1](Fine et al., 2015), [2] (Trading Economics, 2024) and [3] (TESEO, 2023)

2.4.7. Cattle farm

Figure 6 shows that the production of grass and grass silage take part on the cattle farm. It is assumed that three individuals work on this cattle farm and that these individuals are also responsible for providing grass and grass silage to the cows. The cattle farm is located in Ireland. The cattle farm produces 11700 kg of live-weight meat per year (van Paassen et al., 2019). This implies that per kg of meat, 0.0003 workers are needed.

2.4.8. Slaughterhouse

The live weight output of a farm is separated into fresh meat, food grade, feed grade, and other at the slaughterhouse (Van Paassen et al., 2019). The following mass ratios can be found:

- Fresh meat 45.8%
- Food grade 18.7%
- Feed grade 14.1%
- Other 21.4%

Fresh meat is the desirable product that will be compared to cultured meat, the other products are by-products. These by-products entail a large fraction of the total mass and therefore, it is needed to use allocation. The following economic values can be found in euros per kg product:

- Fresh meat 4.00
- Food grade 0.30
- Feed grade 0.05
- Other 0.00

Table 8 shows the economic impact allocation per product. The table implies that 96.7% of the total economic value can be allocated to fresh meat production. This value will also be used in the TCA analysis when allocation is needed.

The slaughterhouse is located in Ireland. 11700 people worked in the red meat sector in Ireland in 2017. The red meat sector consists of pork, sheep, and cow meat (Irish Congress of Trade Unions, 2021). Table 9 shows the quantities of slaughtering per type of meat per year. It is not defined what slaughtering means. Therefore, it is assumed that slaughtering means live weight.

Table 8

Allocation factors of meat

	Mass per year [kg]	Economic value	Allocation factor
Fresh meat	5359	21434,40	0.967
Food grade	2188	656,37	0.003
Feed grade	1650	82,49	0.004
Other	2504	0,00	0.0
Total	*11700*	*22173,26*	*1.00*

Table 9

Quantity of meat production in Ireland per year.

Type of meat	**Quantity [1000 tonnes]**
Beef and veal	617
Pork	294
Sheep	67
Total	*978*

Based on this data, it is predicted that 0.00001 employees in a slaughterhouse produce 1 kg of meat.

3. Method

3.1. Baseline and scenario analysis

The true price of cultured and conventional meat has been calculated using the baseline scenario described in chapters 2.3 and 2.4. The framework used to calculate the true costs for the different impact categories is formulated in Chapter 2.1.

In addition, to the baseline scenario, a scenario analysis has been performed on the true price of cultured meat. The scenarios were formulated around two main differences with the baseline scenario: 1) the type of energy mix that was used and 2) the quantity of medium input that is required. The scenarios were compatible with the LCA used in the baseline scenario and the TEA analysis of cultured meat (Sinke et al., 2023; Odegard et al., 2021). Hence, the results from this LCA and the TEA were used. The following scenarios were defined:

1) Baseline scenario: ambitious benchmark + medium input
2) Ambitious benchmark + low input
3) Ambitious benchmark + high input
4) Renewable scope 1+2 and low input
5) Renewable scope 1+2 and medium input
6) Renewable scope 1+2 and high input
7) Global average energy and low input
8) Global average energy and medium input
9) Global average energy and high input

The following definitions for the different energy mixes were defined:

- ''Ambitious Benchmark 2030: Renewable energy for scope 1, 2, and 3 (scope 3 modeling only for culture medium ingredients, scaffold, filters, and water purification)
- Renewable scope 1 and 2: Renewable energy for scope 1 and 2 (at the facility), average mix for scope 3 (upstream)
- Global average energy: Global average energy mix for scope 1, 2, and 3'' (Sinke et al., 2023, p. 241)''

3.2. Data

If applicable, data and/or results from the LCA and TEA analysis were used for the calculations of the true price of cultured and conventional meat (Sinke et al., 2023; Odegard et al., 2021). If the data from these papers did not meet the data required for the TCA method, data from other sources were used together with assumptions. The other sources consisted of scientific papers, grey papers, and open data sources such as the World Bank or websites. Scientific papers were preferred over grey papers, grey papers over open data sources, and so on. However, if high-quality data sources were not available, lower-quality data was used to have any data to work with. In addition, several assumptions were made related to the production processes.

3.3.Method deviations from the TCA method

Chapter 2.1 presents the method and framework that was used to calculate the true costs of cultured and conventional meat. However, sometimes deviations have been made from the proposed metrics to make them compatible with LCA results. If there was a deviation, it will be described per impact category how it deviated from the proposed metrics.

3.3.1.Soil erosion

In LCAs, the land use to produce a certain f.u. of product was given in m2 crop area. The total land use per f.u. was divided among the input factors, medium ingredients, or feed for the cows. The input factors were assumed to be produced in a certain country. For every country, it has been decided what the expected soil erosion is (Borrelli et al., 2017). The soil erosion in a country is displayed in a range and large differences exist within countries. Therefore, an expected soil erosion range has been taken if necessary. The land use area per input factor, measured in m2, was multiplied by the expected soil erosion range. Resulting in a true cost range.

3.3.2.Water stress

In the proposed metrics, only water use for irrigation and water use during the processing phase were considered. LCAs give the total water use within the boundaries of the system. Therefore, more production steps were included than only the water used for irrigation and the processing phase.

3.3.3.Water pollution

LCAs measure water pollution in terms of freshwater eutrophication [kg P eq] and marine eutrophication [kg N eq]. The results from these impact categories were multiplied by the monetization factor of P eutrophication and the monetization factor of N eutrophication.

3.3.4.Eutrophication

This impact category is about terrestrial eutrophication. Terrestrial eutrophication has not been included in the LCA by Sinke et al. (2023). Therefore, eutrophication has been left out of the true cost analysis.

3.3.5.Eco-toxicity

The proposed metrics measure eco-toxicity in terms of Cu-eq. LCAs measure eco-toxicity in terms of 1,4-DCB-eq. LCAs specify three impact categories on eco-toxicity: freshwater, marine, and terrestrial. A conversion factor from 1,4-DCB eq to Cu eq was not found. Therefore, it has been decided to use other monetization factors (table 10).

Table 10

Monetization factors for eco-toxicity

Eco-toxicity	**Monetization factors [EUR/1,4-DCB eq]** (True Price Foundation, 2021)
Freshwater	0,0406
Marine	0,0019
Terrestrial	0,0003

3.3.6. Human toxicity

The proposed metrics measure eco-toxicity in terms of Cu-eq. LCAs measure eco-toxicity in terms of 1,4-DCB-eq. Therefore, it has been decided to use conversion factors from 1,4-DCB eq to DALY. A differentiation has been made between carcinogenic and non-carcinogenic human toxicity.

The following conversion factors were found (Huijbregts et al., 2016):

- Carcinogenic: 0,00000332 DALY/kg 1,4-DCB eq
- Non-carcinogenic 0,00000000665 DALY/kg 1,4 DCB eq

3.3.7. Living wage gap

The proposed metrics used month as a timespan for the living wage gap. This gave issues with allocation as all the outputs were measured per year. Therefore, it has been decided to adjust the timespan to a year. Hence, all the monthly wages were multiplied by 12.

4. Results

The results of this thesis can be divided into four sub-chapters. Firstly, the baseline scenario of the true price of cultured and conventional meat. Thereafter, a scenario analysis including both private and the true costs of cultured meat. Subsequently, an overview will be provided of several input requirements when comparing conventional and cultured meat when the production scales up in the Netherlands. Finally, the issues and challenges that were found during the application of TCA will be described. All the intermediate calculations can be found in appendices 2 and 3. Appendix 4, shows the difference in data input between the baseline scenario and the different scenarios.

4.1.True costs baseline scenario cultured meat

Natural capital

GHG emissions

Table 11 presents the results of the different LCAs on cultured meat and the global warming potential. A problem arises when trying to compare the GWP_{100} of conventional meats and cultured meat. Cultured meat production is an energy-intensive process; to produce one f.u. cultured meat 164 MJ energy is needed. This high energy demand consequently causes 84% of the GHG emissions emitted during the production of cultured meat to be CO_2. CO_2 is a long-term climate gas with a lifetime of over 100 years. Consequently, the warming effects of CO_2 add cumulatively over time (Del Prado et al., 2023).

On the contrary, beef production systems are associated with higher relative quantities of CH_4 and N_2O emissions. These GHGs have a higher initial impact, but CH_4 breaks down after around a decade, and the warming effect of this gas over time, by the natural atmospheric removal processes for the given gas. N_2O is removed after around 100 years and the decay of temperature impact is still slow, but still much higher than CO_2.

These differences in emission patterns make it difficult to compare the climate change impact of cultured meat and beef. This is illustrated by a paper by Pierrehumbert and Lynch (2019). They modeled different beef and cultured meat consumption scenarios over a period of 1000 years and suggested that over the long term, the climate change impact is higher on cultured meat because of the high amount of CO_2 emissions associated with cultured meat. This is all despite having a lower GWP_{100} value. Critique on this scenario analysis is that the land use change (and corresponding emissions) of beef and decarbonization of the energy net were not considered.

Table 11

GWP100 Potential (CO2-eq) of 1 kg meat

Beef	Pork	Chicken	Cultured meat	Reference
30.5	4.1	2.3	7.5	(Mattick et al., 2015)
			4.88-25.19[1]	(Tuomisto et al., 2022)
34.9	5.08	2.74	2.82[2]	(Sinke et al., 2023)

[1] Depends on the scenario. 25.19 is the baseline scenario, and 4.88 is a scenario with improvements made in the production process, among which the energy mix and culture medium.
[2] Ambitious benchmark energy mix and baseline medium scenario.

These differences in emission patterns make it difficult to compare the climate change impact of cultured meat and beef. This is illustrated by a paper by Pierrehumbert and Lynch (2019). They modeled different beef and cultured meat consumption scenarios over a period of 1000 years and suggested that over the long term, the climate change impact is higher on cultured meat because of the high amount of CO_2 emissions associated with cultured meat. This is all despite having a lower GWP_{100} value. Critique on this scenario analysis is that the land use change (and corresponding emissions) of beef and decarbonization of the energy net were not considered.

1 f.u. of cultured meat is associated with the following GHG emissions: 2.82 kg CO2 equivalent (Sinke et al., 2023). The true costs of the GHG emissions of cultured meat equals €0.33.

Carbon stock

The impacts of the production of cultured meat on the carbon stock in the soil and tree biomass largely depend on the production of input materials such as soy, wheat, and maize. Land use change and management practices both influence the carbon content in the soil. It depends on many factors such as fertilizer application, tillage or no-tillage, crop rotation, soil type, the usage of cover crops, temperature, and precipitation (Gan et al., 2014; Joshi et al., 2023; Lü et al., 2018; Mohammed et al., 2021). All these different factors influencing the soil organic carbon content in the soil makes it rather difficult to calculate the true costs of carbon stock. Therefore, carbon stock has been left out of the true price analysis of both cultured and conventional meat.

Soil erosion

Cultured meat has a land use of 2.48 m2 crop area per f.u. (Sinke et al., 2023). This crop area needs to be divided among the production stages and medium input. Sinke et al. (2023) did not divide the land use among production stages or input medium. Therefore, results from another LCA on cultured meat are used to define the land use per input and production stage (Mattick et al., 2015). The results are summarized in Table 12.

Table 12 shows that the land use can mostly be assigned to agricultural input production. Therefore, the land use of other production stages is assumed to be neglectable and are excluded. Table 12 also presents the land use per input. The names for the different input ingredients differ from the names used in the baseline scenario description. Hence, these names are also included in a column to provide clarity. In addition, percentages of land use per medium ingredient as a percentage of the total land use are given. These percentages presented in this table will be used to divide the land use defined by Sinke et al., (2023), which equals 2.48 m2 crop area.

Table 12

Land use of cultured meat per production stage and medium ingredient

Total land use	*5.5 m2a*		
	Land use area [m2a]	**Percentage of total land use [%]**	**Comparison table 5**
Land use per production stage			
Agricultural input	5.4		
Feedstock processing	0.02		
Transport	--		
Cell cultivation	0.01		
Facility	0.02		
Cleaning	0.01		
Waste products	--		
Land use per medium input			
Water for culture	0.01	0.2	
Glucose	1.58	28.9	*Glucose*
Glutamine	0.40	7.3	*Conventional amino acids*
Soy hydrolysate	1.74	31.9	*Hydrolysate amino acids*
Basal media	0.12	20.5	*Salts and conventional amino acids*
Cleaning	0.01	0.2	
Transport	--		
Facility	0.02	0.4	
Agitation	--		
Aeration	--		
Microcarrier beads	0.58	10.6	*Not included*
Waste products	---		

Basal media is a media containing around 50 different individual components among which are amino acids, glucose, salts, and vitamins (Mattick et al., 2015). Because of the diversity of these components, it is not possible to estimate which component contributes to the 0.12 m2a land use. Therefore, it is roughly assumed that 50% can be designated to conventional amino acids and glucose. The land use associated with salt is assumed to be neglectable as explained below.

Salt

It is estimated that 4.2 ha per salt production unit is needed. In addition, the output of one production unit is 50000 tons/year. The lifetime of a production unit is 50 years. Total production is therefore 50000*50= 2500000 tons. 2500000 ton/4.2 ha = 595238 ton/ha= 5.95*10^11 gram/ha (Althaus, Chudacoff, et al., 2007, p. 671-679). The input of salt in cultured meat is 224 grams which equals 3.67*10^-10 ha. Therefore, the land use associated with salt is neglectable.

Hydrolysate amino acids

Table 12 shows that 31.9% of the total land use can be designated for the production of hydrolysate amino acids. This equals 0.319*2.48= 0.79 m2. The production of hydrolysate amino acids takes place in Brazil. A figure by IBGE- produção agrícola Municipal (2019) displays the soy production per region Brazil (appendix 1). In the region where the annual soy production is the highest, the soil erosion is between 0-20 Mg per ha per year (Borrelli et al., 2017). To illustrate this, values of 0-20 Mg per ha per year will be taken to show the effect of the true costs.

Conventional amino acids and glucose

The land use associated with conventional amino acids and glucose equals 28.9%+7.3%+(0.5*20.5%)= 46.45%. 0.4645*2.48= 1.15 m2. The factor 0.5*20.5% assumes that half of the land use associated with the basal medium can be allocated to conventional amino acids. The maize and wheat production are located in the Netherlands. Therefore, the soil erosion factor of the Netherlands is taken which equals 250 kg/ha/year (Panagos et al., 2014). According to Borrelli et al. (2017), soil erosion in the Netherlands is between 0 and 1 Mg per ha per year. This indicates that 250 kg/ha/year is a reasonable estimate.

The results show that the true costs of soil erosion of cultured meat are between €0.00 and €40.58, depending on the value taken to calculate the soil erosion of hydrolysate amino acids.

Water stress

Cultured meat production is associated with a water use of 0.253 m^3 (Sinke et al., 2023). The water use takes place in both the Netherlands, Brazil, and China as there the medium ingredients are produced or the production of cultured meat takes place.

The following numbers can be found related to subdividing the water use:

- 44.7 dm3 = 0.04 m3 as medium ingredient
- 10000 L for cleaning= 10 m3 for 3080 kg cultured meat. 0.003 m3 per kg cultured meat
- Cleaning the meat 0.002 m3
- To produce 1000-gram hydrolysate amino acids, 17857-gram water is needed (Mattick et al., 2015).

Based on this information, it is difficult to estimate which fraction of the water use takes place where and to consequently find the Aquaduct baseline water stress factor for a country or region (Aqueduct, n.d.). Therefore, the assumption has been made that all water use takes place in Utrecht, the Netherlands. In Utrecht, the water stress is <10%. It has been not indicated how to use this percentage as a water stress factor. Therefore, it is assumed that the factor equals 0.1.

Based on this information the true costs of water stress of cultured meat equals €0.01.

Water pollution

To indicate the true costs of water pollution, the impact categories freshwater and marine eutrophication have been used (Sinke et al., 2023). The following values can be found for both impact categories:

Freshwater eutrophication	0.001 kg P eq
Marine eutrophication	0.00129 kg N eq

To these values, a monetary value has been assigned giving a true cost of water pollution of €0.02.

Acidification

1 f.u. of cultured meat emits 0.0175 kg SO_2 eq (Sinke et al., 2023). This gives the true cost of acidification of €0.15.

Eco-toxicity

During the production of cultured meat, chemicals are emitted into marine water, freshwater, or terrestrial soil that have an impact on the species there. Table 13 presents the monetization factors and values that have been found.

Based on this information, the true costs of eco-toxicity equal €0.02.

Human Capital

Human toxicity

The following values can be found for human toxicity: carcinogenic human toxicity: 0.127 kg 1,4-DCB-eq and non-carcinogenic human toxicity: 2.25 kg 1,4 DCB-eq. This results in a true cost of human toxicity of €0.03.

Living wage

Salt

No data have been found on the salt industry in China and their wages. China has a minimum wage per province that is based on the concept that the minimum wage is as high as the wage that there would be no poverty for a family. This minimum wage excludes overtime and there is an indication that a part of the workers are not being paid for the overtime (Xu et al., 2014). It is estimated that the living wage in China equals (634+504)/2= 569 dollars, with 1.8 workers per family (Andersen et al., 2023a; Andersen et al., 2023b). This implies that every worker should earn 569/1.8= 316 dollars (290 euros) per month to meet the living wage. There are 48476 workers in the salt industry in China and as there is no indication of what these workers earn, it is assumed that 50% earns the minimum wage and the other 50% earns more than the living wage (IPP Journal, 2022).

Table 13

Monetization factors and values of different eco-toxicity impact categories

Eco-toxicity	**Monetization factors [EUR/1,4-DCB eq]** (True Price Foundation, 2021)	**Values [1,4-DCB eq]** (Sinke et al., 2023)
Freshwater	0,0406	6,60E-02
Marine	0,0019	5,04E-02
Terrestrial	0,0003	54,8

The minimum wage in China differs per region and is somewhere between 13 and 25.3 yuan per hour (1.67 and 3.25 euros) (Statista, 2023e). Assuming a working week of 40 hours, this implies a monthly minimum salary between 267.20 euros and 520 euros. These results show that it depends on the region on whether the living wage is met. It is assumed that the workers that earn the minimum wage, earn €267.20. Based on this information, the living wage gap for the salt industry equals €0.00 per f.u. of cultured meat.

Hydrolysate amino acids

The living wage in Brazil for an average household equals 806 dollars (741.52 euros) (Medinaceli et al., 2023). This implies that an individual worker should earn 436.19 euros per month if there are on average 1.7 workers per household.

