External costs of locally produced cultivated meat compared with three conventional Dutch meat products

Jonna Snoek, Pelle Sinke, Elsje Oosterkamp, Nikki Odenhoven

WAGENINGEN
UNIVERSITY & RESEARCH

External costs of locally produced cultivated meat compared with three conventional Dutch meat products

Jonna Snoek,[1] Pelle Sinke,[2] Elsje Oosterkamp,[1] Nikki Odenhoven[2]

1 Wageningen Economic Research
2 CE Delft

This study was carried out by Wageningen Economic Research and financed by the partners of the PPP True Price van inzicht naar actie and the Dutch that has granted financial support through the Top Sector Agri & Food to the PPP 'True Price: from insight to action' (LWV20.286), within which framework this publication was created.

Wageningen Economic Research
Wageningen, July 2024

REPORT
2024-029

Snoek, J., P. Sinke, E. Oosterkamp, N. Odenhoven, 2024. *External costs of locally produced cultivated meat compared with three conventional Dutch meat products.* Wageningen, Wageningen Economic Research, Report 2024-029. 72 pp.; 14 fig.; 31 tab.; 76 ref.

In this research project, the external costs of RESPECTfarms' locally produced cultivated meat (TRL7) and three conventional meats (chicken, pig, and dairy cow, produced in the Netherlands) are assessed. All products are valued for a 2030 scenario, using on-farm energy partly from PV panels on stable roofs and partly from the grid, with a higher share of sustainable energy than the current mix. The TCA methodology from the PPP Echte en Eerlijke Prijs and the Horizon Europe project FOODCoST was applied. Some modules not yet developed were assessed qualitatively. Per kg boneless meat, the external costs of locally produced cultivated meat are lower than those of the conventional meats. Results should be seen in the context of research limitations due to methodological choices, data accuracy issues, and scenario analysis.

Key words: true costs, external costs, societal costs, cultivated meat, meat, animal production

This report can be downloaded for free at https://doi.org/10.18174/661741 or at www.wur.eu/economic-research (under Wageningen Economic Research publications).

P.O. Box 29703, 2502 LS The Hague, The Netherlands, T +31 (0)70 335 83 30,
E communications.ssg@wur.nl, http://www.wur.eu/economic-research. Wageningen Economic Research is part of Wageningen University & Research.

Wageningen Economic Research Report 2024-029 | Project code 2282100395

Cover photo: Shutterstock

Contents

Preface

One of the partners of the 'PPP True Price from insight to action' (van inzicht naar actie) is interested in the societal costs of cultivated meat. To answer that question the True Cost Accounting (TCA) method can be applied. In this report the societal costs, also called external costs, of cultivated meat will be compared with the societal costs of conventional meat. The report helps us to understand and experience the appliance of TCA to answer questions that support the process of product development, such as cultivated meat.

We thank the PPP partner RESPECTfarms for their contribution to this PPP by posing this relevant question. We also thank other PPP partners for making it possible to do the study within the framework of the PPP.

Finally, we thank the financers: the partners of the PPP True Price from insight to action and the Dutch Ministry of Agriculture, Nature and Food Quality that has granted financial support through the Top Sector Agri & Food to the PPP 'True Price: from insight to action' (LWV20.286), within which framework this publication was created.

Ir. O. (Olaf) Hietbrink
Business Unit Manager Wageningen Economic Research
Wageningen University & Research

Summary

S.1 Main research question: What is the difference in terms of external costs between RESPECTfarms' locally produced cultivated meat and conventional meat in 2030?

Our current food system is a great contributor to planet earth's challenges. We are facing environmental problems, food insecurity, and several social and economic issues. At the same time we face a global growing appetite for meat. The environmental and social problems caused by meat consumption and production are paid for by society in the form of external costs. If we stick to the current way of producing meat, environmental and social problems will likely increase, leading to even greater external costs.
In the Netherlands, the livestock sector also contributes to the nitrogen crisis. Therefore, Dutch policy makers are discussing a reduction of the total number of livestock animals. Consequently, Dutch livestock farmers face an uncertain future.

Cultivated meat can play a role in meeting the future demands for protein. RESPECTfarms developed a cultivated meat concept of short and transparent value chains, with the aim of local production for local demand.

RESPECTfarms wants to make it possible for farmers to participate in this new cultivated meat technology, which will allow them to create value in new ways, in times where the sustainability and profitability of a growing livestock sector is uncertain.

In this study we investigated if the external costs of locally produced cultivated meat are lower than the external costs of conventional meat. Since current cultivated meat technology is still in development, we assessed a 2030 scenario in which cultivated meat has developed to a TRL7 level.[1]

So, the main research question in this study is:

> 'What is the difference in terms of external costs between RESPECTfarms' locally produced cultivated meat and conventional meat, produced in the Netherlands in 2030?'

External costs are assessed over all activities and processes from resource extraction up to unpacked boneless meat production. For cultivated meat a species-agnostic land-based animal meat product is chosen as the reference product. RESPECTfarms' proof-of-concept farm is used as the production chain reference, but it is assumed the technology is developed to a TRL7 level (currently lab-scale). Chicken meat, pig meat and dairy cow meat produced at conventional Dutch farms are chosen as the reference conventional meat products. Beef cattle meat is not considered as no representative data of beef from Dutch beef cattle were available.

RESPECTfarms can use the insights in the external costs of its cultivated meat concept as input for a sustainable business model.

[1] While finishing this study, TRL level expectations changed to TRL8/9 level. This study has been done at the TRL 7 level as expected at the start of the study.