It is difficult to estimate what a soy farmer earns in Brazil. The farm workers earned at least the minimum wage of 1302 Brazilian reals per month (statista, 2023i). This equals 241 euros. It is estimated that ¼ of the workers are wage workers earning the minimum salary (Martin, 2020). 98567 Brazilian reals is also mentioned as the yearly income for a farmer (18398.64 euro). This would give a monthly salary of 1533 euros (Economic Research Institute, n.d.-a) This monthly salary is above the living wage hence, it would indicate that there is no living wage gap. Another reference mentions a salary between 1350 and 4300 BRL (€253-€807) (Salary Explorer, n.d.). It is assumed that the other ¾ of the workers earn more than the living wage and therefore do not contribute to the living wage gap. For the workers who earn less than the living wage, it is assumed that they earn the minimum wage. Based on this information, the living wage gap for hydrolysate amino acid production equals €0.00 per f.u. cultured meat.

Glucose and conventional amino acids

Glucose and conventional amino acids are produced using maize and wheat from the Netherlands. In the Netherlands, it is estimated that the living wage equals 1656 euros per month for a standard family (WageIndicator Foundation, 2019b, corrected for inflation). The minimum wage in the Netherlands equals 1995 euros per month (Ministerie van Sociale Zaken en Werkgelegenheid, 2023b). A standard family in the Netherlands has 1.8 workers which gives a monthly income of 3591 euro per month. This is above the living wage hence, no living wage gap exists for a standardized family.

Cultured meat production facility

People who work in the cultured meat production facility are expected to earn 100 dollars (92 euros) per hour when working full-time (Odegard et al., 2021). This salary is above the hourly minimum wage. Hence, no living wage gap exists for the people who work in the cultured meat production facility.

Summarized, it is estimated that the true costs of the living wage gap equal €0.00.

Excessive working hours

Salt

No report can be found on the salt industry in China and the working hours.

Hydrolysate amino acids
Research shows that with a worker on average 4 hours a day on soy during the growing season on 20 hectares. 4*7 days= 28 hours of work per week. Therefore, no overtime is assumed (Zortea et al., 2018). However, this is not the farm as a whole; other parts of the farm may be more time-consuming and cause overtime. Research shows that the total working hours on a Brazilian farm are between approximately 3000/52=57 hours and 2200/52= 42 hours a week (Stratton et al., 2021)

Glucose and conventional amino acids
Netherlands, the average working hours in agriculture, forestry, and fishing in 2022 is 37.3 < 48, so no excessive working hours are assumed in the production of maize and wheat (Eurostat, 2023a).

Cultured meat production facility
As it is a 2030 scenario, no information exists yet on the (excessive) working hours of the cultured meat facility.

It is not possible to find an outcome as the value of excessive working hours in DALY is not given in the model. Therefore, the true costs cannot be calculated.

Occupational health and safety

Using this impact category according to the proposed metrics several problems arise that will be shortly discussed when these are relevant to understand the assumptions made. An elaborate discussion of these and other problems and their implications can be found in Chapter 5.

The first problem that arises is the usage of disability weights. The used method suggests that for every injury or long-term illness, a disability weight should be linked. 235 unique health states have been defined, all having their disability weight. Keeping track of these health statuses requires a lot of data and information. If an occupation is linked to for example hearing loss, 10 different health statuses can be defined all based on hearing loss. The weights of these disability weights range from a value between 0.003 to 0.7.

Searching for relevant data and information showed that it is difficult to link available data to a disability weight. To illustrate this: Stigas (2022) identified 11 agricultural incidents that happened between 2016 and 2021 in the Netherlands. The accidents are related to falling, trapping of limbs, or hitting something. To use the disability weights, you must know what the consequences are of these accidents; did the individual bruise something for example? However, this is not reported. In addition, organizations are not obligated to report accidents to Stigas. This makes it difficult to know whether these numbers are complete or not. Finally, these accidents can simply be not every illness or injury that happens because of work as only major accidents are mentioned in the report (Stigas, 2022).

Therefore, to be able to find the effect of different disability weight values on the true cost of OHS, a range of 0.2, 0.4, and 0.6 is taken as disability weights for both injuries and long-term illnesses.

Another problem that arises is the differentiation between OHS, human toxicity, and overwork hours, all different impact categories in the proposed model. Human toxicity can be referred to as ''the potential health risk of cancerous and non-cancerous effects of chemicals emitted to the environment (mainly soil and air)'' (True Cost Initiative, 2022, p. 26). The emission of chemicals that occur in a certain stage of the environment can have an impact on human health. In the case of human toxicity, the health problems and (potential) death of an individual are caused because of chemicals. However, one should be conscious because OHS also measures death and illnesses that may or may not be caused by the emissions of chemicals. If the deaths or illnesses caused by chemicals are considered in both impact categories, they will be double counted and may cause a twisted representation of the true costs.

In the case of the impact category excessive hours, the same line of reasoning can be used. Excessive working hours (> 54 hours per week), cause heart diseases, strokes, or even deaths (Pega et al., 2021). The impact of excessive working hours is already accounted for in the impact category of excessive working hours. Therefore, one should be careful to not include these diseases and deaths in the OHS impact category.

Having defined these problems, it is necessary to estimate the fraction of workers who experience death, non-fatal injuries, or chronic illnesses because of work. The following data, assumptions, and results can be found:

- 295 million workers experienced a non-fatal injury of a total of 3.27 billion workers in 2019 (Statista, 2023g; International Labour Organization, 2023). This implies that 12% of the workers will experience a non-fatal injury during work globally. It is assumed that 50% of the injuries happen because of the emission of chemicals and excessive working hours. Therefore, **6%** of the workers experience non-fatal injuries, not related to chemicals, annually.

- 160 million workers experience work-related illnesses annually of the total of 3.02 billion workers in 2011. (International Labour Organization, 2011; Statista; 2023g). This implies that 5% of the workers experience work-related illnesses annually. It is assumed that 50% of illnesses happen because of exposure to chemicals and excessive working hours. This means that **2.5%** of the workers experience illnesses that are accounted for in OHS.

- 2.93 million workers died because of work-related factors in 2019. In total, there were 3.27 billion workers in 2019 (Statista, 2023g; International labour organization, 2023). This implies that 0.09% of the workers die because of work annually. 10% of these deaths are because of injuries and 90% of diseases. It is assumed that 50% of these diseases are caused by the emission of chemicals and excessive working hours. This gives a total of **0.05%** of the workers die because of (non-chemical) work-related diseases or injuries or excessive working hours.
- The disability weight linked to death equals 1.

These percentages are used as probability indexes that individuals who work within the boundaries set in chapter 2.3, experience OHS problems.

Table 14

The true cost of OHS using different disability weights for illnesses and injuries.

Disability weights illnesses and injuries	True cost [€]
Injury 0.2, illness 0.2	573.97
Injury 0.2, illness 0.4	573.97
Injury 0.2, illness 0.6	573.97
Injury 0.4, illness 0.2	1147.92
Injury 0.4, illness 0.4	1147.92
Injury 0.4, illness 0.6	1147.92
Injury 0.6, illness 0.2	1721.88
Injury 0.6, illness 0.4	1721.88
Injury 0.6, illness 0.6	1721.88

Table 14 shows the results of the true costs associated with OHS using different disability weights. The intermediate calculations can be found in Appendix 2.

Social Capital

Gender pay gap

Hydrolysate amino acids

In Brazil, 170296.5 thousand people work in total in 2022. Of which 88113.4 thousand identify as female. This implies that 51% of the workers are female (ILOSTAT, 2023).

In Brazil, female workers earned approximately 44% less than male workers for the same work in 2023 (statista, 2023h). ¾ of the workers in soy are assumed to earn more than the living wage and therefore contribute to the gender pay gap. As already mentioned, it is difficult to estimate how much a soy farmer earns. Therefore, the rough assumption, based on the available data, is made that the females earn 2760 brl (€518) and the males 3974,40 brl (€746) per month. This gives a gender pay gap of €0.00 per f.u. cultured meat.

Glucose, conventional amino acids, and the cultured meat production facility

In the Netherlands, a total of 14629.5 thousand individuals are working in 2022. 7377.4 thousand of these individuals identify as female. This means that 50% of the workers are female (ILOSTAT, 2023). In the Netherlands, it is assumed that female workers work in the private sector. This implies that females earned on average 5 euros less than their male colleagues in 2020 (CBS, 2022b). This indication that females earn 5 euros less per hour is used on the cultured meat production plant. This implies that males earn 100*0.92=92 euros per hour and that females earn 87 euros per hour (Odegard et al., 2021).

This 5 euro average cannot be applied to the people who work on the farm producing maize and wheat. The reason for this is males are assumed to receive a salary of 2420 euros per month (Jooble, n.d.).

If females earn 5 euros less per hour, their monthly salary would be below the minimum wage equals 1995 euros per month. Therefore, it is assumed that females earn the minimum wage as a constructor who works in the agricultural sector. This minimum wage is above the living wage in the Netherlands (WageIndicator Foundation, 2019b).

Based upon this information, the gender pay gap on the cultured meat production plant equals €34.65 and, on the farms, producing wheat and maize €0.02 per f.u. cultured meat.

Salt

In China, a total of 1141071.6 thousand individuals are working in 2020. 578596.8 thousand of these individuals identify as female. This means that 51% of the workers are female (ILOSTAT, 2023). In China, it is estimated that female workers earn 28% less than males for the same work (Bai et al., 2022).

It is difficult to find wages related to salt production in China. The impact category living wage showed that is estimated that there is a living wage gap. Individuals who earn more than the living wage have a possible impact on the gender pay gap. However, as numbers cannot be found, it is left out of the true costs.

Therefore, the summed true costs of the gender pay gap equals €34.67.

Forced Labour

It is not possible to classify the workers of the supply chain of cultured meat on whether they meet these indicators or not with the available data. Therefore, global estimates are used to indicate the effect.

Soy production

In Brazil, the problem of forced labour is still of high importance. Efforts have been made to reduce the numbers, but in 2022 alone 2275 workers were rescued from forced labour (Fair Labor, 2023). These are only the rescued workers; it is estimated that the actual numbers are higher. It is estimated that 1.3 out of thousands experience forced labour in the Americas (International Labour Office, 2017). Using these numbers 262000*(1.3/1000) = 341 workers are forced into the soy industry. However, one should be conscious about using this number as there is a lack of data availability in the Americas.

Salt production

In China, it is estimated 4.0 out of a thousand people experience forced slavery (Walk Free, n.d.). 48476 workers are estimated to work in the salt industry in China, therefore 48476*(4/1000) = 194 workers are assumed to experience forced labour.

Maize and wheat production

It is difficult to find information on forced labour in the agricultural sector of the Netherlands.
It should be noted that the number of migrant workers in the European Union is increasing and that these individuals may or may not meet the criteria of forced labour (Palumbo et al., 2022; International Labour Organization, 2012). This is also the case in the Netherlands in which the migrant workers have

a high dependency on the employees. This creates an environment in which the employee may exploit the worker. As exact numbers and data are difficult to be found, it is hard to gain insight into the extent of forced labour in the Netherlands (Open Society Foundations, 2020).

It is not possible to calculate the true costs of forced labour as the value of DALY is not given.

Child labour

In the case of child labour, it is difficult to find product or even sector-specific information and consequently to have data or information to work with. Therefore, it will be discussed what kind of information can and cannot be found.

Salt

There is no information on the salt industry in China and child labour. No English papers, reports on this topic or even news articles have been found on that child labour may be the case for this industry. To research child labour in China in general; China did not report any official statistics on child labour cases that have been found by their inspection (International Labour Organization, n.d.-a). It has been shown that child labour in China cannot be neglected: 7.7% of the children between the age of 10-15 were working (Tang et al., 2018). More information is needed to link this number to the salt industry.

Soy

In the case of soy production in Brazil, it has been reported that soy production is associated with child labour (Bureau of International Labor Affairs, 2022a). However, exact numbers on child labour related to soy production in Brazil are hard or even impossible to find. It is estimated that 2.1% of the children (ages 5-14) work and do not go to school in Brazil. Half of these children work in the agricultural sector (Bureau of International Labor Affairs, 2022a). Cacao and sugarcane production have been more extensively mentioned in literature as sectors where child labour occurs (Tomei et al., 2020). Without specific numbers on child labour in the soy sector in Brazil, one should be careful to draw conclusions on this topic.

Maize and wheat

Maize and wheat are produced in the Netherlands. In the Netherlands, children till the age of 13 are not allowed to work. Children between the ages of 13 and 18 are allowed to work but have to follow strict rules. These rules prevent that child labour occurs in the Netherlands (Ministerie van Sociale Zaken en Werkgelegenheid, 2023a). It is estimated that in western, southern, and northern European countries 1.3% of all children experienced child labour in 2020 (International Labour Organization, 2021). This indicates that despite all the policies and efforts, child labour is not banned yet. However, with the available data, it is not possible to provide numbers on child labour in the agricultural sector in Western European countries.

Cultured meat plant

No information is available on child labour in the cultured meat production plant. However, because of the technical complexity of the production process, it is suggested that no child labour will occur.

4.2.True costs baseline scenario conventional meat

Natural Capital

GHG Emissions

The GHG emissions emitted during the production of conventional meat equal 0.0349 tons CO_2 eq per f.u. (Sinke et al., 2023). Consequently, the true costs of GHG emissions equal €4.06.

Soil Erosion

To determine the true costs of soil erosion, the total land use needs to be divided among different countries and/or regions. According to the assumptions defined in Chapter 2.4, the following countries contribute to the land use of conventional meat: Ireland, Brazil, the United States, and the United Kingdom. The total land use associated with conventional meat equals 0.00243 ha (Sinke et al., 2023). It is assumed that the total land use can be fully assigned to the land use for feed production. Table 15 presents the total land use divided among the countries. The intermediate calculations can be found in Appendix 3.

Based on the data in Table 15, the true costs of soil erosion is a value between €0.00 and €87.24 per f.u. conventional meat.

Water stress

Water use associated with conventional meat equals 0.253 m^3 (Sinke et al., 2023). It is assumed that all water use takes place in Ireland. In Ireland, the aqueduct baseline water stress factor has a value between 0 and 20 percent (Aqueduct, n.d.). Therefore, a median water stress factor is taken of 0.1. This results in a true cost of €0.03.

Water pollution

In the case of conventional meat, marine eutrophication equals 0.144 kg N equivalent, and freshwater eutrophication equals 0.00174 kg P equivalent (Sinke et al., 2023). This results in the true cost of water pollution €0.27.

Table 15

Land use and soil loss per country

Country	Land use [ha]	Soil loss per country [ton/ha/year][1]
Ireland	0.00238	0-1
Brazil	0.00001	0-20
United States	0.00004	0-20
United Kingdom	0.00002	0-1
Total	**0.00243**	

[1] (Borrelli et al., 2017)

Acidification

During the production of conventional meat, 0.784 kg SO_2 equivalent is emitted (Sinke et al., 2023). This results in a true cost of acidification of €6.86.

Eco-toxicity

The following values can be found regarding the eco-toxicity of conventional meat (Sinke et al., 2023):

- Terrestrial ecotoxicity: 12.8 kg 1,4-DCB equivalent
- Freshwater ecotoxicity: 0.625 kg 1,4-DCB equivalent
- Marine ecotoxicity: 0.132 kg 1,4-DCB equivalent

Monetizing these values results in a true cost of €0.03.

Human Capital

Human toxicity

The human carcinogenic toxicity is estimated to equal 0.0821 kg 1,4 DCB-eq. The human non-carcinogenic toxicity is estimated to equal 65.5 kg 1,4 DCB-eq. This results in a true cost estimate of human toxicity to be 0.04 euros.

Living wage gap

Cattle farm and Barley production

It is estimated that 1 out of 5 workers in Ireland are earning less than the living wage in Ireland. The living wage equals 14.80 euros per hour as a full-time worker (Social Justice Ireland, 2023). Currently, the minimum wage is below the living wage as it equals 12.70 per hour. In 2026, the minimum wage in Ireland will be replaced by a national living wage (Citizensinformation.Ie, n.d.). However, as this is not the case yet, it is assumed that 1 out of 5 workers working on the cattle farm earn less than the living wage. It is predicted that on average agricultural workers earn 12.91 euros per hour (Payscale, n.d.). This gives a summed living wage gap of €0.19 for the cattle farm and barley production.

Barley production United Kingdom

The living wage in the United Kingdom is estimated to be 12 pounds per hour in 2024 (Resolution Foundation, 2023). The current minimum wage (January 2024) equals 10.42 pounds per hour (GOV.UK, 2015). A farmer in the United Kingdom is estimated to earn 14.36 pounds per hour (Talent.com, n.d.). This implies that it is estimated that there is no living wage gap in the United Kingdom as a barley producer.

Soy production

The argumentation of whether there is a living wage gap associated with soy production in Brazil is the same argumentation and data as previously defined. Based upon this information, a living wage gap can be calculated that equals €0.00 per f.u. conventional meat.

Rapeseed meal and maize production

The living wage in the United States equals $25.02 per hour for a standard family (two working adults and 2 children). This implies that one individual worker should earn 12.51 dollars per hour. The living wage depends on the state and region people live in (Living Wage Calculator, n.d.). It is estimated that a farmer in the United States earns around 18 dollars per hour (USDA NASS, 2023). This is above the living wage; hence, no living wage gap is assumed.

Slaughterhouse

Individuals who work as meat processors are estimated to earn 16 euros per hour (Economic Research Institute, n.d.-b). The living wage is estimated to equal 14.80 euros per hour (Social Justice Ireland, 2023). The monthly wage is higher than the living wage which indicates that no living wage gap exists at the slaughterhouse.

Based upon these results is suggested that the living wage gap per f.u. of conventional meat equals €0.19.

Excessive working hours

Cattle farm and Barley production

In Ireland, people who work in the agricultural sector are expected to work on average 46.5 hours. This is below 48 hours hence, no excessive working hours are assumed (Eurostat, 2023a).

Soy production

Research shows that with a worker on average 4 hours a day on soy during the growing season on 20 hectares. 4*7 days= 28 hours of work. Therefore, no overtime is assumed (Zortea et al., 2018). However, this is not the farm as a whole; other parts of the farm may be more time-consuming and cause overtime. Research shows that the total working hours on a Brazilian farm are between approximately 3000/52=57 hours and 2200/52=42 hours a week (Stratton et al., 2021). However, to use this data, more information is needed such as allocation.

Barley production United Kingdom

Farming in the United Kingdom is suggested to be associated with long working hours. A report from 2018 suggested that on average the farmers work 65 hours a week (Tasker, 2018). This is above the 48-hour indication of excessive working hours.

Rapeseed meal and maize production

Agricultural production in the United States is associated with long working hours during peak season, sometimes up to 16 hours a day. On average, agricultural workers work 47.6 hours a week (Elliott et al., 2022). This is a yearly average as during peak season the average hours per working week are higher. However, the yearly average of 47.6 is below 48 hours a week, hence, on average no overtime is assumed.