S.2 Message: In 2030 the external costs of RESPECTfarms' cultivated meat will probably be lower than the external costs of Dutch conventional chicken meat, pig meat and dairy cow meat

In this research project the external costs of RESPECTfarms' locally produced cultivated meat product (TRL7) and three conventional meat products (chicken meat, pig meat and dairy cow meat, produced in the Netherlands) are assessed. All products are valued for a 2030 scenario, where energy used on the farms is partly generated by Photo Voltaic (PV) panels on stable roofs and partly purchased from the grid with the expected average energy mix in the Netherlands in 2030 (which has a higher share of sustainable generated energy than the current average mix).

In the 2030 scenario, the total external costs of the locally produced cultivated meat are assessed to be lower compared to the three conventional meat products. This is shown in Table S.2.1. Assessed external costs strongly depend on the chosen scenario and the monetisation factors of the applied TCA method. As can be seen in Table S.2.1, not all externalities could be assessed quantitatively, since they lack a robust valuation method yet. These external costs are assessed qualitatively.

The largest differences in external costs between cultivated meat and conventional meat take place in the natural and the social (animal-related) capital. Within natural capital, the total external costs are lower for the cultivated meat product than for the three conventional meat products under study. However, the costs of some environmental externalities (such as fossil resource scarcity, water scarcity and, compared to chicken meat, climate change) are expected to be higher for cultivated meat than for conventional meat. The culture medium use is the main hotspot in RESPECTfarms' product system, followed by energy use at the RESPECTfarms' facility. Within the social capital, the difference in external costs is mainly caused by the animal welfare differences. To produce cultivated meat only a very small amount of animals and no slaughtering is needed, resulting in negligible external animal welfare costs for cultivated meat.
Figure S.2.1 shows a comparison of the total costs of the externalities that could be quantified. Note that externalities of which costs were not (yet) possible to be quantified are not included in this figure.

Table S.2.1 *Estimated external costs (in €) per capital and per kg meat product, produced in the Netherlands in 2030 (cradle to farm gate, respectively cradle to slaughterhouse gate)*

Externalities	RESPECTfarms' cultivated meat	Chicken meat	Pig meat	Dairy cow meat a)
Natural capital	***2.17***	***3.58***	***6.25***	***4.91***
• Climate change	0.66	0.53	1.02	1.28
• Air pollution	0.53	1.56	2.94	2.35
• Water pollution	0.10	0.26	0.44	0.32
• Soil pollution	0.04	0.03	0.05	0.03
• Land use	0.27	1.04	1.56	0.73
• Fossil resource scarcity	0.52	0.16	0.23	0.18
• Mineral resource scarcity	0.00	0.00	0.00	0.00
• Scarce water use	0.04	0.01	0.01	0.02
Social capital				
• Social hotspot analysis of feed	A switch from conventional meat to cultivated meat could decrease external social costs since cultivated meat avoids social risks in feed production (especially compared to pork production)			
• Health & Safety of workers (fatal accidents in primary production and slaughterhouses)	Estimated to be zero	0.0003	0.0004	0.0005
• Social benefits/social security of workers (slaughterhouses)	A switch from conventional meat to cultivated meat could decrease external social costs since cultivated meat avoids a considerable number of social risks hours in the slaughterhouse stage			
• Animal welfare – farming stage	negligible	4.11	1.29	0.004
• Animal welfare – slaughtering stage (incl. transport to slaughterhouses)	A switch from conventional meat to cultivated meat could decrease external costs of animal welfare at slaughter since slaughtering is not needed to produce cultivated meat			
• Animal health (antibiotics, contagious animal diseases, and zoonoses)	A switch from conventional meat to cultivated meat could decrease external costs of animal health since the amount of animals needed to produce cultivated meat is very low			
Human capital				
• Diet related consumer health	Still unknown if switch from conventional meat to cultivated meat will change external costs in human capital			
Economic capital	Currently there is no module available for economic capital			

a) The societal impact of the multi-functional dairy cattle system is divided over the multiple output products of the system (raw milk, calves, cows for slaughter >1 year). This means that the impact allocated to the dairy cow meat is relatively low compared to beef from a single-functional beef cattle system where all the impact is allocated to the beef. Since we only have data for the Dutch dairy cattle system, and considering that in the Netherlands beef from dairy cow meat is likely more consumed than beef from beef cattle, we chose to assess dairy cow meat. The environmental impact of beef from beef cattle is higher.