Slaughterhouse

It is difficult to estimate the average working hours per week for the people who work in the slaughterhouse. 56% of the migrant workers say that they work over 40 hours a week and some indicate that they work more than 55 hours a week. 42% of individuals who work in the meat processing sector are migrants (Migrant Rights Sector Ireland, 2020). These numbers suggest that a part of the workers in the meat processing sector experience working hours above 48 hours a week.

The same problem arises again. The DALY value for overtime is not known and therefore it is not possible yet to calculate the excessive hours impact.

Occupational health and safety

In the case of conventional meat, the same fraction of workers who experience OHS problems will be used as defined in Chapter 4.1. The results found in that chapter can be summarized as the following:

- **6%** of the workers experience non-fatal injuries, not related to chemicals, annually.
- **2.5%** of the workers experience illnesses that are accounted for in OHS.
- **0.05%** of the workers die because of (non-chemical) work-related diseases injuries or excessive working hours.

These percentages will be used as probability indexes that individuals who work within the boundaries set in chapter 2.4, experience OHS problems. To be able to find the effect of different disability weight values on the true cost of OHS, a range of 0.2, 0.4, and 0.6 is taken as disability weights for both injuries and long-term illnesses.

The true costs of OHS of conventional meat using different disability weights can be found in Table 16.

Table 16

True costs of OHS and safety using different disability weights for injuries and illnesses.

Disability weight	True costs OHS and safety [€]
Injury 0.2, illness 0.2	326.58
Injury 0.2, illness 0.4	326.59
Injury 0.2, illness 0.6	326.60
Injury 0.4, illness 0.2	651.47
Injury 0.4, illness 0.4	651.48
Injury 0.4, illness 0.6	651.49
Injury 0.6, illness 0.2	976.35
Injury 0.6, illness 0.4	976.36
Injury 0.6, illness 0.6	976.37

Social Capital

Child Labour

Cattle farm, barley production, and the Slaughterhouse

The cattle farm and the slaughterhouse are located in Ireland. Barley production takes place in the United Kingdom and Ireland. Both countries are Western European countries. It is estimated that in western, southern, and northern European countries 1.3% of all children experienced child labour in 2020 (International Labour Organization, 2021). However, as already mentioned in Chapter 4.1, it is difficult to link this percentage to the agricultural sector in these countries, and therefore, it is difficult to predict child labour on cattle farms or during the production of barley. The same line of reasoning can be applied to child labour in the slaughterhouse.

Soy production

In Chapter 4.1, available information on child labour during the production of soy can be found.

Rapeseed meal and maize production

Rapeseed and maize are produced in the United States. In the United States, it is suggested that child labour is increasing as the labour market is tight. Several newspapers and reports provide examples of child labour in the United States with some cases of children performing hazardous work (Economic Policy Institute, 2023; Reuters, 2022). In addition, efforts are being made by some states to weaken child labour laws (Sainato, 2023). However, the same problem arises as it is difficult to link the estimated increase in child labour back to maize and rapeseed production.

Gender Pay Gap

To calculate the gender pay gap, it is needed to know which percentage that work is female and which percentage is male. If possible, sector-specific data is used. If that data cannot be found, country average data is used.

Cattle farm and Barley Production

- In Ireland, 88% of the farmers are male and 12 % are female (IFA, 2019).
- In Ireland, males are estimated to earn 5.7% more than females (Department of Public Expenditure and Reform, 2022). In addition, it is estimated that on average agricultural workers earn 12.91 euros per hour (Payscale, n.d.). Therefore, it is assumed that females earn 12.17 euros per hour.

Barley production United Kingdom

- In the United Kingdom, there were approximately 68000 females in agriculture, fishery, and forestry of the total of 268000 employers. Based on this data, it is suggested that 25.4% of the workers are female (statista, 2023j).
- In elementary agricultural occupations, females earn 4% less than men (Office for national statistics, 2023). A farmer in the United Kingdom is estimated to earn 14.36 pounds per hour (Talent.com, n.d.). Based on this data, it is assumed that female farmers earn 14.04 pounds per hour (€16.26).

Soy production

- In Brazil, 170296.5 thousand people work in total in 2022. Of which 88113.4 thousand identify as female. This means that 51% of the workers are female (ILOSTAT, 2023).
- In Brazil, female workers earned approximately 44% less than male workers for the same work in 2023 (statista, 2023h). In Brazil, soy farmers earn at least 1302 Brazilian reals per month. This equals 241 euro per month. Assuming 40 hours of work a week, this equals an hourly salary of 1.50 euros. It is assumed that male workers earn 44% more, hence 1.50*1,44= 2.17 euro (Statista, 2023h).

Rapeseed meal and maize production

- 36% of the farmers are suggested to be female (U.S. Department of Agriculture, 2023).
- In the United States, females are estimated to earn 5-6% less than male workers (Fisher et al., 2021). It is estimated that a farmer in the United States earns around 18 dollars per hour (USDA NASS, 2023). Based on this data, it is assumed that females earn 17.19 dollars (€15.71) per hour.

Slaughterhouse

- 27% of the individuals who work in a meat processing plant are female (Irish Country Meats, 2022).
- Females earn on average 15% less in the meat processing industry (Irish Country Meats, 2022). Individuals who work as meat processors are estimated to earn 16 euros per hour (Economic Research Institute, n.d.-b). This suggests that females earn 13.60 euros per hour.

This data results in the true costs of the gender pay gap of €0.29 per f.u. conventional meat.

Forced Labour

As already mentioned in Chapter 4.1, it is not possible to classify the workers of the supply chain of cultured meat on whether they meet the specified indicators or not with the available data. Therefore, global, regional, or sector-based estimates are used to illustrate forced labour.

Cattle farm and Barley production Ireland

Only a little information can be found on forced labour in the agricultural sector of Ireland. It should be noted that the number of migrant workers in the European Union is increasing and that these individuals may or may not meet the criteria of forced labour (Palumbo et al., 2022; International Labour Organization, 2012).

Barley production United Kingdom

In the United Kingdom, individuals have been identified who are the victim of forced labour in the agricultural sector; 68 victims in 2016. The number seems small, but because of the forced labour hidden nature, this number is likely to be higher (GOV.UK, n.d.).

Soy production

In Brazil, the problem of forced labour is still of high importance. Efforts have been made to reduce the numbers, but in 2022 alone 2275 workers were rescued from forced labour (Fair Labor, 2023). These are only the rescued workers; it is estimated that the actual numbers are higher. It is estimated that 1.3 out of thousands experience forced labour in the Americas (International Labour Office, 2017). Using these numbers 262000*(1.3/1000) = 341 workers are forced into the soy industry. However, one should be conscious about using this number as there is a lack of data availability in the Americas (Fair Labor, 2023).

Rapeseed meal and maize production

Half of the forced labour risk in the US food supply chain can be designated to domestic production or processing of food. The United States relies on migrant workers to produce and process food who are vulnerable to forced labour (Blackstone et al., 2023).

Slaughterhouse

In the case of the Irish meat processing industry, there is a high dependency on migrant workers (59% of the total workforce). The report indicates that these migrant workers experience working conditions that meet the indicators of forced labour. Examples of indicators that may be met are excessive overtime and intimidation and threats (Migrant Rights Sector Ireland, 2020).

4.3. Private costs

As described in Chapter 2.1.1, the true costs of both products equal the true costs of a product plus the private costs. To compare the true costs of conventional and cultured meat, the private costs of both products should be determined.

Conventional cattle beef

In December 2023, the retail price of beef equaled 4.79 dollars per kg (4.41 euros per kg) (World Bank, 2024).

Cultured meat

In the case of cultured meat, the retail price is not known yet. The scenario described in chapter 2.3, was used in a techno-economic assessment (Odegard et al., 2021). This model only includes the direct goods of production. The following costs are included:

- Capital costs
- Operation costs: material inputs (culture medium ingredients, electricity, heat, and others) and staff
- Wastewater treatment
- Maintenance.

Based on these costs the private costs of $1708 (€1571.36) were found for the baseline scenario.

4.4.Summary true price cultured and conventional meat baseline scenario

The true cost range found for both cultured and conventional meat is summarized in Table 17. In addition, the private costs are included giving the true price range.

Table 17

Summary of the true costs for both cultured and conventional divided among the three capitals in addition to the private costs and the true price.

	Cultured meat [1 f.u.]	**Conventional cattle meat [1 f.u.]**
Natural Capital		
GHG emissions	€0.33	€4.05
Carbon stock	a	a
Soil Erosion	€0.00-€40.58	€0.00-€87.24
Soil organic matter build-up	a&b	a&b
Water stress	€0.01	€0.03
Water pollution	€0.02	€0.27
Acidification	€0.15	€6.86
Eutrophication	a	a
Eco-toxicity	€0.02	€0.03
Total Natural Capital	€0.53-€41.11	€11.24-€98.48
Human Capital		
Human toxicity	€0.03	€0.04
Living wage gap	€0.00	€0.19
Excessive working hours	a	a
OHS and safety	€573.97-€1721.88	€326.58-€976.37
Total Human Capital	€574.00-€1721.91	€326.81-€976.60
Social Capital		
Forced labour	a&b	a&b
Child labour	a&b	a&b
Gender pay gap	€34.67	€0.29
Total Social Capital	€34.67	€0.29
Total True costs	**€609.20-€1797.69**	**€338.34-€1075.37**
Private costs	**€1571.36**	**€4.41**
True price	**€2180.56-€3369.05**	**€342.75-€1079.78**

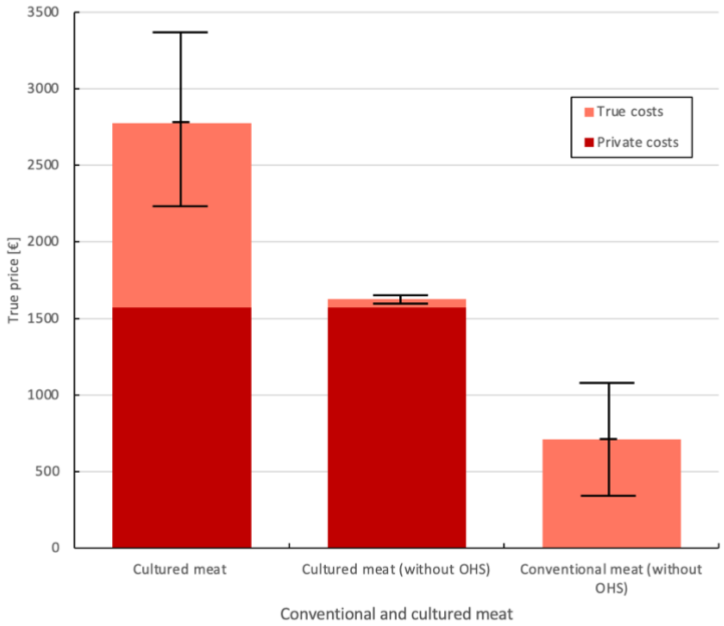
a) True costs could not be found because of data information

b) True costs could not be found because of an error in the formula.

Figure 7 shows the true price range of both conventional and cultured meat. For cultured meat, the price range is shown for a situation with and without the inclusion of the impact category OHS.

Figure 7

The true price of conventional and cultured meat, baseline scenario.



4.5. True price scenario analysis

4.5.1. True costs

Figure 8 shows the effect of the different scenarios on the true costs of cultured meat. The bars display the average true costs, the lines describe the minimum and maximum value. OHS is not included in the scenario analysis as Figure 7 shows that the true cost values found for OHS are disproportionally high compared to other impact categories. Figure 8 suggests that the true costs of cultured meat increase when the quantity of input medium increases. In addition, it is suggested that the effect of changes in the energy mix on the true costs is minimal as for the same medium input, the difference in true costs is relatively small when changing the energy mix. In addition, figure 9 presents the true price of the three low-input medium scenarios, of which the private costs are the lowest ($150) (Odegard et al., 2021). Figure 9 shows that despite the lower private costs of cultured meat, the true price of cultured meat is still higher than conventional meat.

Figure 8

True costs of cultured meat using different scenarios that differ in the energy mix and quantity of medium ingredients per f.u. cultured meat.

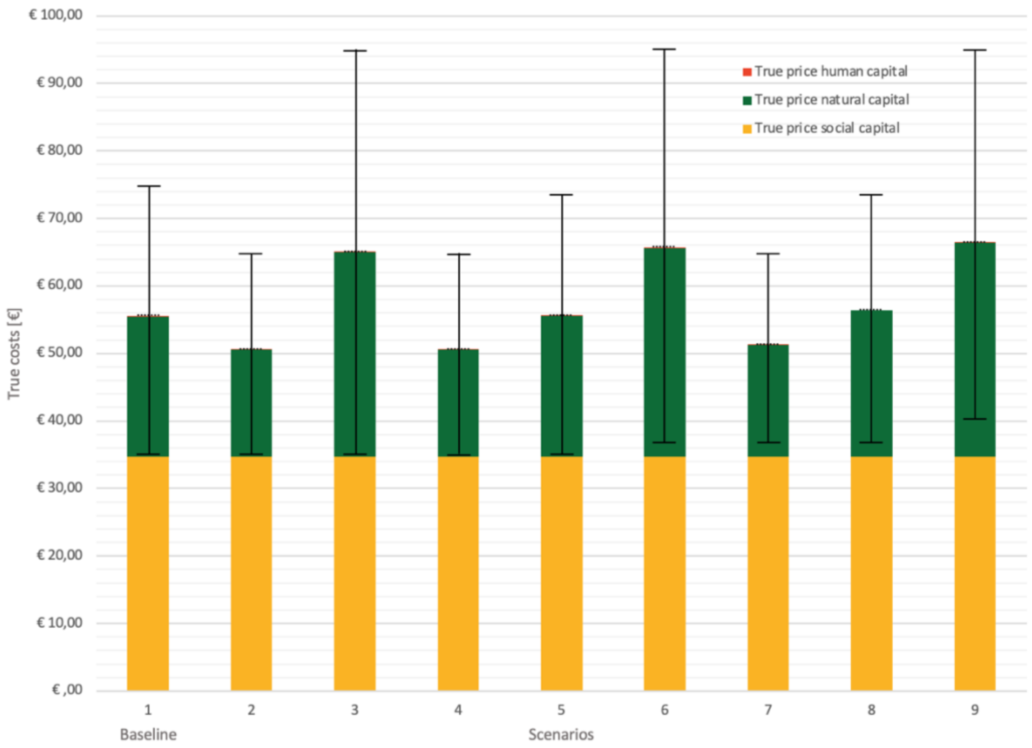
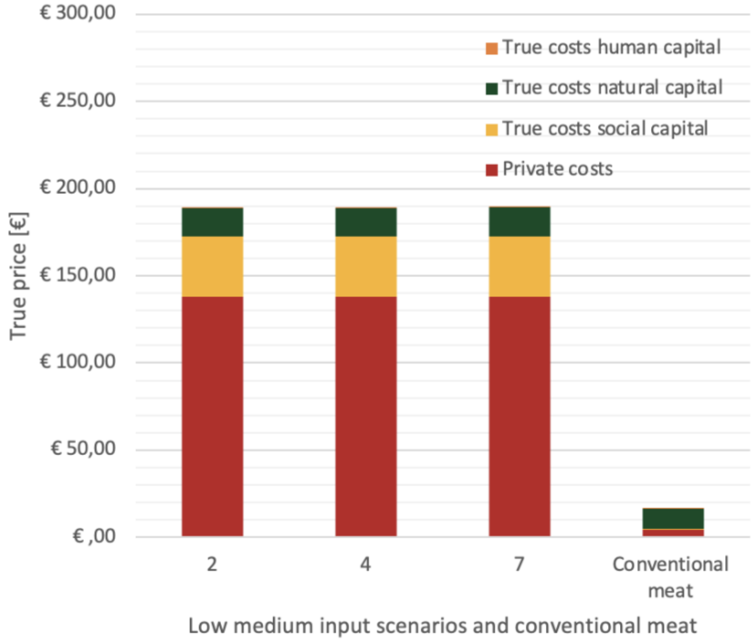


Figure 9

The true price of cultured meat using the low input medium ingredient scenarios.



4.5.2.Private costs

In the case of the private costs of the cultured meat production process, 8 distinct scenarios have been described:

1. ‘’scenario based on high-medium usage and high current prices for medium ingredients.
2. as (1) + mid-medium usage and mid-current prices for medium ingredients.
3. as (1) + low-medium usage and low current prices for medium ingredients (Odegard et al., 2021).’’

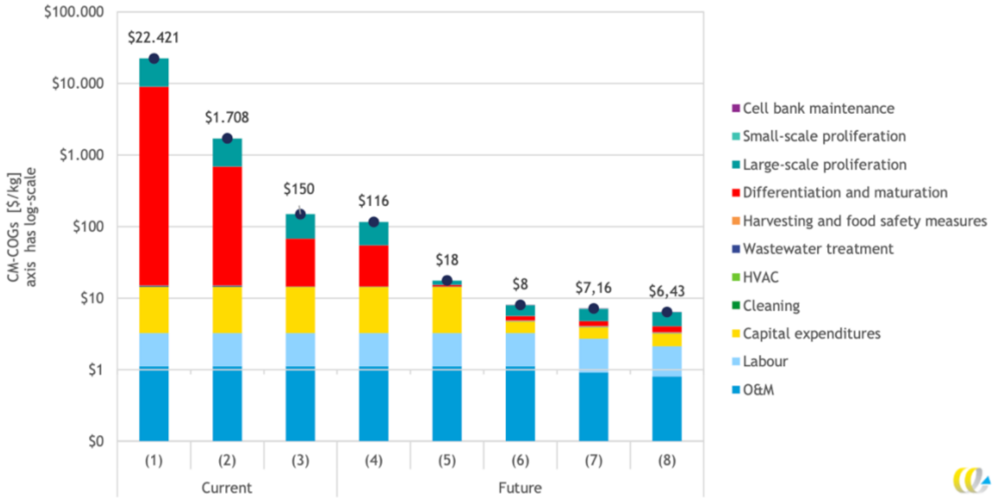
These scenarios use the global average energy mix as energy input and represent scenarios respectively 7, 8, and 9 in the true price scenario analysis (figure 8)

For the other scenarios (4-8), the environmental impacts have not been assessed and are therefore not included in the true price scenario analysis. However, the effects of these scenarios on the private costs are important and therefore it has been decided to briefly describe the scenarios and to show the effects on the private costs (figure 10).

4. ‘’as (3) + lower prices for specific growth factors. The lower prices are assessed as feasible in 2030.
5. as (4) + lower costs for recombinant proteins. Reductions in the use of recombinant proteins and lower production prices were assessed as feasible in 2030.
6. as (5) + social investment criteria. Reductions in capital expenditures because of more relaxed, but feasible, criteria for return on investment.
7. as (6) + shorter production run time. More efficient cultured meat production process that leads to reductions in media use, equipment requirements, and energy use.
8. as (7) + larger cell volume. More efficient cultured meat production process that leads to reductions in equipment requirements and energy use (Odegard et al., 2021, p. 16).’’

Figure 10

Private costs of cultured meat using different scenarios that illustrate improvements in the production process (Odegard et al., 2021).



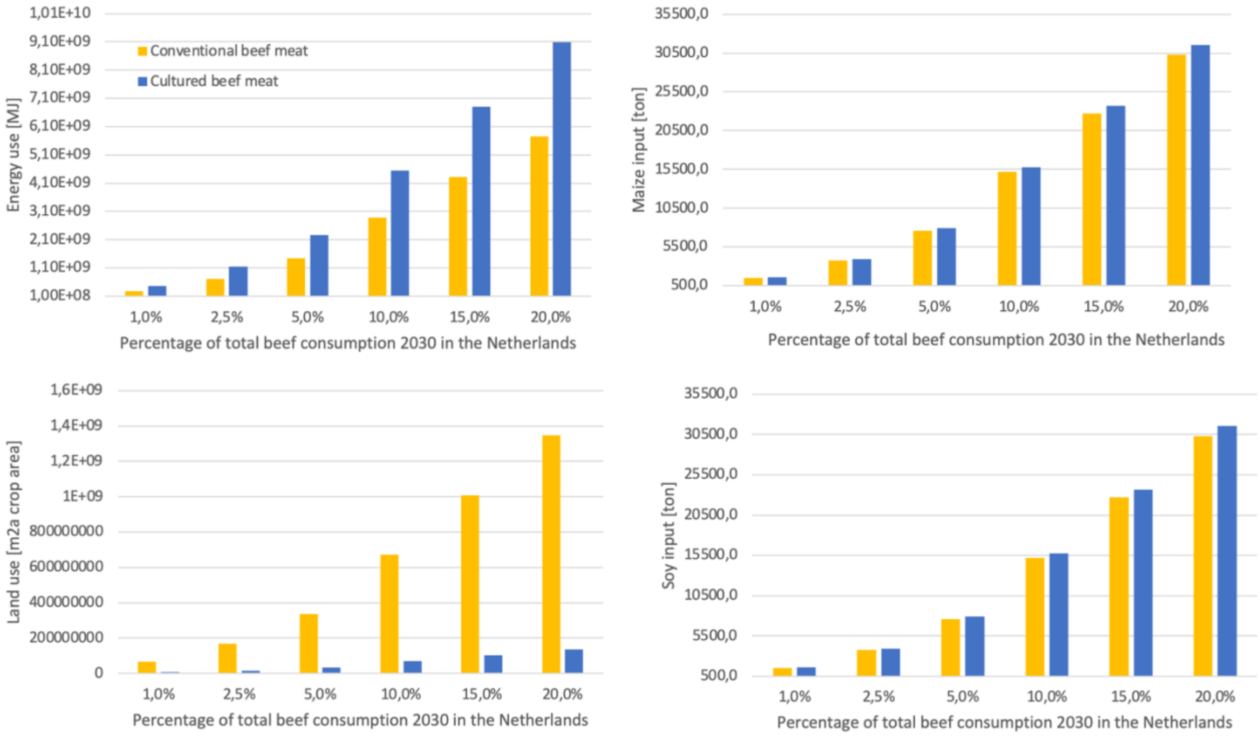
4.5.3.Scaling up

In the Netherlands, 15.1 kg of cattle meat was consumed per capita in 2020 (Dagevos et al., 2023). This equaled 20% of the total meat consumption per year. Globally, beef consumption in 2030 is expected to increase by 5.9% in 2030 compared to 2020. This increase is not realistic in the Netherlands as changes in consumer preferences, aging, and slower-growing populations lead to leveling off meat consumption per capita in 2030 in high-income countries (OECD & FAO, 2021). Data between 2005 and 2022 shows that cattle meat consumption has decreased from 15.9 to 15.0 kg per capita per year in the Netherlands. In addition, total meat consumption has decreased/stabilized around 76 kg per capita per year (Dagevos et al., 2023). Therefore, it is assumed that cattle meat consumption in 2030 equals 15 kg per capita.

It is estimated the population in the Netherlands will range between 18 million and 18.9 million in 2030 with an average of 18.47 million (CBS, 2023a). This implies that beef consumption increases between 2.8% and 7.9% between 2020 and 2030 in the Netherlands. It is not possible to predict how much cultured beef meat will be consumed in the Netherlands in 2030 as there are too many influential factors such as regulation, price competitiveness, or consumer preferences. Therefore, a percentage range is taken that represents the fraction of the beef consumption in 2030 that is cultured beef. Figure 11 presents the input that is required to produce cultured meat for the different percentages. This is compared to the input that is required to produce the same fractions of meat using conventional beef production.

Figure 11

The difference in input requirements for conventional and cultured meat in 2030.



If 10% of the beef consumption in the Netherlands is cultured beef meat in 2030, the following values can be found when comparing it to the same fraction of conventional beef meat:

- 58% increase in energy input required.
- 4% increase in maize input
- 1% decrease in soy input
- 90% decrease in land required for production.

The energy input required to produce both conventional and cultured meat is based upon the ambitious benchmark mix. The ambitious benchmark mix consists of 50% of the input energy from on-shore wind and 50% of solar PV electricity. The heat comes from thermal sources (Sinke et al., 2023). In 2022, 15% of the gross national energy consumption in the Netherlands consisted of renewable energy sources (CBS, 2023b). This includes also energy generated by biomass. In 2030, the target is to produce 27% of the total energy consumption using renewable sources in the Netherlands (Ministerie van Algemene Zaken, 2023).

4.6.TCA applied on cultured meat: issues and challenges.

4.6.1.References

In general, there are no references given on what information the metrics are based on that are used to calculate the true costs. This is regrettable because in some cases the metrics, description, or even the impact categories themselves are ambiguous. Moreover, from a scientific standpoint, this ambiguity diminishes the overall scientific accuracy and validity of the model.

4.6.2.Double counting

Some impact categories have an overlap with each other. This is also highlighted in Table 18, where the overlap is mentioned per impact indicator. The overlap can have two origins: the source of the problem is similar (e.g. fuels) or the consequence is the same (health problems because of the chemicals). Both problems cause double counting in terms of monetary value.

4.6.3.Data Intensity

A supply chain consists of boundaries that need to be defined according to the scope of research. In the case of cultured meat, Sinke et al. (2023) defined boundaries to calculate the environmental impact of cultured meat (figure 5). In this thesis, the true price of some impact indicators is calculated for a fraction of this system. Other impact categories use the whole system, but this is only the case when the LCA results are directly used in the TCA analysis.

Ideally, to calculate the true price of cultured meat, data should be gathered for all production steps and all impact indicators. In addition, the data should be of high quality and detail (FAO, 2023). Finding data for all impact indicators and every production step implies that in every step in the chain, data for all 53 parameters need to be found to calculate the true price. In addition, some of these parameters are based around individual worker information such as OHS or the gender pay gap. This implies that for every worker in that specific step in the chain, data needs to be collected on these parameters. This means that the true pricing of a product is an unquestionably data-intensive process.

Currently, the cost of finding high-quality data at low costs is the main problem of scaling up TCA (FAO, 2023). Two suggestions have been given to overcome this. Firstly, using the data that is available, making assumptions, and understanding the limitations of the outcome. It is recommended to start doing this in the short term. If primary data is not available, it is recommended to start using secondary data with assumptions or to use models to estimate the results. Secondly, it is recommended to systematically start collecting data that is needed for TCA using surveys or obligated reporting of relevant data (FAO, 2023). Gathering all this data and making structural changes to have this data available in the future will again be a cost and time-intensive process as it involves public and governmental institutions, countries with different income profiles, and regulation of different scales. Using TCA as a decision-making tool will cause a shift in how the world gathers and handles data which comes at considerable costs. These costs and system changes are recognized (FAO, 2023). However, the magnitude, impact, and who is going to pay these costs is not researched and calculated.

4.6.4.Competence with LCAs

The usage of LCAs in TCA is one of the difficulties and points of discussion that can be found. LCAs are generalized models that neglect on-farm practices. These on-farm practices can significantly influence the outcome results through, for example, circularity, erosion prevention measures, or cover crops (True Cost Initiative, 2022). Including these on-farm practices in TCA requires primary data which is not always available. Therefore, secondary data is used, if necessary, with LCAS as one of the recommended tools. LCA is one of the recommended tools (True Cost Initiative, 2022).

In the method, it is not always clear how to use LCA results, despite LCAs being one of the recommended tools. For example, human toxicity is divided into non-carcinogenic and carcinogenic human toxicity, both measured in 1,4- DCB equivalent in LCAs. In the TCA method, this is generalized into human toxicity measured in Cu equivalent. This raises two questions or problems. Firstly, can non-carcinogenic and carcinogenic 1,4- DCB equivalents be added? Secondly, the units are different which implies that a conversion factor from 1,4-DCB equivalent to Cu equivalent should be found using our research. This conversion factor couldn't be found. Hence, the method to calculate the true costs of human toxicity had to be redesigned (chapter 3.3).

LCAs can be seen as a starting point to gather data for TCA. However, it should be acknowledged that LCAs is a model that has its flaws. For example, LCAs favor high-input intensive agricultural systems over less intensive agricultural systems. These flaws can carry over to the true cost analyses. Therefore, using LCAs in TCA should be handled with care (FAO, 2023).

4.6.5.Monetary values

According to the theory described in chapter 2.2.9, the monetary values should be based on the remediation costs. According to the theory, the monetary values should contain restoration or compensation costs, prevention costs, and retribution costs (Galgani et al., 2021). In the framework, five types of valuation approaches can be distinguished one of them is assigned to one impact category:

- Prevention costs
- Damage costs
- Restoration costs
- Living wage gap costs: the difference between the living wage and the received wage by the worker.
- The gender pay gap: difference the between the wage of the individual with a lower wage and the individual with a higher wage (True Cost Initiative, 2022).

Based on the theory, it can be suggested that the valuation approaches used in the method are not complete.

In addition to the incompleteness of the monetary values, the monetary value of 80000 EUR/DALY can be argued as this value is suggested to be used around the world. The reasoning for this is that every life is worth the same no matter where an individual lives (True Cost Initiative, 2022). From a social point of view, this can be seen as a correct statement, but from an economic point of view, this can be argued. The 80000 euro per DALY is the cost of treating a kidney patient for one year in the Netherlands. The costs for healthcare differ between countries for the same set of services (OECD, 2020). In addition, the willingness to pay for healthcare differs globally (McDougall et al., 2020).

4.6.6.Impact indicator-specific problems

Table 18 presents problems associated with specific indicators. Various problems are repeated across different impact categories. In addition to the described problems, there are two additional columns. The first column mentions whether the problem is recognized by the authors in the chapter ‘’Shortcomings of the TCA indicators’’ (True Cost Initiative, 2022, p. 75-76). In addition, an email was sent to the contact address of the handbook to ask for a response for a few of the problems (appendix 6). When a question related to a problem is included in the email, a yes is included in the designated column.

Table 18

Presentation of problems per impact category

Impact category	**Problem**	**Recognized by authors (True Cost Initiative, 2022).**	**Explanation asked of the authors**
GHG emissions	Conventional measuring of GHG emissions in terms of GWP_{100}.		
Carbon stock and soil organic matter build-up	No clear distinction between both impact categories in the described method. The impact category SOC buildup is about the composition and decomposition of SOC. Carbon stock is about emissions from the soil and tree biomass. When SOC is decomposed, eventually CO_2 is formed. This causes double counting of the same problem.		Yes
	Need of primary data (field measurements) as it is not included in LCAs. Primary data is difficult to find.	Yes	
	Timespan problem. According to the proposed metrics, the carbon emissions from the soil should be calculated according to the difference between SOC at time t and time t-20. This requires field measurements over a 20-year timeframe. As primary data is already difficult to find, it is even more difficult over a 20-year timeframe. In addition, it is not given what reference the 20-year timeframe is based on.		
	In the proposed method, tillage factor, input factor, base factor, and reference carbon stock are used to calculate SOC content. It is not explained what these factors mean and how to calculate or find them.		
Soil erosion	Soil erosion cannot be measured on the field. A model or location-based estimates have to be used to predict soil erosion. Two options have been given in the method: a model based on farm data (RUSLE), which requires primary data from the farmer, or the global soil erosion map (Borrelli et al., 2017). The global soil erosion map has a resolution of 250 x 250 meters, but estimating soil erosion at a specific location is difficult to estimate from the paper as it shows soil erosion on a global map.		

Impact category	**Problem**	**Recognized by authors (True Cost Initiative, 2022).**	**Explanation asked of the authors**
	Wind erosion is not included.	Yes	
Water stress	In the way the metric is formulated, only water use for irrigation and water demand in de processing phase is included in the total water demand. This is not all the water use that is associated with conventional or cultured meat production. Using this proposed metric would give incomplete results of water stress.	Yes	
Water pollution	Based on the definitions provided, three impact categories should be used in LCAs: terrestrial, freshwater, and marine eutrophication. It depends on the method used whether all three impact categories are included and therefore on whether the data is available.		
	Marine eutrophication is not included in the description of water pollution. Unclear on whether to include it or not in the true costs' calculations.		
Eutrophication	This indicator considers ''energy use, diesel combustion and production of non-organic fertilizers and their terrestrial eutrophication potential''. This impact category considers the emissions of NO_x substances into the atmosphere. The NO_x emissions are removed from the atmosphere through different pathways eventually forming NHO_3 which can be removed through wet and dry deposition. HNO_3 has an acidifying effect on the soil through the release of H^+. This causes overlap and double counting with the impact category acidification		
Acidification	As already mentioned, the substances that cause eutrophication and acidification are the same causing double counting of a substance with two consequences.	Yes	
Eco-toxicity	The primary data that is used to calculate the true costs of eco-toxicity are crop protection use, energy use, and packaging. These three sources of primary data are not the only substances that have an eco-toxicity impact during the production process of agri-food products.	Yes	

Impact category	Problem	Recognized by authors (True Cost Initiative, 2022).	Explanation asked of the authors
	For new substances, the eco-toxicity potential is not known yet.		
	One of the recommended tools to calculate eco-toxicity is LCAs. LCAs calculate eco-toxicity in three areas: terrestrial, freshwater, and marine. It is not clear how to deal with the differences between those in the TCA method. In addition, in LCAs eco-toxicity is measured in 1,4-DCB eq and not Cu eq which is the proposed unit in the TCA method. A conversion factor from 1,4-DCB eq to Cu eq has not been found.		
	The eco-toxicity impact of fertilizers is not suggested to be one of the primary data sources in eco-toxicity. Fertilizer use is included as the primary data source for human toxicity. Why is it included in one of them and not in the other?		
Human toxicity	For new substances, the human toxicity potential is not known yet.		
	Only the primary data of food protection, fuel use, fertilizer use, and material use are chosen to calculate the human toxicity impact.		
	Including fertilizer use as a primary data source causes double counting as the effect of the product (fertilizer) is also included in water pollution.		
	In the proposed metrics, no differentiation has been made between the cancerous and non-cancerous effects of human-toxic substances. While the conversion factor from 1,4-DCB equivalent to DALY differs between carcinogenic and non-carcinogenic substances (Huijbregts et al., 2016).		
	Again, LCA software is suggested as a recommended tool and LCA analysis measures human toxicity in 1,4-DCB eq not in Cu eq.		
OHS	235 health states are defined to which all disability weights are assigned which will be used in the metrics to calculate the true costs of OHS (Salomon et al., 2015). This requires extensive administration of health problems.		Yes

Impact category	Problem	Recognized by authors (True Cost Initiative, 2022).	Explanation asked of the authors
	The health states are rather specific. Only for hearing loss, 10 different states are defined all having their disability weight.		Yes
	Data and privacy are a real issue as they require specific information that can be seen as confidential. From an outsider, it is difficult to get insight into this information.	Yes	
	The following metrics to calculate the true costs of injuries can be found: True costs injuries = sum of all injuries ((number of injuries type k * disability weight injury type k) * (life expectancy worker j – age worker j)) The metrics to calculate the true costs of injuries imply that at the moment the worker experiences a work-related injury, the true costs need to be calculated from that moment till the national life expectancy. This lacks coherence as a cut also counts as a work-related injury (True Cost Initiative, 2022). Why should the true costs be calculated from the moment of the cut till the national life expectancy? Especially because in case of illnesses, the true costs are calculated according to the number of days per year the worker experiences the illness.		
	Overlap with human toxicity as work-related illnesses, injuries or even deaths can be caused by inhalation or ingestion of direct contact with toxic chemicals. This causes double counting of problems with the same origin.		Yes
	Unclear what happens if a worker experiences multiple health problems. Can these problems be cumulatively added or not?		
Excessive working hours	The following metric is used to calculate the true costs of excessive working hours: $EWH = \sum_{i=1}^{m}\sum_{j=1}^{n}\frac{H_{EWH}^{j} - 48}{48} * 0.5DALY\ if\ H_{EWH} > 48\ hours\ per\ week$		Yes

Impact category	**Problem**	**Recognized by authors (True Cost Initiative, 2022).**	**Explanation asked of the authors**
	The factor 0.5DALY is based on around half the costs of kidney patient treatment. It is not clear why it has been decided that it is half the costs of a kidney patient treatment. Reference and explanation for this is lacking		
	DALY value is not known and given. This way, the true costs of excessive working hours cannot be calculated.		
	Again, there is an overlap with OHS as excessive working hours are known to cause several diseases. This implies that there will be again double counting.		Yes
	Unclear on how to deal with seasonal work. The agri-food sector is known to have excessive working hours during specific seasons. On average over all working weeks, there might be no excessive working hours, but in these specific seasons, there are. Consequently, this might or might not have an impact on the true costs of excessive working hours.		
Child labour	DALY value is not known and given. This way, the true costs of child labour cannot be calculated.		
	The factor 0.5DALY is based on around half the costs of kidney patient treatment. It is not clear why it has been decided that it is half the costs of a kidney patient treatment. Reference and explanation for this is lacking		
	Difficult to find information and data on this topic. Especially, because it is required to know how many hours a year a child works to calculate the true costs of child labour. The number of children experiencing child labour is already scarce, not to mention the hours.	Yes	
	The metric to calculate child labour is the following: $$SC_{CL} = \sum_{i=1}^{n} (H_{CL}^{i} - 560)/2240 * 0.5DALY\ if\ H_{CL}^{i} > 560\ hours$$		

Impact category	**Problem**	**Recognized by authors (True Cost Initiative, 2022).**	**Explanation asked of the authors**
	Based on the information provided it is unclear why the value is divided by 2240. 2240 is the standard working hours per year outside Europe. Especially when comparing it with excessive working hours where the factor is divided by 48.		
Forced labour	DALY value is not known and given. This way, the true costs of child labour cannot be calculated.		Yes
	The factor 0.5DALY is based on around half the costs of kidney patient treatment. It is not clear why it has been decided that it is half the costs of a kidney patient treatment. Reference and explanation for this is lacking		
	In the metrics, 3 or more indicators of forced labour need to be met to classify a worker as forced labour. According to the explanation given in the handbook, a worker can also be classified as a forced laborer if one or two indicator(s) are met in some cases.		
	The following metrics can be found: $$FL = h * 0.5DALY \ with \ h = \sum_{i=1}^{n} h_i$$ h is the number of hours a forced laborer works. This metric shows inconsistencies with the way the true costs of excessive working hours and child labour are calculated. In the latter two metrics, the hours worked are divided by 48 and 2240. In the metrics of forced labour, no division takes place.		