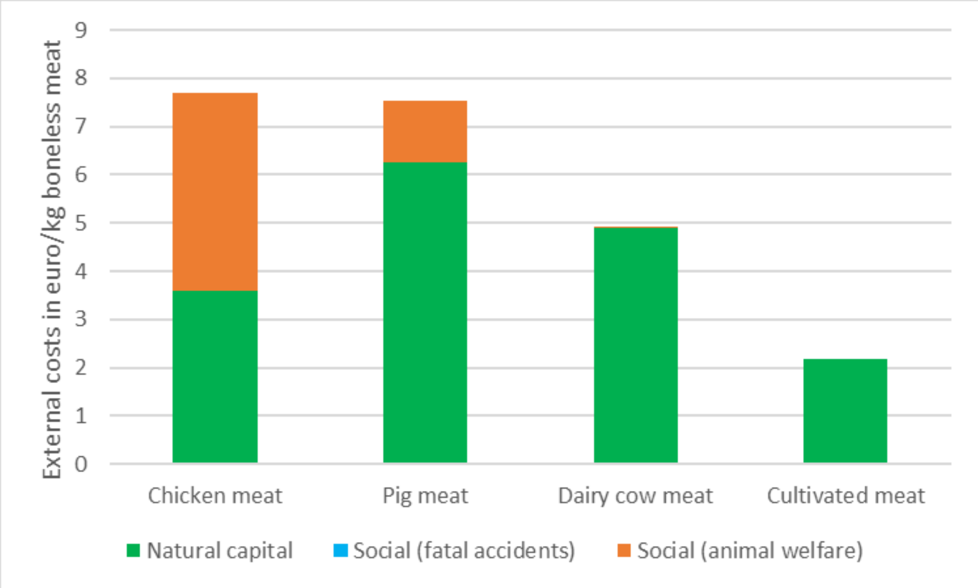


Figure S.1 *Quantitative assessment of external costs on natural capital and social capital (fatal accidents and animal welfare) of three Dutch conventional meat products and Dutch cultivated meat (expected for 2030), in euro per kg boneless meat. Note that externalities of costs which were not (yet) possible to quantify are not included in this figure*

In 2030 it is estimated that a switch from Dutch conventional chicken meat, pig meat, and dairy meat production to RESPECTfarms' locally produced cultivated meat production will probably:

- Decrease the external costs on the natural capital: although the external costs of fossil resource scarcity and scarce water use will increase, the external costs of air pollution, water pollution and land use will decrease. For climate change, the external costs of cultivated meat will increase if cultivate meat replaces chicken meat, but decrease if cultivated meat replaces pig meat and dairy cow meat.
- Decrease the external costs on the social capital, although not all social issues could be valued. A switch is expected for five reasons:
  - To avoid social risks in feed production (especially compared to pig meat production).
  - To avoid a considerable number of social risks hours in the slaughterhouse stage and it avoids risks on a decline in lung function and risks on an increase in the prevalence of asthma in the more intensive primary sectors.
  - To decrease the external costs of fatal accidents in the primary sector and slaughterhouses, although the contribution to the total assessed external costs is very low.
  - To decrease animal related social issues, especially if cultivated meat replaces chicken meat. The decrease is a consequence of the very limited amount of (donor) animals needed for cultivated meat production (0,002% compared to cattle animals). Still, animal welfare should be ensured for the limited animals used in the cultivated meat production.
  - To decrease the external costs on animal health because of the reduced number of livestock animals, although this is still largely unknown.

Within the human health capital no clear trend in external costs can be made when shifting from conventional meat to cultivated meat, because impact studies are still limited. Cultivated meat is a protein and iron supplier and can be a supplier of vitamins B1 and B12 and zinc and selenium, if added. If so, it could match the nutritional value of conventional meat. Diet-related consumer health risks (e.g., risks of stroke, diabetes, colorectal and lung cancer) of cultivated meat have not yet been investigated and therefore no external cost estimation could be done.

External costs on economic capital are not assessed since currently no assessment method has been developed.

Results of the TCA assessment must be seen in the context of research limitations caused by methodological choices, data accuracy issues, and scenario analyses.
In this study, we had to deal with the fact that currently the production of cultivated meat is developed at lab- and pilot-scale only, while the production of conventional meat is very well developed and optimised. The true cost assessment of cultivated meat is based on forecast data of a TRL7 production level. Methodological limitations of this study are caused by limitations of the applied impact assessment methods and by limitations of the valuing methods. An important limitation of the true cost assessment is the lack of true cost accounting modules for some social and human health issues. Therefore, only qualitative assessments have been done for these externalities. For economic capital, a true cost assessment method still has to be developed.

The comparison of cultivated meat with beef was done using dairy cow meat, because no representative data of beef from Dutch beef cattle were available. The Dutch beef cattle sector is very small. Most beef produced in the Netherlands comes from the dairy sector. Since milk is the economic driver of the dairy sector, external costs of the sector are mainly allocated to the milk. Therefore, the impact allocated to beef is relatively small. If beef from beef cattle was used the impact would have been larger.

S.3 Methodology: True cost accounting has been applied to assess the external costs of cultivated and conventional meat

In this study True Cost Accounting (TCA) has been applied to get insight into the external costs of the various meat products. The external costs of a product or service give a picture of the hidden societal costs of the production of food products or services. TCA includes the impact on following capitals:
- Natural capital
- Social capital
- Human capital (diet related human health)
- Economic capital (currently there is no module available for economic capital)

In this study, we applied the TCA methodology that has been developed in the PPP Echte en Eerlijke Prijs and the Horizon Europe project FOODCoST. Modules that have not been developed yet have been assessed in a qualitative way.

A four-step approach is followed to come to the TCA comparison (Figure S.2):
- Step 1: Frame and scope definition: definition of reference unit (functional unit) and system boundaries
- Step 2: Impact assessment: assessment of environmental impact, (not animal related) social impact, impact on animal welfare and animal health and impact on diet related human health
- Step 3: Valuing of impacts: monetisation of impacts assessed in step 2; quantitatively where possible, otherwise qualitatively
- Step 4: Report: reporting of results, limitations and conclusion

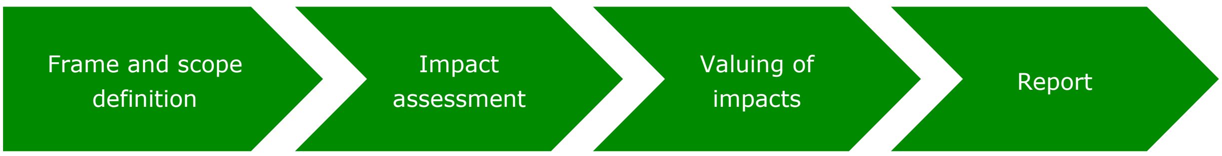


Figure S.2 *The four-step approach of the TCA assessment*

1 Need for insight into the external costs of cultivated meat in 2030 and a comparison with conventional meat

1.1 Dutch livestock farmers face an uncertain future

Our food system is a great contributor to planet earth's challenges these days. We are facing environmental problems such as climate change, biodiversity loss, water, air and soil pollution as well as food certainty problems, social and economic issues such as fair payments, (feed) grain shortages in Ukraine, and animal diseases. The livestock sector causes about 15% of the global greenhouse gas emissions. Furthermore, there are challenges in terms of animal welfare, social issues, and health-related food-issues. At the same time, we face a global growing appetite for meat. Such consequences of the environmental and social problems caused by the livestock sector are paid by society in the form of external costs. If we stick to the current way of meat production, environmental and social problems will likely increase, leading to even greater external costs.