5. Discussion

The following structure of the discussion can be defined. Firstly, the results of the true costs of cultured and conventional meat will be discussed. This includes both the baseline scenario and the scenario analysis. Thereafter, the model and data that were used to find the different true costs will be discussed. Based on this information, the question is raised how much value can be attached to the true costs found when critically assessing the data and model used. Thereafter, a broader perspective will be used that focuses on discussing true pricing in general from both an economic and social perspective. Finally, recommendations will be given for future research.

5.1. True pricing applied on cultured and conventional meat

5.1.1. Baseline

Figure 7 shows that a distinction has been made between the true price of cultured meat with and without the inclusion of OHS. The reason for presenting both is that the true costs of OHS are disproportionally high compared to the other true costs. Table 14 shows the true costs of OHS range between €573.97 and €1721.88 depending on the disability weights. In comparison, the sum of all the other true costs ranges between €35.23 and €75.81 for cultured meat. Therefore, it has been decided to examine the true price of cultured and conventional meat without OHS. From Figure 7, two conclusions can be drawn. Firstly, the true costs are lower for cultured meat. This implies cultured meat offers a sustainable alternative to conventional meat. Secondly, the average true price of cultured is meat nearly 2.3 times higher due to its current lack of price competitiveness.

In recent years, significant investments have been made in cultured meat. In addition, the policy fields are changing to allow the testing, labeling, or selling of cultured meat. Furthermore, researchers are globally trying to improve the quality of cultured meat, improve the efficiency of the process, or are trying to find new innovative medium ingredients. These changes are all made under the assumption that cultured meat is a sustainable alternative to conventional meat. According to TCA theory, lower true costs suggest that a product, diet, or even a system is more sustainable. This legitimates policy changes, investments, and research.

5.1.2. Scenario analysis

Figure 8 suggests two points of discussion. Firstly, an increase in the quantity of input materials causes an increase in the true costs. Secondly, a change in energy mix has a minimal effect on the true costs of cultured meat. For example, if a high input medium scenario is used, the following values can be found when changing the energy mix:

- Ambitious benchmark energy mix: €35.65-€94.40 range of true costs.
- Renewable scope 1+2 energy mix: €36.73-€94.49 range of true costs
- Global average energy mix: €38.07-€94.85 range of true costs.

These numbers suggest that amount of renewable energy increases, the true cost range decreases. However, this effect is minimal compared to the effect changes in the medium scenarios have.

Figure 10 shows that a low-medium input scenario has the lowest private costs. In the low-medium input scenario, two factors are adjusted: the quantity of input ingredients per kg of cultured meat decreases and the costs per kg of medium ingredient decrease for some of the recombinant proteins and growth factors used (appendix 4). Consequently, the private costs decrease to $150 per kg of cultured meat. Figure 9 shows the true price for conventional meat and the three low-medium input scenarios. This figure suggests that despite the relatively low private costs and true costs of cultured meat, the true price of cultured meat is still high compared to conventional meat.

Figure 10 shows that if five additional scenarios are achieved, the private costs of cultured meat can decrease to $6.43 per kg cultured meat which would significantly increase the price competitiveness with conventional meat. The effect of these scenarios on the true price cannot be examined due to data availability. Therefore, these are not further included.

In addition to the true price, it has been examined what the effect of producing cultured meat is on different resources such as wheat and soy. If 10% of the produced meat is cultured meat in 2030, in the Netherlands, a 4% increase in wheat production and a 1% increase in soy production is required compared to conventional meat. In addition, land use decreases by 90%. This provides opportunities for farmers as additional quantities of wheat and soy need to be produced. In addition, the agricultural land that was used for conventional meat production can be used to produce other agricultural products. This is of great importance as the global food demand is increasing and is expected to increase in the future.

Cultured meat is an energy-intensive process. A 58% increase in energy is required if 10% of the meat consumption in 2030 in the Netherlands is cultured meat. In the baseline scenario, a renewable energy mix is assumed. This implies that cultured meat is produced fully using renewable energy. It can be argued how realistic this scenario is as the goal is that 27% of the energy produced, is renewable energy in the Netherlands in 2030. Consequently, the cultured meat plant needs to produce its own renewable energy to meet the baseline scenario. However, the scenario analysis showed that the effect of changing the energy mix on the true costs of cultured meat is minimal. This suggests that the importance of how realistic the renewable energy scenario is, is insignificant.

5.1.3.TCA method, data, boundaries

At first glance, the True Cost Accounting Agri-food Handbook seems a ready-to-use handbook, and several benefits were distinguished. However, when trying to use this handbook both general and impact indicator specific problems were found. These issues raise questions about the validity of the obtained results.

For example, the true costs of OHS are disproportionally high compared to the true costs of other impact categories (figure 7). Therefore, it has been decided to exclude it from the scenario analysis. Examination of the impact category and recommended tools shows several problems (table 18). It is argued that data and privacy are an issue by the authors of the handbook. This raises the question of why a tool for disability weights would be suggested that requires data on such a level of detail that 235 health states can be defined. This implies that documentation is needed on 235 health states for every worker in the supply chain of a product. In addition, it can be debated that it is peculiar that a worker needs to be compensated for an injury throughout its expected lifetime. Someone can recover from an injury and start working again or might be able to do another job. In both cases, it can be reasoned that the worker doesn't need to be compensated for the injury during their expected lifetime. This is especially strange because if a person has an illness, the worker only needs to be compensated for the days the worker experiences that illness per year. The consequence of this decision is presented in Tables 14 and 16. The tables show that when the disability weight of illnesses increases by 0.2, there is a maximum €0.01 increase in true costs. On the contrary, if the disability weight of injuries increases by 0.2, there is an increase in €574.95 per kg of cultured meat. Henceforth, it can be concluded that the impact of illnesses is negligible, while the significance of injuries stands pronounced.

The metrics provided by the impact categories excessive working hours, forced labour, or child labour make it not possible yet to calculate the true costs of these impact categories because the DALY value is missing. In addition, the impact category soil organic built-up shows such an overlap with carbon stock that it can't be included and it can be debated on whether it is included in the first place. These problems suggest that careful examination and testing of the metrics to calculate the true costs of OHS did not happen. No reference is given on what information the metrics are based and therefore it is not possible to examine how this could have happened. The number of problems does significantly increase in the case of the human and social capital-related impact categories.

Besides the problems in the model, data availability and accuracy are problems as well. To find the true price of both conventional meat and cultured meat many assumptions have been made around the data. Furthermore, no primary data has been used. Data that was used is from LCAs, reports on global averages, general country data, and, if fortunate, data from a specific sector in a country.

In addition, TCA is a model; it is not the reality. However, as shown in Figure 5, only a part of the shown cultured meat production steps is included in the true price analysis of cultured meat. Consequently, the true price analysis is not complete. The same problem arises in the case of conventional meat, some production steps are excluded resulting in an incomplete true price analysis.

Based upon the problems around data, boundaries, and method, it can be debated whether any conclusions should be drawn on the sustainability of cultured meat with TCA as a method.

5.2.True cost accounting into a broader perspective

5.2.1.Data

As already mentioned, TCA requires a lot of data. In the used method, 53 parameters are defined to which a value needs to be assigned. Ideally, for every part of the supply chain, the true costs need to be calculated which are summed to give the final true costs and consequently price of the product. This implies that for every part of the supply chain, data needs to be collected for these 53 parameters. Only a fraction of the required data to apply TCA on a larger scale is currently available. Especially high quality, primary data is currently lacking. In particular, this data is missing from low-income countries. Gathering all the data required will cause a shift in how we treat and collect data globally. In addition, it requires systematic gathering of data per defined timeframe, as parts of the system may change affecting the true price of a product. This systematic change in the quantity of required data and setting up methods on how to periodically collect the data will be costly and it is not researched what these costs will be. In addition, who is going to pay the costs? Mostly, data from low-income countries is lacking. Do these low-income countries have to pay for the costs of data collection themselves or do high-income countries provision this?

5.2.2.Infinite true prices

The true price is aimed to be calculated throughout the supply chain of a product. A product can be homogenous, but the homogeneous product can have an entirely different supply chain or production process. Consequently, a difference in the process, diminutive or substantial, can have an impact on the true price of the product. This implies that for every product thinkable, homogenous, or not, it is likely that a different true price applies. Globally, innumerable products can be found giving infinite true price options. It warrants attention that product is only one of the scopes of which true price can be calculated: system, investments, diet, or organizations are also possible scopes. As a result, even more infinite true prices can be defined.

5.2.3.Impact categories

In the method used, sixteen impact categories are defined which are all externalities of a product. However, this is only a fraction of all externalities a product has. It is aimed that in the future all externalities or true costs are included in TCA models. It has been acknowledged that for some of these externalities, it is not possible to use monetization. However, it should already be questioned whether the monetization of some impact categories is even preferable in the method used in this thesis, such as child labour or human health in general. Especially because it has been decided that child labour is worth 0.5DALY. 0.5 is based on half the costs of kidney treatment per year. As no references are given, it can be debated on what information or personal conclusion this decision has been based on. It should be carefully decided on which impact categories or externalities can be included in TCA, whether these can be monetized, and which monetary value can be used.

5.2.4.Implications

TCA is aimed at supporting individuals, governments, or organizations in their decision-making process between different products, systems, policies, or investments. Again, it should be urged that TCA is likely to be an expensive tool that requires large quantities of data and systematic changes in how we treat data globally. The costs of arranging this new system and how to arrange it are currently neglected in literature and by policymakers. Policy decisions is one of the areas where TCA can be used as an informative instrument. Coase already indicated in 1960 that changing the existing (policy) system will lead to an economic improvement in some decisions but will worsen the overall welfare in others. The total effect of these policy changes should be considered when making a policy decision and do not base it only on decreasing the true costs or increasing the benefits. The question should be raised on whether it is desirable to influence the government, organizations, or individuals in such manner that the hidden costs will be decreased and/or societal benefits increase, as it is likely that this will only happen in some situations. In other situations, the economic losses are likely to be greater than what is gained using TCA. Especially because the costs for operating TCA and of gathering all the data are not considered. Situations may emerge where investments in a company decrease because the TCA method defines the company as an unsustainable investment, while from a societal and economic point of view, this company is of substantial importance. The broader economic perspective and logical reasoning will be potentially lost if the focus lies on these TCA models as a decision-making instrument.

5.2.5.Standardization

Over thirty TCA methods can be distinguished of which a few specialize in agri-food. Two problems can be found: there is no standardization of the frameworks and the frameworks that are present are not strengthened enough. Trying to use one of these methods in this thesis showed a lot of problems. Almost all of these problems need to be solved to use the method in the future by policymakers or organizations. On the other hand, boundaries need to be set clearly. Which externalities can be internalized and which cannot because of ethical considerations or economic perspectives. In addition, standardize the monetary values. The theory mentioned that remediation costs should be used. However, the method of this thesis used only a fraction of the remediation costs and for every impact category, the costs were based on something different. Furthermore, how are the TCA boundaries defined; cradle-to-cradle or cradle-to-gate, and which time dimension will be used? Otherwise, the same problems will arise as in the case of LCAs where two LCAs about the same product cannot be compared with each other because of methodical differences.

5.2.6.Recommendations future research

It is aimed that TCA as a decision-making instrument should start now, even if primary high-quality data is not available (FAO, 2023). Now, momentarily suspend consideration of that idea and revert to foundational principles by initiating the development of standardized models of higher quality. More in-depth testing of these models is required to show the problems and improve the quality of the models. In addition, start having discussions about which impact categories can be internalized and which cannot and which monetary values to assign. All of this is to improve the standardization of TCA methods. Furthermore, start researching all the costs and benefits that are associated with the system changes that are associated with applying TCA on a large scale, including the question of who is going to pay for these costs. After all these costs and benefits are known, reconsidering whether TCA is something we desire to have as a tool in the future and on what scale. Especially when considering that the economic losses may be greater than the gains when implementing TCA.

6. Conclusion

To what extent can TCA serve as a conclusive measure in assessing the sustainability of cultured meat as an alternative to conventional meat production, within the context of welfare economics and with a critical examination of TCA?

The results suggest that the true costs of cultured meat are lower compared to conventional meat. This implies that cultured meat can be seen as a sustainable alternative to conventional meat. According to the TCA theory, this supports the investments and policy changes that are made to increase the price competitiveness of cultured meat, advance the quality, and allow labeling, testing, and even selling of the product. However, a significant number of issues and limitations were found during the application of the TCA method. This includes both general problems and issues related to specific impact indicators. Consequently, the value of the sustainability conclusion can be seen as limited. Further testing and improvement of this method is recommended before it can be used by any policymaker or organization. In addition, work towards standardization of the methods as this is currently not the case. In a broader context, TCA can be seen as a method that needs considerable system changes related to how we collect data globally. This change in system and more importantly, the costs associated with this system change are currently neglected and not known. It has been concluded that using TCA on a larger scale should start now, even if high-quality primary data is not available. However, it is advisable to put a hold on that particular thought. Foremost, realize what the implications will be for our society as the broader economic perspective is lost in the discussion around standardization, data, and which method to use. In 1960, it has already been proven by Coase that it should be known whether the gain from changing the system is higher than the losses elsewhere. In other words, are the gains from using TCA as a decision-making tool higher than the losses caused by the tool, especially considering all the costs of changing and maintaining the system. The scale on which TCA can be implemented is substantial; infinite true prices can be distinguished on different scopes such as product, diet, or system. With the scale TCA can and likely will be implemented on, it is likely that a decrease in overall economic efficiency will happen. Acknowledge this fact and reconsider why we would use such an instrument in the first place.

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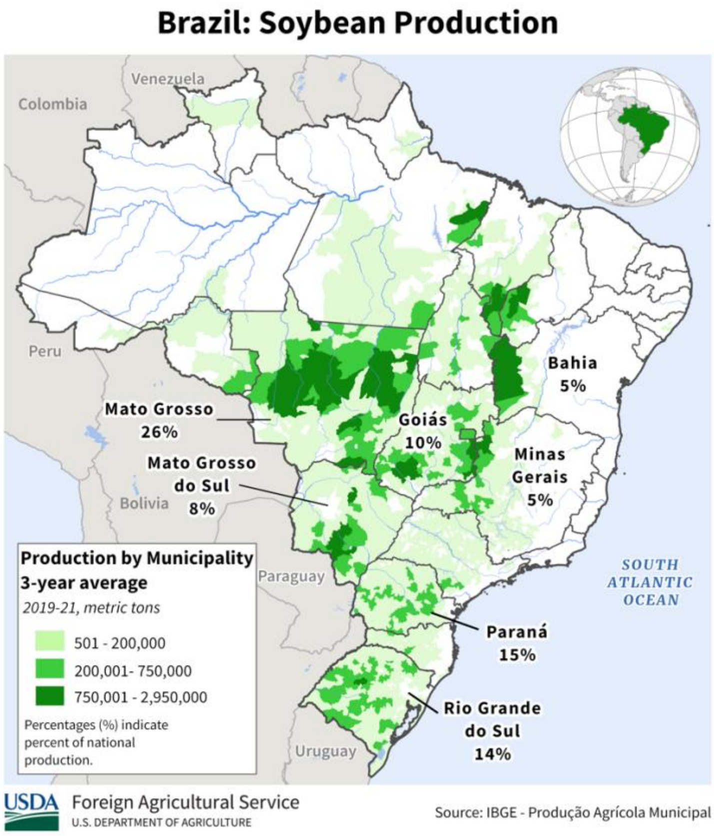
8. Appendix

Appendix 1: Map of soy production in Brazil

Figure 12

Soybean production in Brazil (IBGE- produção agrícola Municipal, 2019)



Source: IBGE - Produção Agrícola Municipal

Appendix 2: True costs baseline calculations cultured meat.

Table 19

True costs GHG emissions cultured meat

Parameter	unit	value	Reference to value
GHG emissions	tonne CO2 eq	=2.82/1000	(Sinke et al., 2023)
Monetization factor GHG emissions	EUR2017/tonne CO2 eq	116	(True Cost Initiative, 2022)
Calculation	=(2.82/1000)*116		
True costs GHG emissions	Euro	0.33	

Table 20

Soil loss hydrolysate amino acids

Hydrolysate amino acids			
Parameter	**unit**	**value**	**Reference to value**
Soil loss	kg/ha/year	0-20000	(Borrelli et al., 2017)
Land use	ha	31.9%*2.48/1000=0.0000791	(Sinke et al., 2023; Mattick et al., 2015)
Calculation	=0*0.0000791=0 =10000*0.0000791=0.79 =20000*0.0000791=1.58		

Table 21

Soil loss glucose and conventional amino acids

Glucose and conventional amino acids			
Parameter	**unit**	**value**	**Reference to value**
Soil loss	kg/ha/year	250	(Panagos et al., 2014)
Land use	ha	46.45%*2.48/1000= 0.000115	(Sinke et al., 2023; Mattick et al., 2015)
Calculation	=250*0.000115= 0.029		

Table 22

True costs soil erosion cultured meat

Parameter	unit	value	Reference to value
Soil loss	kg/ha/year	0.00-1.61	
Monetization factor soil erosion	EUR/kg soil loss	=27.38*0.92[a]	(True Cost Initiative, 2022)
Calculation	=0.00*(27.38*0.92) =(0.79+0.029)*(27.38*0.92) =(1.58+0.029)*(27.38*0.92)		
True costs GHG emissions	Euro	0.00-20.65-40.58	

[a]Conversion from dollar to euro

Table 23

True costs water stress cultured meat

Parameter	unit	value	Reference to value
Water use	M3	0.0857	(Sinke et al., 2023)
Aqueduct baseline water stress factor		0.1	(Aqueduct, n.d.)
Monetization factor water stress	EUR2017/m3	1	(True Cost Initiative, 2022)
Calculation	=1*0.1*0.0857		
True costs GHG emissions	Euro	0.01	

Table 24

True costs water pollution cultured meat

Parameter	unit	value	Reference to value
Marine eutrophication	kg N eq	0.00129	(Sinke et al., 2023)
Freshwater eutrophication	Kg p eq	0.001	(Sinke et al., 2023)
Monetization factor nitrogen	EUR2017/kg N	1.75	(True Cost Initiative, 2022)
Monetization factor phosphor	EUR2017/kg P	12.76	(True Cost Initiative, 2022)
Calculation	=(0.00129*1.75)+(0.001*12.76)		
True costs GHG emissions	Euro	0.01	

Table 25

True costs acidification cultured meat

Parameter	unit	value	Reference to value
Terrestrial acidification	Kg SO2 eq	0.0175	(Sinke et al., 2023)
Monetization factor acidification	EUR2017/kg SO2-eq	8.75	(True Cost Initiative, 2022)
Calculation	=8.75*0.0175		
True costs GHG emissions	Euro	0.15	

Table 26

True costs eco-toxicity cultured meat

Parameter	unit	value	Reference to value
Terrestrial ecotoxicity	kg 1,4-DCB eq	54.8	(Sinke et al., 2023)
Freshwater ecotoxicity	kg 1,4-DCB eq	0.066	(Sinke et al., 2023)
Marine ecotoxicity	kg 1,4-DCB eq	0.0504	(Sinke et al., 2023)
Monetization factor terrestrial ecotoxicity	EUR/kg 1,4-DCB eq	0.0003	(True Price Foundation, 2021)
Monetization factor freshwater ecotoxicity	EUR/kg 1,4-DCB eq	0.0406	(True Price Foundation, 2021)
Monetization factor marine ecotoxicity	EUR/kg 1,4-DCB eq	0.0019	(True Price Foundation, 2021)
Calculation	=(54.8*0.0003)+(0.066*0.0406)+(0.0504*0.0019)		
True costs GHG emissions	Euro	0.02	

Table 27

True costs human toxicity cultured meat

Parameter	unit	value	Reference to value
Human carcinogenic toxicity	kg 1,4-DCB eq	0.127	(Sinke et al., 2023)
Human non-carcinogenic toxicity	Kg 1,4-DCB eq	2.25	(Sinke et al., 2023)
Conversion factor carcinogenic toxicity	DALY/1,4-DCB eq	0.00000332	(True Price Foundation, 2021)
Conversion factor non-carcinogenic toxicity	DALY/1,4-DCB eq	0.00000000665	(True Price Foundation, 2021)
Monetization factor	EUR/DALY	80000	(True Cost Initiative, 2022)
Calculation	=((0.127*0.00000332)+(2.25*0.00000000665))*80000		
True costs GHG emissions	Euro	0.03	

Table 28

Living wage gap salt industry, China

Parameter	unit	value	Reference to value
Standard working hours per worker i per year	hours	2240	(True Cost Initiative, 2022)
Annually net wage being paid to worker i	Euro	=267.20*12=3206.40	(Statista, 2023e)
Local or national annual living wage per worker	Euro	=12*(634+504[1])/2/1,8[2]*0,92[3]= 3489.87	(Andersen et al., 2023a; Andersen et al., 2023b)
number of workers		=48476*0.5=24238	(IPP Journal, 2022)
Salt production annually	kg	49850000000	
Salt content per f.u. cultured meat	kg	0.224	(Sinke et al., 2023)
Calculation	=(3489.87-3206.40)*24238		
Annual living wage gap	Euro	6870665.07	
Calculation	=6870665.07/49850000000*0.224		
Living wage gap per f.u. cultured meat	Euro	0.00	

[1] Average living wage from two places in China per month

[2] Living wage is measured per 1.8 workers per household. 1 worker should earn a part of the total household income.

[3] Conversion from dollar to euro.

Table 29

Living wage gap hydrolysate amino acids, Brazil

Parameter	unit	value	Reference to value
Standard working hours per worker i per year	hours	2240	(True Cost Initiative, 2022)
Annually net wage being paid to worker i	Euro	=12*241=2892	(Statista, 2023j)
Local or national annual living wage per worker	Euro	=12*436.19= 5234.28	(Medinaceli et al., 2023)
number of workers		=262000*(0,25[1])=65500	(DIEESE, 2022)
Soy production annually	kg	1.56E+11	
Soy per f.u. cultured meat	kg	0.544	(Sinke et al., 2023)
Calculation	=(5234.28-2892)*65500		
Annual living wage gap	Euro	153419340	
Calculation	=153419340/1.56E+11*0.544		
Living wage gap per f.u. cultured meat	Euro	0.00	

[1]Assumed that ¼ of the soy workers earn the minimum wage.

Table 30

OHS maize and wheat production, Netherlands

Parameter	**unit**	**value**	**Reference to value**
Number of fatal accidents per year		=(3+3[1])*(0.05[2]/100)=0.003	(Statista, 2023h; International Labour Organization, 2023)
Number of fatalities per killed worker j (equals 1)		1	(True Cost Initiative, 2022)
Disability weight (equals 1 in case of death)		1	(True Cost Initiative, 2022)
National life expectancy	Year	79.7	(CBS, 2022a)
Age of worker j	Year	42.4	(CBS, n.d.)
Number of injuries per injury type k per year		=(3+3)*0.06[3]=0.36	(Statista, 2023h; International Labour Organization, 2023)
Disability weight of injury type k		0.2[4]	
Number of people with injury		=(3+3)*0.06=0.36	
Age of worker k		42.4	(CBS, n.d.)
Number of people with illness		=3*0.025[5]=0.075	(Statista, 2023h; International Labour Organization, 2023)
Number of days with illness type l per year	Days	30	Own assumption
Disability weight of illness type l		0.2[4]	
Maize yield	Kg/ha	=12.1*1000=12100	(Centraal Bureau Statistiek, 2023)
Wheat yield	Kg/ha	=9.6*1000=9600	(Centraal Bureau Statistiek, 2023)
Calculation total OHS	=((0.03*1*1)*(79.7-42.4))+(0.36*0.2*0.36*(79.7-42.4))+((0.075*30*0.2)/365)		
Work-related illness, injuries, and fatal incidents allocated to 1 ha of maize and 1 ha of wheat	DALY	1.08	
Calculation 1	=1.08*((0.569/12100)*0.5*0.05[6])		
Calculation 2	=1.08*((0.035/9600)*0.5*0.05[7])		

Parameter	unit	value	Reference to value
OHS Maize (569 grams needed per f.u.)	DALY	1.27E-06	
OHS Wheat (35 grams per f.u.	DALY	9.84E-08	

[1] 3 individuals work on 1 ha of maize, and 3 individuals work on 1 ha of wheat.

[2] 0.05% of the workers die because of non-chemical-related diseases, injuries, or excessive working hours.

[3] 6% of the workers experience work (non-chemical) related injuries

[4] To illustrate the effect of disability weights, these have been adjusted and the results are presented in Table 14. The other parameters remain constant.

[5] 3.5% of the workers experience work-related illnesses.

[6] 0.569 kg maize per f.u. cultured meat, the maize yield per ha equals 12100 kg, and maize and wheat are divided 50/50. Allocation is needed: 5% of the economic value of the farm is assumed to be 1 ha of maize.

[7] 0.035 kg wheat per f.u. cultured meat, wheat yield per ha is 9600 kg, and maize and wheat are divided 50/50. Allocation is needed: 5% of the economic value of the farm is assumed to be 1 ha of wheat.

Table 31

OHS salt production, China

Parameter	**unit**	**value**	**Reference to value**
Number of fatal accidents per year		=(48476)*(0.05[1]/100)=24	(IPP Journal, 2022)
Number of fatalities per killed worker j (equals 1)		1	(True Cost Initiative, 2022)
Disability weight (equals 1 in case of death)		1	(True Cost Initiative, 2022)
National life expectancy	Year	78	(World Bank Open Data, 2021b)
Age of worker j	Year	38	(Song et al., 2023)
Number of injuries per injury type k per year		=48476*0.06[2]=2909	(Statista, 2023h; International Labour Organization, 2023)
Disability weight of injury type k		0.2[3]	
Number of people with injury		2909	
Age of worker k		38	(Song et al., 2023)
Number of people with illness		=48476*0.025[4]=1212	(Statista, 2023h; International Labour Organization, 2023)
Number of days with illness type l per year	Days	30	Own assumption
Disability weight of illness type l		0.2[4]	
Salt production	kg	4.99E+10	(SMM, 2023)
Calculation total OHS	=((24*1*1)*(78-38))+(2909*0.2*2909*(78-38))+((1212*30*0.2)/365)		
Work-related illness, injuries, and fatal incidents allocated to salt production in China	DALY	67678759.63	
Calculation per f.u.	=67678759.63/4.99E+10*0.224		
OHS Salt (224 grams needed per f.u.)	DALY	0.0003	

[1] 0.05% of the workers die because of non-chemical-related diseases, injuries, or excessive working hours.

[2] 6% of the workers experience work (non-chemical) related injuries

[3] To illustrate the effect of disability weights, these have been adjusted and the results are presented in Table 14 The other parameters remain constant.

[4] 3.5% of the workers experience work-related illnesses.

Table 32

OHS hydrolysate amino acids, Brazil

Parameter	unit	value	Reference to value
Number of fatal accidents per year		=(262000)*(0.05[1]/100)=131	(DIEESE, 2022)
Number of fatalities per killed worker j (equals 1)		1	(True Cost Initiative, 2022)
Disability weight (equals 1 in case of death)		1	(True Cost Initiative, 2022)
National life expectancy	Year	73	(World Bank Open Data, 2021a)
Age of worker j	Year	32.4	(Statista, 2023d)
Number of injuries per injury type k per year		=262000*0.06[2]=15720	(Statista, 2023h; International Labour Organization, 2023)
Disability weight of injury type k		0.2[3]	
Number of people with injury		=262000*0.06=15720	
Age of worker k		32.4	(Statista, 2023d)
Number of people with illness		=262000*0.025[4]=6550	(Statista, 2023h; International Labour Organization, 2023)
Number of days with illness type l per year	Days	30	Own assumption
Disability weight of illness type l		0.2[4]	
Soy yield	kg	1,557E+11	(OEC, n.d.-a)
Calculation total OHS	=((131*1*1)*(73-32.4))+(15720*0.2*15720*(73-32.4))+((6550*30*0.2)/365)		
Work-related illness, injuries, and fatal incidents allocated to soy production in Brazil	DALY	2006606834	
Calculation per f.u.	=2006606834/1,557E+11*0.533		

Parameter	unit	value	Reference to value
OHS soy (533 grams needed per f.u.)	DALY	0.007	

[1] 0.05% of the workers die because of non-chemical-related diseases, injuries, or excessive working hours.

[2] 6% of the workers experience work (non-chemical) related injuries

[3] To illustrate the effect of disability weights, these have been adjusted and the results are presented in Table 14. The other parameters remain constant.

[4] 3.5% of the workers experience work-related illnesses.

Table 33

True costs OHS cultured meat

Parameter	unit	value	Reference to value
OHS maize	DALY	1.27E-06	
OHS soy	DALY	0.007	
OHS Salt	DALY	0.0003	
OHS wheat	DALY	9.84E-08	
Monetization factor OHS	EUR/DALY	80000	
Calculation	=(1.27E-06+0.007+0.0003+9.48E-08)*80000		
True costs OHS	Euro	573.97	

Table 34

Gender pay gap glucose and conventional amino acids production, the Netherlands

Parameter	unit	value	Reference to value
Average salary per hour of the sex with the higher salary	Euro/hour	=2420/4/40[1]=15.13	(Jooble, n.d.)
Average salary per hour of the sex with the lower salary	Euro/hour	=1995/4/40=12.47	(Ministerie van Sociale Zaken en Werkgelegenheid, 2023b)
Number of workers of the sex with the higher salary j		3	
Number of workers of the sex with the lower salary i		3	
Standard working hours per employer per year		1840	(True Cost Initiative, 2022)
Maize yield	Kg/ha	=12.1*1000=12100	(Centraal Bureau Statistiek, 2023)
Wheat yield	Kg/ha	=9.6*1000=9600	(Centraal Bureau Statistiek, 2023)
Calculation	=3*1840*(15.13-12.47)		
GPG for 1 ha maize and 1 ha wheat	Euro	14662.50	
Calculation 1	= (0.569/12100*0.5[2])*14662.50*0.05[3]		
Calculation 2	=(0.035/9600*0.5[4])*14662.50*0.05[5]		
GPG Maize (36 plus 533 equals 569 grams needed per f.u.)	Euro	0.02	
GPG Wheat (35 grams per f.u.)	Euro	0.00	

[1] Higher salary is assumed to equal 2420 per month. This gives the hourly salary of 15.13 per hour.

[2] 0.569 kg maize per f.u. cultured meat, the maize yield per ha equals 12100 kg, and maize and wheat are divided 50/50

[3] Allocation is needed: 5% of the economic value of the farm is assumed to be 1 ha of maize.

[4] 0.035 kg wheat per f.u. cultured meat, wheat yield per ha is 9600 kg and maize and wheat are divided 50/50

[5] Allocation is needed: 5% of the economic value of the farm is assumed to be 1 ha of wheat.

Table 35

Gender pay gap cultured meat production plant, the Netherlands

Parameter	unit	value	Reference to value
Average salary per hour of the sex with the higher salary	Euro/hour	=100*0.92[1]=92	(Odegard et al., 2021)
Average salary per hour of the sex with the lower salary	Euro/hour	=92-5=87	(CBS, 2022b)
Number of workers of the sex with the higher salary j		99	(Odegard et al., 2021)
Number of workers of the sex with the lower salary i		101	(Odegard et al., 2021)
Standard working hours per employer per year		1840	(True Cost Initiative, 2022)
Cultured meat output per year	Kg	26766.67	(Odegard et al., 2021)
Calculation	=101*1840*(92-87)		
GPG cultured meat production plant	Euro	927360.00	
Calculation	=927360.00/26766.67		
GPG f.u. cultured meat	Euro	34.65	

[1] Conversion from euro to dollar is needed.

Table 36

Gender pay gap hydrolysate amino acids, Brazil

Parameter	**unit**	**value**	**Reference to value**
Average salary per hour of the sex with the higher salary	Euro/hour	2.17	
Average salary per hour of the sex with the lower salary	Euro/hour	1.50	
Number of workers of the sex with the higher salary j		=262000-(0.25*262000)*0.49= 94829[1]	(DIEESE, 2022)
Number of workers of the sex with the lower salary i[1]		(262000-(0.25*262000))*0.51= 101671[2]	(DIEESE, 2022)
Standard working hours per employer per year	hours	2240	(True Cost Initiative, 2022)
Annual soy production	Kg	1.56E+11	(OEC, n.d.-a)
Calculation	=101671*2240*(2.17-1.50)		
GPG cultured meat production plant	Euro	23172944.86	
Calculation	=23172944.86/1.56E+11*0.544		
GPG f.u. cultured meat	Euro	0.00	

[1] A total of 262000 people in the soy industry. Assumed that ¼ earns less than the living wage. Hence, these individuals need to be subtracted. Of the remaining individuals it is assumed that 49% is female.

[2] A total of 262000 people in the soy industry. Assumed that ¼ earns less than the living wage. Hence, these individuals need to be subtracted. Of the remaining individuals it is assumed that 51% are female.

Appendix 3: True costs baseline calculations conventional meat.

Table 37

True costs GHG emissions conventional meat

Parameter	unit	value	Reference to value
GHG emissions	tonne CO2 eq	=34.9/1000	(Sinke et al., 2023)
Monetization factor GHG emissions	EUR2017/tonne CO2 eq	116	(True Cost Initiative, 2022)
Calculation	=(34.9/1000)*116		
True costs GHG emissions	Euro	4.05	

Table 38

Feed input per kg conventional meat. Based upon (van Paassen et al., 2019).

	Kg input per kg meat	**Country 1**	**Kg input per kg meat**	**Country 2**
kg grass per kg meat	41.09	Ireland		
Kg grass silage per kg meat	12.78	Ireland		
kg Barley per kg meat	0.38	UK	0.38	Ireland
kg Rapeseed meal per kg meat	0.39	USA		
kg Soy per kg meat	0.31	Brazil		
kg Maize per kg meat	0.55	USA		
Total kg per kg meat	**55.87**			

Table 39

Land use is divided among feed production countries.

Total land use	ha	0.00243	(Sinke et al., 2023)
Country	**Feed input [kg]**	**Land use [ha]**	
Ireland	=41.09+12.78+0.38=54.25	=54.25/55.87*0.00243=0.00236	
UK	0.38	=0.38/55.87*0.00243=0.00002	
USA	=0.39+0.55=0.94	=0.94/55.87*0.00243=0.00004	
Brazil	0.31	=0.31/55.87*0.00243=0.00001	
Total feed per kg meat [kg]	55.87		(van Paassen et al., 2019),.