In the Netherlands, the livestock sector also contributes to the nitrogen crisis. Therefore, Dutch policy makers are discussing a reduction of the number of livestock animals. Furthermore, despite subsidies from the Dutch government to the livestock sector, some Dutch farmers still struggle with unpaid wages. If a reduction in the number of animals will take place in the Netherlands, Dutch livestock farmers will need new business models in order to produce protein for human consumption. So, Dutch livestock farmers face an uncertain future.

Producing cultivated meat in their stables instead of livestock could be a solution for Dutch livestock farmers. RESPECTfarms' concept offers an alternative for farmers who want to continue producing meat, without the need for animal slaughter. In the Netherlands, cultivated meat is successful on a lab-scale, but not yet allowed to be sold on the market. It needs to be approved by the European Food Safety Authority (EFSA) as a novel food before it can be sold on the Dutch (and EU) market. Singapore, USA, and Israel already allow the sale of cultivated meat.

1.2 Cultivated meat and TCA could contribute to a more sustainable food system and offer an alternative business model to Dutch livestock farmers

To overcome the environmental, social and economic challenges of the livestock sector, one way is a change of animal farms into cultivated meat production farms. These cultivated meat farms should be based on a sustainable business model, where farmers earn fair wages and where governmental subsidies are fairly allocated, taking into account the external costs of the sector.

The Dutch company RESPECTfarms designed and executed a feasibility study of a 'proof-of-concept' farm where farmers can reduce their livestock while transforming their stables into a cultivated meat production plant. Key design and scope aspects of this concept farm are described in Section 2.1.1.

1.3 What is the difference in the external costs of locally produced cultivated meat and conventional meat?

RESPECTfarms faces two knowledge gaps, which have been elaborated in this project.

1. What is the societal value – in terms of positive and negative externalities – of cultivated meat compared to conventional meat?
2. How to come to a value-based business model for cultivated meat production.

To fill in these knowledge gaps, RESPECTfarms needs insight in the production of conventional meat at Dutch farms and the new production system of cultivated meat. Since currently the production of cultivated meat is developed at lab-scale only, a scenario analysis for 2030 was done in which cultivated meat production is developed to a TRL7 level[2] (estimate by RESPECTfarms) and energy use comes from more sustainable sources. Therefore, the main research question answered in this report is:

What is the difference in external costs of RESPECTfarms cultivated meat and conventional meat, produced in the Netherlands in 2030?
In this report, we assessed the external costs of RESPECTfarms' locally produced cultivated meat (TRL7) and compared those to the external costs of three Dutch conventional meat products:
- Conventional chicken meat, produced in the Netherlands
- Conventional pig meat, produced in the Netherlands
- Conventional dairy cow meat, produced in the Netherlands.

To answer the research question the True Cost Accounting method has been used to assess the external costs. True cost accounting (TCA) gives a picture of the hidden societal costs, also called external costs, of the production and consumption of food products. TCA includes the impact on following capitals:
- Natural capital
- Social capital
- Human capital (diet related human health)
- Economic capital (currently there is no module available for economic capital).

A four-step approach has been followed to come to the TCA comparison (Figure 1.1):
- Step 1: Frame and scope definition: definition of reference unit (functional unit) and system boundaries
- Step 2: Impact assessment: assessment of environmental impact, (not animal related) social impact, impact on animal welfare and animal health and impact on diet related human health
- Step 3: Valuing of impacts: monetisation of impacts assessed in step 2; quantitatively where possible, otherwise qualitatively
- Step 4: Report: reporting of results, limitations and conclusion.

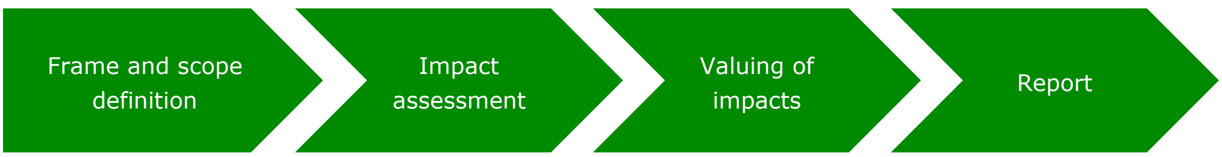


Figure 1.1 *The four-step approach of the TCA assessment*

In this study we applied the TCA methodology that has been developed in the PPP Echte en Eerlijke Prijs and the Horizon Europe project FOODCoST.

[2] While finishing this study, TRL level expectations changed to TRL8/9 level. This study has been done at the TRL 7 level as expected at the start of the study.

2 Frame and scope definition of cultivated meat and conventional meat products under study

2.1 Functional unit: 1 kg boneless meat

To make a fair comparison of the external costs of cultivated meat versus conventional meat the first step is to define the functional unit. The functional unit is the reference unit as a base for comparison. The reference unit describes the function the product fulfils. The functional unit is defined as:

> 1 kg boneless meat product (ground meat-like texture, combination of muscle and fat cells, minimum 25% dry matter content), produced in 2030 in the Netherlands, intended as protein source for human consumption, excluding packaging.

2.1.1 For cultivated meat, a species-agnostic land-based animal meat product is chosen as the reference product

RESPECTfarms' proof-of-concept farm is used as the production chain reference. The geographical scope is production in the Netherlands (NL), with sourcing of various culture medium ingredients inside the Netherlands or in Europe. The temporal scope is 2030. Energy mixes used for production of RESPECTfarms and some of the main inputs into RESPECTfarms production process are adapted to this geographical and temporal scope. For culture medium ingredients, European market mixes are assumed unless stated otherwise. It is assumed that in 2030 the technology is developed to a TRL7 level[3] (currently lab-scale). The starting cells are bovine stem cells.

RESPECTfarms' proof-of-concept farm is based on:
1. Production in 20 litres and 200 litres Single Use Wave Rocking Bioreactors that have a total working volume of 10.000 litres per farm for muscle and fat cells. Production: 104 tonnes of cultivated meat/year.
2. Local culture medium ingredients: Glucose (NL production), hydrolysate from by-product from the beer sector (brewer's spent yeast), microbially produced amino acids and proteins (EU production).
3. Solar energy, locally generated on the roof of the building, supplemented with NL-average grid mix electricity.
4. Re-use of stable building, land, and labour.[4]

The flowchart is included in Section 2.2.

2.1.2 For conventional meat three livestock production chains are chosen as the reference product

For conventional meat, the current average Dutch production chains of the following products are used for comparison:
1. Chicken meat
2. Pig meat
3. Dairy cow meat.

[3] While finishing this study TRL level expectations changed to TRL8/9 level. This study has been done at the TRL7 level as agreed at the start of the study.

[4] Capital goods are out of scope in the Agri-footprint LCA database, used for the reference products. Since the share of capital goods in the total environmental impact of 1 kg meat is limited, this is acceptable in our opinion. It is therefore decided to keep capital goods (including buildings) out of scope. An exception is made for the bioreactors, as they substitute the animal bodies used in conventional meat production. Land use of the stable building is therefore also out of scope.

The selection of chicken meat, pig meat and dairy cow meat is based on:
- The relative high share of these broiler farms, pig farms and dairy farms in total animal husbandry sector in the Netherlands (Wageningen Economic Research, 2022).
- The relative high share of these products in the total amount of meat consumption in the Netherlands (Dagevos and Verbeke, 2022; van Rossum et al., 2022). It must be noted that the mentioned studies do not make a division between beef meat from dairy cattle and beef meat from beef cattle. Beef data in these reports reflect the combined consumption of meat consumption from dairy cattle as well as from beef cattle, and of imported meat as well as meat produced in the Netherlands. If we only take into account beef that is produced in the Netherlands *and* consumed in the Netherlands most of this meat comes from dairy cattle (expert opinion WUR).
- Environmental and economic data availability for these three meat products.

It must be noted that dairy cow meat is an environmentally relatively low impact beef product compared to beef from beef cattle: the environmental impact of the multi-functional dairy cattle system is divided over the multiple output products of the system (raw milk, calves, cows for slaughter >1 year), whereas the environmental impact of the single-functional beef cattle system is fully allocated to the single output product beef. The beef cattle sector in the Netherlands is small and representative data of Dutch beef cattle farms are not available. Although no comparable data are available for the Dutch dairy cow based and suckler-based beef production systems, a literature study about European beef production systems shows higher GHG emissions per kg carcass for suckler-based systems compared to the dairy-based system (Pishgar-Komleh and Beldman, 2022). Also on a global level dairy-based production systems show lower environmental impact per kg than suckler-based systems (De Vries et al., 2015). So, the external costs related to the natural capital of conventional dairy cow meat must be seen as a low impact variant of beef.

In Figure 2.1 an overview is given of various types of conventional and cultivated meat products and their position in the market (local versus global) and their scale of production (small versus global). As can be seen in the figure, RESPECTfarms' cultivated meat is a small scale production system with a local supply chain and local sales market, whereas conventional meat is a large scale production system within a global production system and a global sales market. In this study we focus on conventional meat from Dutch farms, fed with a global feed mix.