Table 40

Soil loss Ireland

Ireland			
Parameter	**unit**	**value**	**Reference to value**
Soil loss	kg/ha/year	0-1000	(Borrelli et al., 2017)
Land use	ha	0.00236	(Sinke et al., 2023; van Paassen et al., 2019),.
Calculation	Min =0*0.00236=0 Max =1000*0.00236=2.36		

Table 41

Soil loss United Kingdom

United Kingdom			
Parameter	**unit**	**value**	**Reference to value**
Soil loss	kg/ha/year	0-1000	(Panagos et al., 2014)
Land use	ha	0.00002	(Sinke et al., 2023; van Paassen et al., 2019)
Calculation	Min =0*0.00002=0 Max =1000*0.0002=0.016		

Table 42

Soil loss USA

USA			
Parameter	**unit**	**value**	**Reference to value**
Soil loss	kg/ha/year	0-20000	(Panagos et al., 2014)
Land use	ha	0.00004	(Sinke et al., 2023; van Paassen et al., 2019)
Calculation	Min =0*0.00004=0 Max =20000*0.00004=0.82		

Table 43

Soil loss Brazil

Brazil			
Parameter	**unit**	**value**	**Reference to value**
Soil loss	kg/ha/year	0-20000	(Panagos et al., 2014)
Land use	ha	0.00001	(Sinke et al., 2023; van Paassen et al., 2019)
Calculation	Min =0*0.00001=0 Max =20000*0.00001=0.27		

Table 44

True costs soil erosion conventional meat

Parameter	**unit**	**value**	**Reference to value**
Soil loss	kg/ha/year	0-(0.27+0.82+0.016+2.36)= 0-3.46	
Monetization factor soil erosion	EUR/kg soil loss	=27.38*0.92[a]	(True Cost Initiative, 2022)
Calculation	=0.00*(27.38*0.92) =3.46*(27.38*0.92)		
True costs GHG emissions	Euro	0.00-87.24	

[a]conversion from dollar to euro

Table 45

True costs water stress conventional meat

Parameter	**unit**	**value**	**Reference to value**
Water use	M3	0.253	(Sinke et al., 2023)
Aqueduct baseline water stress factor		0.1	(Aqueduct, n.d.)
Monetization factor water stress	EUR2017/m3	1	(True Cost Initiative, 2022)
Calculation	=1*0.1*0.253		
True costs GHG emissions	Euro	0.03	

Table 46

True costs water pollution conventional meat

Parameter	unit	value	Reference to value
Marine eutrophication	kg N eq	0.144	(Sinke et al., 2023)
Freshwater eutrophication	Kg p eq	0.00174	(Sinke et al., 2023)
Monetization factor nitrogen	EUR2017/kg N	1.75	(True Cost Initiative, 2022)
Monetization factor phosphor	EUR2017/kg P	12.76	(True Cost Initiative, 2022)
Calculation	=(0.144*1.75)+(0.00174*12.76)		
True costs GHG emissions	Euro	0.27	

Table 47

True costs acidification conventional meat

Parameter	unit	value	Reference to value
Terrestrial acidification	Kg SO2 eq	0.784	(Sinke et al., 2023)
Monetization factor acidification	EUR2017/kg SO2-eq	8.75	(True Cost Initiative, 2022)
Calculation	=8.75*0.784		
True costs GHG emissions	Euro	6.86	

Table 48

True costs eco-toxicity conventional meat

Parameter	unit	value	Reference to value
Terrestrial ecotoxicity	kg 1,4-DCB eq	12.8	(Sinke et al., 2023)
Freshwater ecotoxicity	kg 1,4-DCB eq	0.624	(Sinke et al., 2023)
Marine ecotoxicity	kg 1,4-DCB eq	0.132	(Sinke et al., 2023)
Monetization factor terrestrial ecotoxicity	EUR/kg 1,4-DCB eq	0.0003	(True Price Foundation, 2021)
Monetization factor freshwater ecotoxicity	EUR/kg 1,4-DCB eq	0.0406	(True Price Foundation, 2021)
Monetization factor marine ecotoxicity	EUR/kg 1,4-DCB eq	0.0019	(True Price Foundation, 2021)
Calculation	=(12.8*0.0003)+(0.624*0.0406)+(0.132*0.0019)		
True costs GHG emissions	Euro	0.03	

Table 49

True costs human toxicity conventional meat

Parameter	unit	value	Reference to value
Human carcinogenic toxicity	kg 1,4-DCB eq	0.00821	(Sinke et al., 2023)
Human non-carcinogenic toxicity	Kg 1,4-DCB eq	65.5	(Sinke et al., 2023)
Conversion factor carcinogenic toxicity	DALY/1,4-DCB eq	0.00000332	(True Price Foundation, 2021)
Conversion factor non-carcinogenic toxicity	DALY/1,4-DCB eq	0.00000000665	(True Price Foundation, 2021)
Monetization factor	EUR/DALY	80000	(True Cost Initiative, 2022)
Calculation	=((0.00821*0.00000332)+(65.5*0.00000000665))*80000		
True costs GHG emissions	Euro	0.04	

Table 50

Living wage gap grass, grass silage, and the cattle farm, Ireland

Parameter	**unit**	**value**	**Reference to value**
Standard working hours per worker i per year	hours	2240	(True Cost Initiative, 2022)
Annually net wage being paid to worker i	Euro	=12.91*40*4*12[1]=24787.20	(Payscale, n.d.)
Local or national annual living wage per worker	Euro	=14.80*40*4*12=28416	(Social Justice Ireland, 2023)
number of workers		3[2]/5	
Output farm meat annually	kg	11700	(van Paassen et al., 2019)
Calculation	=(28416-24787.20)*(3/5)		
Annual living wage gap	Euro	2177.28	
Calculation	=2177.28/11700*0.96[3]		
Living wage gap per f.u. conventional meat	Euro	0.18	

[1] 4 weeks per month, 40 hours per week, 12 months a year.

[2] 3 workers on the farm and 1/5 out of the workers in Ireland receive less than the living wage.

[3] 0.96 can be allocated to live weight.

Table 51

Living wage gap soy, Brazil

Parameter	unit	value	Reference to value
Standard working hours per worker i per year	hours	2240	(True Cost Initiative, 2022)
Annually net wage being paid to worker i	Euro	=12*241=2892	(Statista, 2023j)
Local or national annual living wage per worker	Euro	=12*436.19= 5234.28	(Medinaceli et al., 2023)
number of workers		=262000*(0,25[1])=65500	(DIEESE, 2022)
Soy production annually	kg	1.56E+11	
Soy per f.u. conventional meat	kg	0.31	(Sinke et al., 2023)
Calculation	=(5234.28-2892)*65500		
Annual living wage gap	Euro	153419340	
Calculation	=153419340/1.56E+11*0.31		
Living wage gap per f.u. conventional meat	Euro	0.00	

[1] Assumed that ¼ of the soy workers earn the minimum wage.

Table 52

Living wage gap barley, Ireland

Parameter	**unit**	**value**	**Reference to value**
Standard working hours per worker i per year	hours	2240	(True Cost Initiative, 2022)
Annually net wage being paid to worker i	Euro	=12.91*40*4*12[1]=24787.20	(Payscale, n.d.)
Local or national annual living wage per worker	Euro	=14.80*40*4*12=28416	(Social Justice Ireland, 2023)
number of workers per ha Barley		3[2]/5	
Barley yield	Kg/ha	6200	(Strutt & Parker, 2020).
Input Barley per f.u. conventional meat	kg	0.38	(van Paassen et al., 2019)
Calculation	=(28416-24787.20)*(3/5)		
Annual living wage gap farm	Euro	2177.28	
Calculation	=2177.28/6200*0.05*0.38[3]		
Living wage gap per f.u. conventional meat	Euro	0.01	

[1] 4 weeks per month, 40 hours per week, 12 months a year.

[2] 3 workers on the farm and 1/5 out of the workers in Ireland receive less than the living wage.

[3] 5% of the farm income can be allocated to 1 ha of Barley. In addition, the yield per ha is 6200 kg.

Table 53

OHS slaughterhouse and cattle farm, Ireland

Parameter	unit	value	Reference to value
Number of fatal accidents per year		=(0.00025+0.00001[1])*(0.05[2]/100)= 0.00000013	(Statista, 2023h; International Labour Organization, 2023)
Number of fatalities per killed worker j (equals 1)		1	(True Cost Initiative, 2022)
Disability weight (equals 1 in case of death)		1	(True Cost Initiative, 2022)
National life expectancy	Year	82	(World Bank, 2021a)
Age of worker j	Year	37.3	(Statista, 2023c)
Number of injuries per injury type k per year		=(0.00025+0.00001[1])*0.06[3]= 0.0000156	(Statista, 2023h; International Labour Organization, 2023)
Disability weight of injury type k		0.2[4]	
Number of people with injury		=(0.00025+0.00001[1])*0.06= 0.0000156	
Age of worker k	year	37.3	(Statista, 2023c)
Number of people with illness		=(0.00025+0.00001[1])*0.025[5]= 0.0000065	(Statista, 2023h; International Labour Organization, 2023)
Number of days with illness type l per year	Days	30	Own assumption
Disability weight of illness type l		0.2[4]	
Calculation total OHS	=((0.00000013*1*1)*(82-37.3))+(0.0000156*0.2*0.0000156*(82-37.3))+((0.0000065*30*0.2)/365)		
OHS Slaughterhouse and cattle farm	DALY	5.92E-06	

[1] to produce 1 kg of conventional meat, 0.00025 farmers are needed on the cattle farm and 0.00001 workers in the slaughterhouse.

[2] 0.05% of the workers die because of non-chemical-related diseases, injuries, or excessive working hours.

[3] 6% of the workers experience work (non-chemical) related injuries

[4] To illustrate the effect of disability weights, these have been adjusted and the results are presented in Table 16. The other parameters remain constant.

[5] 2.5% of the workers experience work-related illnesses.

Table 54

OHS barley production, Ireland

Parameter	**unit**	**value**	**Reference to value**
Number of fatal accidents per year		$=3*(0.05^2/100)=0.0015$	(Statista, 2023h; International Labour Organization, 2023)
Number of fatalities per killed worker j (equals 1)		1	(True Cost Initiative, 2022)
Disability weight (equals 1 in case of death)		1	(True Cost Initiative, 2022)
National life expectancy	Year	82	(World Bank, 2021a)
Age of worker j	Year	37.3	(Statista, 2023c)
Number of injuries per injury type k per year		$=3*0.06^3=0.18$	(Statista, 2023h; International Labour Organization, 2023)
Disability weight of injury type k		0.2^4	
Number of people with injury		0.18	
Age of worker k	year	37.3	(Statista, 2023c)
Number of people with illness		$=3* 0.025^5=0.075$	(Statista, 2023h; International Labour Organization, 2023)
Number of days with illness type l per year	Days	30	Own assumption
Disability weight of illness type l		0.2^4	
Barley yield	Kg/ha	6200	(Strutt & Parker, 2020).
Input Barley per f.u. conventional meat	kg	0.38	(van Paassen et al., 2019)
Calculation OHS 1 ha of Barley	$=((0.0015*1*1)*(82-37.3))+(0.18*0.2*0.18*(82-37.3))+((0.075*30*0.2)/365)*0.05^6$		
OHS 1 ha of Barley	DALY	0.36	
Calculation OHS per f.u.	=0.36/6200*0.38		
OHS per f.u. conventional meat	DALY	2.19E-05	

[1] to produce 1 kg of conventional meat, 0.00025 farmers are needed on the cattle farm and 0.00001 workers in the slaughterhouse.

[2] 0.05% of the workers die because of non-chemical-related diseases, injuries, or excessive working hours.

[3] 6% of the workers experience work (non-chemical) related injuries

[4] To illustrate the effect of disability weights, these have been adjusted and the results are presented in Table 16. The other parameters remain constant.
[5] 2.5% of the workers experience work-related illnesses.
[6] Allocated to 1 ha of Barley

Table 55

OHS rapeseed production, USA

Parameter	unit	value	Reference to value
Number of fatal accidents per year		=3*(0.05[1]/100)=0.015	
Number of fatalities per killed worker j (equals 1)		1	(True Cost Initiative, 2022)
Disability weight (equals 1 in case of death)		1	(True Cost Initiative, 2022)
National life expectancy	Year	76	(World Bank, 2021b)
Age of worker j	Year	41.8	(U.S. Bureau of Labor Statistics, 2023)
Number of injuries per injury type k per year		=3*0.06[2]=0.18	(Statista, 2023h; International Labour Organization, 2023)
Disability weight of injury type k		0.2[3]	
Number of people with injury		0.18	
Age of worker k		41.8	(U.S. Bureau of Labor Statistics, 2023)
Number of people with illness		=3*0.025[4]=0.075	(Statista, 2023h; International Labour Organization, 2023)
Number of days with illness type l per year	Days	30	Own assumption
Disability weight of illness type l		0.2[4]	
Rapeseed yield per ha	Kg/ha	1460	(Our World in Data, 2021)
Calculation total OHS	=(0.015*1*1)*(76-41.8))+(0.18*0.2*0.18*(76-41.8))+((0.075*30*0.2)/365)*0.05[5]		
OHS 1 allocated to 1 ha of Rapeseed	DALY	0.27	
Calculation per f.u.	=0.27/1460*0.390*0.37[6]		
OHS Rapeseed (390 grams needed per f.u.)	DALY	0.0003	

[1] 0.05% of the workers die because of non-chemical-related diseases, injuries, or excessive working hours.

[2] 6% of the workers experience work (non-chemical) related injuries

[3] To illustrate the effect of disability weights, these have been adjusted and the results are presented in Table 16. The other parameters remain constant.

[4] 2.5% of the workers experience work-related illnesses.

[5] 5% of the economic value of the farm can be allocated to 1 ha of rapeseed.

[6] 0.37 is the allocation factor of rapeseed meal vs oil.

Table 56

OHS maize production, USA

Parameter	unit	value	Reference to value
Number of fatal accidents per year		=3*(0.05[1]/100)=0.015	
Number of fatalities per killed worker j (equals 1)		1	(True Cost Initiative, 2022)
Disability weight (equals 1 in case of death)		1	(True Cost Initiative, 2022)
National life expectancy	Year	76	(World Bank, 2021b)
Age of worker j	Year	41.8	(U.S. Bureau of Labor Statistics, 2023)
Number of injuries per injury type k per year		=3*0.06[2]=0.18	(Statista, 2023h; International Labour Organization, 2023)
Disability weight of injury type k		0.2[3]	
Number of people with injury		0.18	
Age of worker k		41.8	(U.S. Bureau of Labor Statistics, 2023)
Number of people with illness		=3*0.025[4]=0.075	(Statista, 2023h; International Labour Organization, 2023)
Number of days with illness type l per year	Days	30	Own assumption
Disability weight of illness type l		0.2[4]	
Maize yield per ha	Kg/ha	12000	(Langemeier & Zhou, 2022).
Calculation total OHS	=(0.015*1*1)*(76-41.8))+(0.18*0.2*0.18*(76-41.8))+((0.075*30*0.2)/365)*0.05[5]		
OHS 1 allocated to 1 ha of Rapeseed	DALY	0.27	
Calculation per f.u.	=0.27/12000*0.55		
OHS Rapeseed (390 grams needed per f.u.)	DALY	1.25E-05	

[1] 0.05% of the workers die because of non-chemical-related diseases, injuries, or excessive working hours.

[2] 6% of the workers experience work (non-chemical) related injuries

[3] To illustrate the effect of disability weights, these have been adjusted and the results are presented in Table 16. The other parameters remain constant.
[4] 2.5% of the workers experience work-related illnesses.
[5] 5% of the economic value of the farm can be allocated to 1 ha of maize.

Table 57

OHS soy, Brazil

Parameter	**unit**	**value**	**Reference to value**
Number of fatal accidents per year		=(262000)*(0.05[1]/100)=131	(DIEESE, 2022)
Number of fatalities per killed worker j (equals 1)		1	(True Cost Initiative, 2022)
Disability weight (equals 1 in case of death)		1	(True Cost Initiative, 2022)
National life expectancy	Year	73	(World Bank Open Data, 2021a)
Age of worker j	Year	32.4	(Statista, 2023d)
Number of injuries per injury type k per year		=262000*0.06[2]=15720	(Statista, 2023h; International Labour Organization, 2023)
Disability weight of injury type k		0.2[3]	
Number of people with injury		=262000*0.06=15720	
Age of worker k		32.4	(Statista, 2023d)
Number of people with illness		=262000*0.025[4]=6550	(Statista, 2023h; International Labour Organization, 2023)
Number of days with illness type l per year	Days	30	Own assumption
Disability weight of illness type l		0.2[4]	
Soy yield	kg	1,557E+11	(OEC, n.d.-a)
Calculation total OHS	=((131*1*1)*(73-32.4))+(15720*0.2*15720*(73-32.4))+((6550*30*0.2)/365)		
Work-related illness, injuries, and fatal incidents allocated to soy production in Brazil	DALY	2006606834	
Calculation per f.u. conventional meat	=2006606834/1,557E+11*0.31		
OHS soy [0.31 kg]	DALY	0.004	

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[1] 0.05% of the workers die because of non-chemical-related diseases, injuries, or excessive working hours.

[2] 6% of the workers experience work (non-chemical) related injuries

[3] To illustrate the effect of disability weights, these have been adjusted and the results are presented in Table 16. The other parameters remain constant.
[4] 2.5% of the workers experience work-related illnesses.

Table 58

OHS barley production, UK

Parameter	unit	value	Reference to value
Number of fatal accidents per year		=3*(0.05[1]/100)=0.0015	(Statista, 2023h; International Labour Organization, 2023)
Number of fatalities per killed worker j (equals 1)		1	(True Cost Initiative, 2022)
Disability weight (equals 1 in case of death)		1	(True Cost Initiative, 2022)
National life expectancy	Year	80.7	(World Bank, 2021c)
Age of worker j	Year	40.2	(GlobalData, 2021)
Number of injuries per injury type k per year		=3*0.06[2]=0.18	(Statista, 2023h; International Labour Organization, 2023)
Disability weight of injury type k		0.2[4]	
Number of people with injury		0.18	
Age of worker k	year	40.2	(GlobalData, 2021)
Number of people with illness		=3* 0.025[5]=0.075	(Statista, 2023h; International Labour Organization, 2023)
Number of days with illness type l per year	Days	30	Own assumption
Disability weight of illness type l		0.2[4]	
Barley yield	Kg/ha	6200	(Strutt & Parker, 2020).
Input Barley per f.u. conventional meat	kg	0.38	(van Paassen et al., 2019)
Calculation OHS 1 ha of Barley	=((0.0015*1*1)*(80.7-40.2))+(0.18*0.2*0.18*(80.7-40.2))+((0.075*30*0.2)/365)*0.05[6]		
OHS 1 ha of Barley	DALY	0.32	
Calculation OHS per f.u.	=0.36/6200*0.38		
OHS per f.u. conventional meat	DALY	1.98E-05	

[1] 0.05% of the workers die because of non-chemical-related diseases, injuries, or excessive working hours.

[2] 6% of the workers experience work (non-chemical) related injuries

[3] To illustrate the effect of disability weights, these have been adjusted and the results are presented in Table 16. The other parameters remain constant.

[4] 2.5% of the workers experience work-related illnesses.

Table 59

True costs OHS conventional meat

Parameter	**unit**	**value**
OHS slaughterhouse and cattle farm	DALY	5.92E-06
OHS barley Ireland	DALY	2.19E-05
OHS rapeseed	DALY	0.00003
OHS maize	DALY	1.25E-05
OHS barley UK	DALY	1.98E-05
OHS soy	DALY	0.0039
Monetization factor OHS	EUR/DALY	80000
Calculation	=(5.92E-06+2.19E-05+0.00003+1.25E-05+1.98E-05+0.0039)*80000	
True costs OHS	Euro	326.58

Table 60

Gender pay gap cattle farm, Ireland

Parameter	unit	value	Reference to value
Average salary per hour of the sex with the higher salary	Euro/hour	12.91	(Payscale, n.d.)
Average salary per hour of the sex with the lower salary	Euro/hour	12.17	(Department of Public Expenditure and Reform, 2022)
Number of workers of the sex with the higher salary j		=3-0.6-0.3[2]=2.1	
Number of workers of the sex with the lower salary i		=(3-0.6)*0.12=0.3[1]	
Standard working hours per employer per year		1840	(True Cost Initiative, 2022)
Meat per year on the farm		11700	(Van Paassen et al., 2019)
Calculation	=(12.91-12.17)*1840*0.3/11700		
GPG for 1 f.u. conventional meat	Euro	0.03	

[1] 3 workers on the farm. In the impact category living wage gap, it was found that 0.6 workers earn below the living wage, this worker needs to be subtracted. 12% of the farmers are female and earn a lower wage.