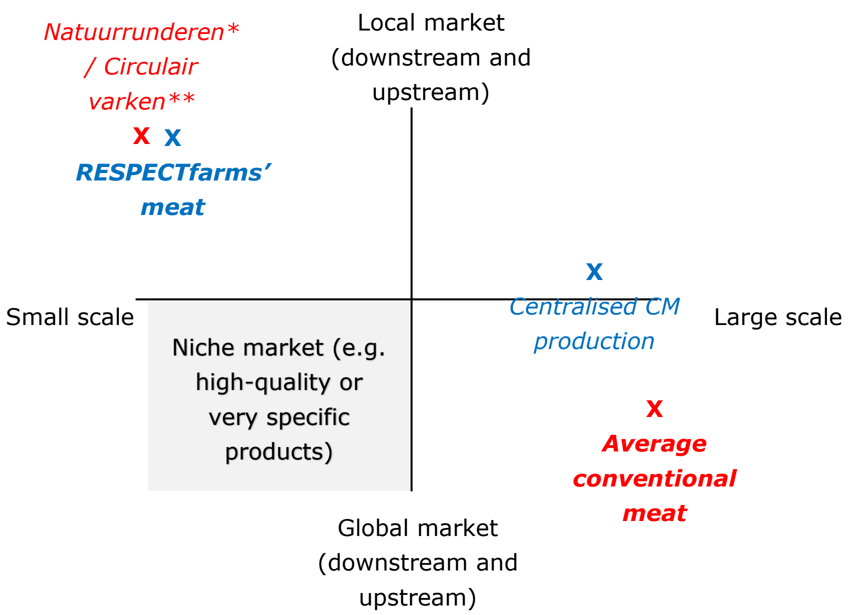


Figure 2.1 *Overview of different type of conventional meat (red) and cultivated meat (blue) products and their specific market and production scale*
**Natuurrunderen = meat from grass fed cattle used for maintenance of nature; **Circulair varken = meat from pigs farmed according to circular concepts (https://hetcirculairevarken.nl/)*
Source: Expert judgement CE Delft and Wageningen Economic Research.

2.2 System boundaries: cradle to farm-gate/slaughterhouse-gate

System boundaries define which processes and activities in the production chain are included in the analysis. System boundaries should match with the goal of the study (ISO 14044, 2006b). The goal of the study focuses on 'insight in the difference in the external costs between locally produced cultivated meat and conventional meat that can be used as input for a sustainable business model'. Therefore we take into account all activities and processes from resource extraction up to unpacked boneless meat production. For cultivated meat, this means the system boundary includes all activities from cradle-to-cultivated meat plant (Figure 2.2.). For conventional meat this means the system boundary includes all activities from cradle-to-slaughterhouse-gate (Figure 2.3). Production losses during production of the RESPECTfarms' product and the conventional meat products are included. While our model includes localised upstream processes (such as raw material input of cultivated meat), the downstream processes (such as distribution and consumption of cultivated meat) are excluded due to the high uncertainty and better alignment with the goal of the study.[5] Some processes produce more than one type of product (e.g., dairy farms produce dairy and meat). Impacts are allocated over the various co-products based on economic value (see Section 3.1 about multifunctionality).

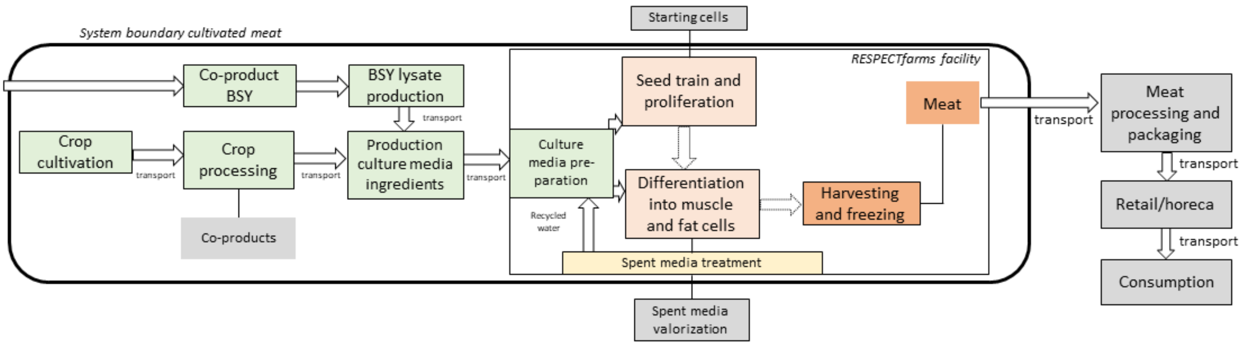


Figure 2.2 *System boundaries for cultivated meat*
Source: RESPECTfarms, CE Delft, Agri-footprint.

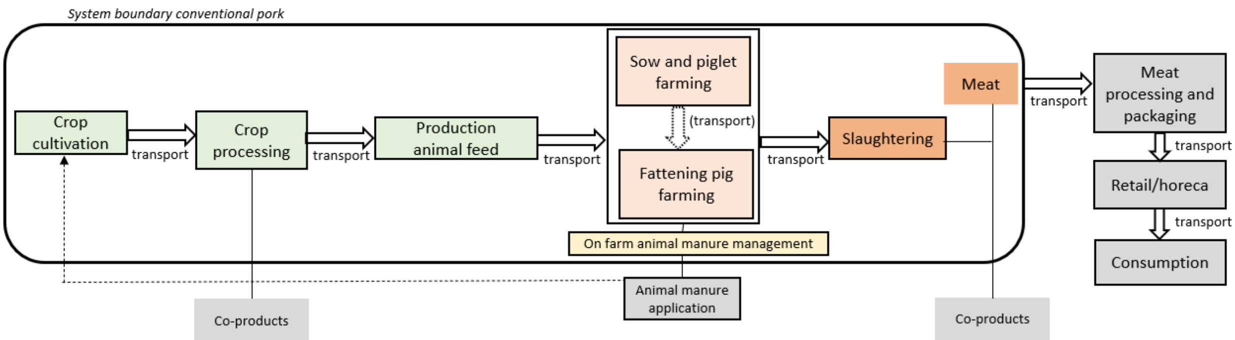


Figure 2.3 *System boundaries for conventional meat (example pork meat)*
Source: Agri-footprint 6.

[5] More information about the sustainability differences between short chain and conventional chain downstream activities can be found here: Een handreiking voor het uitvoeren van een TCA voor korte voedselketens (wur.nl)

3 Methodology: LCA, S-LCA, Welfare Quality Index score, and desk research are used as underlying methods for TCA

The external costs of a product or service give a picture of the hidden societal costs of the production of food products or services. The external costs can be assessed by a True Cost Accounting (TCA) assessment. TCA includes the impact on following capitals:

- Natural capital
- Social capital
- Human capital (diet related human health)
- Economic capital (currently there is no module available for economic capital).

In this study, we applied the TCA methodology that has been developed in the PPP Echte en Eerlijke Prijs and the Horizon Europe project FOODCoST. Impacts for which quantification modules[6] have not been developed yet, have been assessed in a qualitative way (Table 3.1).

Table 3.1 *Overview of societal impacts quantitatively and qualitatively assessed and monetised*

	Quantitatively assessed	Qualitatively assessed	Monetised
Environmental capital			
• Fossil depletion and other non-renewable resources	x		x
• Water scarcity	x		x
• Air pollution	x		x
• Soil pollution	x		x
• Water pollution	x		x
• Climate change	x		x
• Land use and biodiversity a)	x	x	x
• Noise, odour, landscape disturbance: not assessed, since currently no modules are available			
Social capital			
• Social hotspot analysis of feed	x		
• Health & Safety of workers	x	x	x
• Social benefits/ social security of workers	x		
• Animal welfare – farming stage	x		x
• Animal welfare – slaughtering stage		x	
• Animal health (antibiotics, contagious animal diseases and zoonoses)		x	
Human capital			
• Diet related consumer health		x	
Economic capital			
• Economic capital related issues are not assessed at all, since currently no module is available			

a) Quantification of biodiversity is under development. Currently there is no sufficiently robust method that fully matches with the monetisation factors of the applied TCA method of PPP Echte en Eerlijke Prijs and FOODCoST. Loss of biodiversity is partly covered by other impact categories (including land use, climate change, air and soil pollution, and water scarcity). Direct biodiversity loss due to, for example, hunting and overfishing is not covered within the current impact assessment methods. In this study, the monetisation of biodiversity losses has been linked to land use.

[6] The modules can be found here: https://trueprice.org/natural-capital-modules-for-true-price-assessment/

To assess the external costs first the impact on the natural, social, and human capital must be assessed, whereafter the assessed impacts must be monetised. Monetisation has been done with the help of monetisation factors. Monetisation factors represent the societal costs per unit of product due to an impact of that product on natural, social, and human capital. Monetisation factors can be country specific or global average, depending on the area of influence of a specific impact. For example, greenhouse gas emissions at a specific location have a global effect, while the negative consequences of the formation of fine particulate matter in the air are local. In this study, global average monetisation factors have been applied.
In this chapter, we report how the impact in the natural (Section 3.1), social (Section 3.2), and human health (Section 3.3) capital has been assessed and which monetisation factors have been used.

3.1 Natural capital is assessed with Life Cycle Assessment

The environmental impact of cultivated meat and conventional meat has been assessed with help of Life Cycle Assessment (LCA). Life Cycle Assessment is a method to quantify the environmental impacts of a product or process, considering its complete life cycle (or part of it), covering multiple environmental problems. To come to the external costs the environmental impact is valued applying the monetisation factors of the corresponding modules of PPP Echte en Eerlijke Prijs and the Horizon Europe project FOODCoST. The environmental indicators of these modules mainly match with the so-called midpoint indicators of the Life Cycle Impact Assessment method ReCiPe 2016 (H) (Huijbregts et al., 2016).
For some indicators a direct match was not possible, but an indirect match could be made (see Table 3.2). For the indicator land use, the monetisation factor of True Price is expressed in euro per mean species abundance * ha (MSA*ha), while the ReCiPe 2016 Midpoint category Land use is expressed in m^2a crop-eq. A converting calculation has been done to monetise land use (explanation given in textbox 3.1). For the indicator scarce water use, ReCiPe 2016 midpoint Water consumption is converted to water scarcity by country-specific water scarcity factors of Galgani et al. (2021b) (explanation given in Textbox 3.2). No match with ReCiPe 2016 was found for the indicators soil degradation. Therefore soil degradation could not be included in the TCA. Local impacts as noise, odour and landscape disturbance are not assessed, since no TCA module of these local impacts is available yet.

Table 3.2 *Match True Price footprint indicators and ReCiPe 2016 (H) midpoint categories*

True Price impact category	True Price footprint indicator	Corresponding LCA impact category based on ReCiPe 2016 midpoints	Unit
Contribution to climate change	GHG emissions	Climate change	kg CO_2-eq
Air pollution	Toxic emissions – Human toxicity	Human carcinogenic toxicity	kg 1,4-DCB
		Human non-carcinogenic toxicity	kg 1,4-DCB
	Particulate matter formation	Fine particulate matter formation	kg $PM_{2.5}$ eq
	Photochemical oxidant formation	Ozone formation, human health	kg NO_x eq
	Acidification	Terrestrial acidification	kg SO_2 eq
	Ionising radiation	Ionising radiation	kBq Co-60 eq
	Ozone layer depleting emissions	Stratospheric ozone depletion	kg CFC11 eq
Water pollution	Toxic emissions – Freshwater ecotoxicity	Freshwater ecotoxicity	kg 1,4-DCB
	Toxic emissions – Marine ecotoxicity	Marine ecotoxicity	kg 1,4-DCB
	Freshwater eutrophication	Freshwater eutrophication	kg P eq
	Marine eutrophication	Marine eutrophication	kg N eq
Soil pollution	Toxic emissions – Terrestrial ecotoxicity	Terrestrial ecotoxicity	kg 1,4-DCB
	Photochemical ozone formation – terrestrial ecosystems	Ozone formation, terrestrial ecosystems	kg NO_x eq
Land use	Land use	Land use – occupation	m^2a crop eq a)
	Land transformation	Land use – transformation	m^2a crop eq a)
Fossil fuel depletion	Fossil fuel depletion	Fossil resource scarcity	kg oil eq
(Other) non-renewable material depletion	(Other) non-renewable material depletion	Mineral resource scarcity	kg Cu eq
Scarce water use	Scarce water use	Water consumption b)	m^3
Soil degradation c)	Soil erosion: water- and wind erosion	x	x
	Soil Organic Carbon (SOC) loss	x	x
	Soil compaction	x	x