[2] 3 workers on the farm. In the impact category living wage gap, it was found that 0.6 workers earn below the living wage. Furthermore, 0.3 workers are female. Both need to be subtracted to find the number of male workers.

Table 61

Gender pay gap barley production, Ireland

Parameter	**unit**	**value**	**Reference to value**
Average salary per hour of the sex with the higher salary	Euro/hour	12.91	(Payscale, n.d.)
Average salary per hour of the sex with the lower salary	Euro/hour	12.17	(Department of Public Expenditure and Reform, 2022)
Number of workers of the sex with the higher salary j		=3-0.6-0.3[2]=2.1	
Number of workers of the sex with the lower salary i		=(3-0.6)*0.12=0.3[1]	
Standard working hours per employer per year		1840	(True Cost Initiative, 2022)
Barley yield per ha	Kg/ha	6200	(Strutt & Parker, 2020).
Calculation	=(12.91-12.17)*1840*0.3*0.05[3]		
GPG allocated to 1 ha Barley	Euro	19.61	
Calculation	=19.61/6200*0.38		
GPG per f.u. conventional meat	Euro	0.00	

[1] 3 workers on the farm. In the impact category living wage gap, it was found that 0.6 workers earn below the living wage, this worker needs to be subtracted. 12% of the farmers are female and earn a lower wage.

[2] 3 workers on the farm. In the impact category living wage gap, it was found that 0.6 workers earn below the living wage. Furthermore, 0.3 workers are female. Both need to be subtracted to find the number of male workers.

[3] 5% of the economic output of the farm is one hectare of barley.

Table 62

Gender pay gap maize production, USA

Parameter	unit	value	Reference to value
Average salary per hour of the sex with the higher salary	Euro/hour	16.42	
Average salary per hour of the sex with the lower salary	Euro/hour	15.71	
Number of workers of the sex with the higher salary j		=3-1.08[2]=1.92	
Number of workers of the sex with the lower salary i		=3*0.36[1]=1.08	
Standard working hours per employer per year		1840	(True Cost Initiative, 2022)
Barley yield per ha	Kg/ha	12000	(Langemeier & Zhou, 2022)
Calculation	=(16.42-15.71)*1840*0.3*0.05[3]		
GPG allocated to 1 ha maize	Euro	85.88	
Calculation	=85.88/12000*0.55		
GPG per f.u. conventional meat [0.55 kg maize]	Euro	0.00	

[1] 3 workers on the farm. 36% of the farmers are female.

[2] 3 workers on the farm of who are 1.08 are female.

[3] 5% of the economic output of the farm is one hectare of maize.

Table 63

Gender pay gap rapeseed production, USA

Parameter	unit	value	Reference to value
Average salary per hour of the sex with the higher salary	Euro/hour	16.42	
Average salary per hour of the sex with the lower salary	Euro/hour	15.71	
Number of workers of the sex with the higher salary j		=3-1.08[2]=1.92	
Number of workers of the sex with the lower salary i		=3*0.36[1]=1.08	
Standard working hours per employer per year		1840	(True Cost Initiative, 2022)
Rapeseed yield per ha	Kg/ha	1460	(Our World in Data, 2021)
Calculation	=(16.42-15.71)*1840*0.3*0.05[3]		
GPG allocated to 1 ha Rapeseed	Euro	85.88	
Calculation	=85.88/1460*0.39*0.37[4]		
GPG per f.u. conventional meat [0.39 kg maize]	Euro	0.01	

[1] 3 workers on the farm. 36% of the farmers are female.

[2] 3 workers on the farm of who are 1.08 are female.

[3] 5% of the economic output of the farm is one hectare of maize.

[4] 37% of the economic value of rapeseed can be allocated to rapeseed meal.

Table 64

Gender pay gap soy, Brazil

Parameter	**unit**	**value**	**Reference to value**
Average salary per hour of the sex with the higher salary	Euro/hour	2.17	
Average salary per hour of the sex with the lower salary	Euro/hour	1.50	
Number of workers of the sex with the higher salary j		=262000-(0.25*262000)*0.49= 94829[1]	(DIEESE, 2022)
Number of workers of the sex with the lower salary i[1]		(262000-(0.25*262000))*0.51= 101671[2]	(DIEESE, 2022)
Standard working hours per employer per year	hours	2240	(True Cost Initiative, 2022)
Annual soy production	Kg	1.56E+11	(OEC, n.d.-a)
Calculation	=101671*2240*(2.17-1.50)		
GPG cultured meat production plant	Euro	23172944.86	
Calculation	=23172944.86/1.56E+11*0.310		
GPG f.u. cultured meat	Euro	0.00	

[1] A total of 262000 people in the soy industry. Assumed that ¼ earns less than the living wage. Hence, these individuals need to be subtracted. Of the remaining individuals it is assumed that 49% is female.

[2] A total of 262000 people in the soy industry. Assumed that ¼ earns less than the living wage. Hence, these individuals need to be subtracted. Of the remaining individuals it is assumed that 51% are female.

Table 65

Gender pay gap barley production, UK

Parameter	**unit**	**value**	**Reference to value**
Average salary per hour of the sex with the higher salary	Euro/hour	16.65	(Talent.com, n.d.)
Average salary per hour of the sex with the lower salary	Euro/hour	16.26	(Office for National Statistics, 2023)
Number of workers of the sex with the higher salary j		=3-0.762[2]=2.1	
Number of workers of the sex with the lower salary i		=3*0.254[1]=0.762	
Standard working hours per employer per year		1840	(True Cost Initiative, 2022)
Barley yield per ha	Kg/ha	6200	(Strutt & Parker, 2020).
Calculation	=(16.65-16.26)*1840*0.762*0.05[3]		
GPG allocated to 1 ha Barley	Euro	27.34	
Calculation	=19.61/6200*0.38		
GPG per f.u. conventional meat	Euro	0.00	

[1] 3 workers on the farm. 25.4% are female and earn a lower wage.

[2] 3 workers on the farm minus the number of females working on the farm.

[3] 5% of the economic output of the farm is one hectare of barley.

Table 66

Gender pay gap slaughterhouse, Ireland

Parameter	unit	value	Reference to value
Average salary per hour of the sex with the higher salary	Euro/hour	16	(Economic Research Institute, n.d.-b)
Average salary per hour of the sex with the lower salary	Euro/hour	13.60	(Irish Country Meats, 2022)
Number of workers of the sex with the higher salary j		=0.00001-0.0000027= 0.0000073	
Number of workers of the sex with the lower salary i		= 0,00001*0.27[1]=0.0000027	
Standard working hours per employer per year		1840	(True Cost Initiative, 2022)
Calculation	=(16-13.60)*1840*0.0000027*96.7[2]		
GPG for 1 f.u. conventional meat	Euro	0.01	

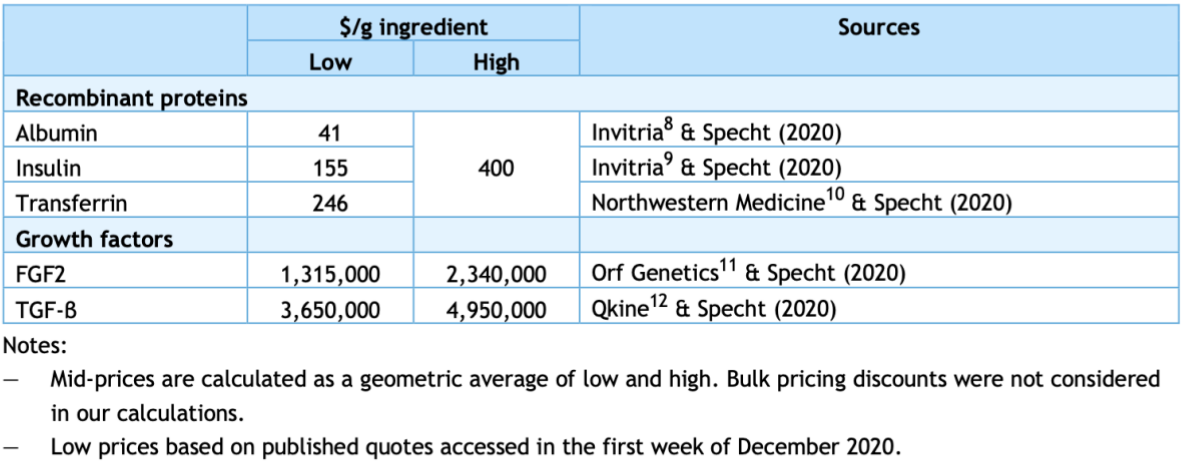
[1] 0.00001 worker per kg meat. 27% of the workers in the meat processing is female.

[2] Allocation to fresh meat

Appendix 4: Data scenario analysis

Table 67

Change in costs of different input medium ingredients for the low and high medium scenarios (Odegard et al., 2021).



	$/g ingredient		Sources
	Low	High	
Recombinant proteins			
Albumin	41	400	Invitria[8] & Specht (2020)
Insulin	155		Invitria[9] & Specht (2020)
Transferrin	246		Northwestern Medicine[10] & Specht (2020)
Growth factors			
FGF2	1,315,000	2,340,000	Orf Genetics[11] & Specht (2020)
TGF-ß	3,650,000	4,950,000	Qkine[12] & Specht (2020)

Notes:

- Mid-prices are calculated as a geometric average of low and high. Bulk pricing discounts were not considered in our calculations.
- Low prices based on published quotes accessed in the first week of December 2020.

Low input medium scenario data

Table 68

Low input medium ingredient weights

Medium ingredient	Weight [gram]
Hydrolysate amino acids	150
Glucose	319
Conventional amino acids	50
Salts	100

Hydrolysate amino acids

- Produced in Brazil.
- 262000 individuals work in the soy plantations in Brazil, producing 155,7 million tons of soy in 2021 (DIEESE, 2022; OEC, n.d.).
- To produce 150-gram hydrolysate amino acids, 150*2*(1000/780)= 384.6-gram soy seeds is needed (Ernster, 1990; Fine et al., 2015).
- The soybean yield per ha in Brazil equals 3.5 tons per ha (Statista, 2023b).

Glucose

- Maize is used as input material for the production of glucose.
- To produce 319 grams of glucose, 319* 1.34= 427.5 grams of whole maize is needed. (Round table on responsible soy, 2022).
- It is assumed that the maize is produced in the Netherlands. In addition, it is assumed that the people (or farm) who produce the maize for conventional amino acid production also produce the maize for glucose production.

- The same holds for the production: the maize for the production of conventional amino acids is from the same hectare as the maize for glucose production. To go from maize to glucose, additional production steps are needed. These additional steps are not included in the true costs model.

Conventional amino acids

- Conventional amino acids are produced from wheat and maize (Mattick et al., 2015; Marinussen & Kool, 2010).
- It is assumed that wheat and maize are produced in the Netherlands.
- A 50% mass ratio is assumed, hence 50% of the mass of conventional amino acids comes from wheat and 50% maize. To produce 50 grams of conventional amino acids, 25 grams of wheat and 25 grams of maize are needed.
- It is assumed that per ha, 3 people work on the production of maize and 3 people on the production of wheat.
- The yield per ha of maize is 12.1 tons per ha. The yield per ha of wheat equals 9.6 tons per ha. To go from maize and wheat to conventional amino acids, additional production steps are needed. These additional steps are not included in the true costs model.
- The wheat and maize production (1 ha production each) are only a part of the expected farm production of outputs and income. It is assumed that 5% of the economic value of the farm can be allocated to 1 ha of maize and 5% to 1 ha of wheat.

Salts

- Salt is assumed to be produced in China.
- In 2022, they produced 49.85 million mt salts (SMM, 2023
- This company employs approximately 48476 workers (IPP Journal, 2022). Based upon this data, it is estimated that every employer produces 1028 mton annually.
- It is assumed that the employees who work in the salt industry only produce salt. Hence, the economic allocation can be fully allocated to salt.

High input medium scenario data

Table 69

High input quantity of medium ingredients

Medium ingredient	Weight [gram]
Hydrolysate amino acids	300
Glucose	396
Conventional amino acids	100
Salts	500

Hydrolysate amino acids

- Produced in Brazil.
- 262000 individuals work in the soy plantations in Brazil, producing 155,7 million tons of soy in 2021 (DIEESE, 2022; OEC, n.d.).

- To produce 300-gram hydrolysate amino acids, 300*2*(1000/780)= 769.2-gram soy seeds is needed (Ernster, 1990; Fine et al., 2015).
- The soybean yield per ha in Brazil equals 3.5 tons per ha (Statista, 2023b).

Glucose

- Maize is used as input material for the production of glucose.
- To produce 396 grams of glucose, 396* 1,34= 530,64 grams of whole maize is needed. (Round table on responsible soy, 2022).
- It is assumed that the maize is produced in the Netherlands. In addition, it is assumed that the people (or farm) who produce the maize for conventional amino acid production also produce the maize for glucose production.
- The same holds for the production: the maize for the production of conventional amino acids is from the same hectare as the maize for glucose production. To go from maize to glucose, additional production steps are needed. These additional steps are not included in the true costs model.

Conventional amino acids

- Conventional amino acids are produced from wheat and maize (Mattick et al., 2015; Marinussen & Kool, 2010).
- It is assumed that wheat and maize are produced in the Netherlands.
- A 50% mass ratio is assumed, hence 50% of the mass of conventional amino acids comes from wheat and 50% maize. To produce 100 grams of conventional amino acids, 50 grams of wheat and 50 grams of maize are needed.
- It is assumed that per ha, 3 people work on the production of maize and 3 people on the production of wheat.
- The yield per ha of maize is 12.1 tons per ha. The yield per ha of wheat equals 9.6 tons per ha. To go from maize and wheat to conventional amino acids, additional production steps are needed. These additional steps are not included in the true costs model.
- The wheat and maize production (1 ha production each) are only a part of the expected farm production of outputs and income. It is assumed that 5% of the economic value of the farm can be allocated to 1 ha of maize and 5% to 1 ha of wheat.

Salts

- Salt is assumed to be produced in China.
- In 2022, they produced 49.85 million mt salts (SMM, 2023).
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- It is assumed that the employees who work in the salt industry only produce salt. Hence, the economic allocation can be fully allocated to salt.

Appendix 5: Results scenario analysis cultured meat

Table 70

Different cultured meat production scenarios related to changes in energy mix and quantity of medium ingredients.

	Ambitious benchmark energy mix		**Renewable scope 1 and 2**		
	Medium input	**Low input**	**High input**	**Low input**	**Medium input**
	Baseline scenario				
Natural Capital					
GHG emissions	0.33	0.27	0.58	0.34	0.47
Carbon stock	a	a	a	a	a
Soil Erosion	0.00-40.58	0.00-30.93	0.00-58.74	0.00-30.76	0.00-40.42
Soil organic matter build up	a&b	a&b	a&b	a&b	a&b
Water stress	0.01	0.01	0.02	0.01	0.01
Water pollution	0.02	0.01	0.04	0.01	0.02
Acidification	0.15	0.13	0.27	0.13	0.16
Eutrophication	a	a	a	a	a
Eco-toxicity	0.02	0.02	0.03	0.02	0.02
Human Capital					
Human toxicity	0.03	0.03	0.06	0.03	0.03
Living wage gap	0.00	0.00	0.00	0.00	0.00
Excessive working hours	a	a	a	a	a
OHS	573.97-1721.88	b	b	b	b
Social Capital					
Forced labour	a&b	a&b	a&b	a&b	a&b
Child labour	a&b	a&b	a&b	a&b	a&b
Gender pay gap	34.66	34.66	34.67	34.66	34.66
Total True costs [€]	**609.20-1797.69**	**35.13-66.05**	**35.65-94.40**	**35.19-65.96**	**35.37-75.79**

	Renewable scope 1+ 2	Global average energy mix		
	High input	**Low input**	**Medium input**	**High input**
Natural Capital				
GHG emissions	1.60	1.50	1.66	2.88
Carbon stock	a	a	a	a
Soil Erosion	0.00-57.76	0.00-29.78	0.00-39.44	0.00-56.78
Soil organic matter build up	a&b	a&b	a&b	a&b
Water stress	0.01	0.01	0.01	0.01
Water pollution	0.04	0.01	0.02	0.05
Acidification	0.33	0.21	0.25	0.42
Eutrophication	a	a	a	a
Eco-toxicity	0.02	0.01	0.01	0.01
Human Capital				
Human toxicity	0.05	0.02	0.02	0.03
Living wage gap	0.00	0.00	0.00	0.00
Excessive working hours	a	a	a	a
OHS	b	b	b	b
Social Capital				
Forced labour	a&b	a&b	a&b	a&b
Child labour	a&b	a&b	a&b	a&b
Gender pay gap	34.67	34.66	34.66	34.67
Total True costs [€]	**36.73-94.49**	**36.42-66.20**	**36.63-76.06**	**38.07-94.85**

Appendix 6: Questions asked to the authors.

How can the differentiation be made between carbon stock and soil organic carbon build-up? Both impact categories use Csoil as part of their metric and the method to calculate Csoil is exactly the same for both impact categories. This will cause double counting of the same effect, right? Do you have any recommendation on how to clearly differentiate between those impact categories?

Occupational health and safety. It is suggested to use disability weights. These disability weights are assigned to 235 individual health states. Only for hearing loss, 10 different disability weights can be found. This requires very detailed documentation of the supply in all these 235 health states. As already mentioned in the shortcomings chapter, privacy is a real issue in acquiring this data. In addition, this list of health states includes health states that can be caused by overwork or toxic substances such as strokes, cancer, or heart diseases. If these health effects are included in human toxicity or overwork and occupational health the problem of double counting is there again. How do you think this problem could be handled?

Occupational health and safety: in the metric proposed in occupational health, three different types of occupational health problems can be found: deaths, injuries, and illnesses. In the case of illnesses, it is accounted for that only a fraction of the year this illness occurs, and the occupational health is adjusted accordingly. In the case of injuries, this factor does not exist, and the costs of injuries are based on the age of the worker and the life expectancy. Doing it this way it is suggested that when an injury occurs, the worker has a lifelong problem and should be paid for that accordingly. However, from the injuries suggested in your method, an individual can recover, and the injury will only affect them for a short period of time. To cite your definition of injuries: ''Any injury, such as a cut, fracture, sprain, amputation, and so forth''. From a cut or fracture, individuals are expected to recover and start working again. Do they still need to be compensated for that cut or fracture throughout their expected lifetime?

Child labour, forced labour, and excessive working hours have included all ''0.5DALY'' in their described metrics. Two questions related to this: why the 0.5? Reading the framework, it is based around the concept of ''half the cost of treating a kidney patient for one year''. Is there any reference or scientific evidence as to why this should be 0.5? In addition, is there any information about the value of DALY in the three metrics?