a) The True Price Footprint indicator Land use is expressed as mean species abundance * ha (MSA*ha), while the ReCiPe 2016 Midpoint category Land use is expressed in m^2a crop-eq. A converting calculation has been done to monetise land use; b) Water consumption is converted to scarce water use by water scarcity factors of Galgani et al. (2021b); c) Soil degradation is not presented in ReCiPe 2016 and can therefore not be included.

An attributional LCA has been applied using LCA software SimaPro version 9.5 and impact assessment methods ReCiPe (ReCiPe 2016 Midpoint (H) V1.08 / World (2010)). In case of multifunctional systems (e.g., meat from dairy cattle) economic allocation has been chosen as the default allocation method (Galgani et al., 2023a). Emissions from manure application are fully allocated to the cultivation stage of crops since they are seen as by-products of the husbandry system. Emissions from manure management on animal farms are allocated to the farm.

Textbox 3.1 Converting calculation ReCiPe 2016 midpoint Land use into True Price impact category Land use

The True Price impact category Land use is expressed in mean species abundance x hectare x year (MSA.ha.yr), while ReCiPe 2016 midpoint Land use is expressed in m^2a annual crop-equivalent. Although a direct relationship between both indicators does not exist (Goedkoop et al., 2022), an indirect relationship has been assessed based on biodiversity loss coefficients, as Land use is a major driver of loss of biodiversity (De Baan et al., 2013; Galgani et al., 2021a). Galgani et al. (2023b) report an average global value of biodiversity loss in terrestrial ecosystems in 2020 of 0.33 EUR/PDF.m^2.yr. According to Galgani et al. (2023b) (Appendix G) the monetisation factor based on Huijbregts et al. (2016) can be assessed by:

$$MF_{I,ED} = \frac{CoF_{I,ED}}{SD_e} \times B_e$$

Where:
- $CoFI,ED$: Midpoint to endpoint conversion factor for indicator (ecosystems damage) (species.yr/footprint indicator unit): 8.88 x 10^{-9} species/m^2 annual crop eq
- SDe: Average species density of ecosystem (species/m^2): 1.48 x 10^{-8} species/m^2
- Be: Valuation of biodiversity loss of ecosystem (EUR/PDF.m^2.yr): 0.33 euro/PDF.m^2.yr

So, a monetisation factor of 8.88 x 10^{-9}/1.48 x 10^{-8} x 0.33 = 0.198 euro/m^2a crop-eq is used in this study.

Textbox 3.2 Converting calculation ReCiPe 2016 midpoint Water consumption into True Price impact category Scarce water use

The True Price impact category Scarce water use is calculated as a scarcity adjusted blue water footprint, using the following formula (Galgani et al., 2021b):

WUSE = BLUEWUSE x SCARCITY

Where:
- WUSE is scarce water use (in m^3/unit output)
- BLUEWUSE is blue water use (in m^3/unit output); in this study assessed by ReCiPe2016 Midpoint water consumption
- SCARCITY is the water scarcity factor; according to the True Pricing module scarce water use normalised water scarcity factors of (Galgani et al. (2021b) are applied.

Activities in the value chain of meat products take place in different countries (e.g. feed crop cultivation takes place in various countries). To assess scarce water use a weighted scarcity factor has been applied based on the top 5 water consuming countries of the value chain.

Approach:
Per meat product value chain activities are ranked by their relative share of water consumption (cut-off 0.5%), based on ReCiPe2016 water consumption values.

Normalised water scarcity factors of the top 5 countries with highest share in total water consumption are applied to activities in these countries.

For activities taking place in other countries than top 5 countries: An ‘other countries’ water scarcity factor is defined as the weighted average of the top 5 factors.

Monetisation factors natural capital

Monetisation factors of natural capital are based on the natural capital modules of the PPP Echte en Eerlijke Prijs, also applying inflation up to 2021. Table 3.3 provides an overview of the monetisation factors used in this analysis.

Table 3.3 *Monetisation factors natural capital*

True Price impact category	True Price footprint indicator	Monetisation factor, based on 2021 (euro/unit)	Unit
Contribution to climate change	GHG emissions	0.157	kg CO_2-eq
Air pollution	Toxic emissions – Human carcinogenic toxicity	0.342	kg 1,4-DCB
	Toxic emissions – Human non-carcinogenic toxicity	0.023	kg 1,4-DCB
	Particulate matter formation	64.84	kg $PM_{2.5}$ eq
	Photochemical oxidant formation	0.09	kg NO_x eq
	Acidification	4.68	kg SO_2 eq
	Ionising radiation	8.76×10^{-04}	kBq Co-60 eq
	Ozone layer depleting emissions	56.21	kg CFC11 eq
Water pollution	Toxic emissions – Freshwater ecotoxicity	0.040	kg 1,4-DCB
	Toxic emissions – Marine ecotoxicity	0.0018	kg 1,4-DCB
	Freshwater eutrophication	203	kg P eq
	Marine eutrophication	14.07	kg N eq
Soil pollution	Toxic emissions – Terrestrial ecotoxicity	0.00025	kg 1,4-DCB
	Photochemical ozone formation – terrestrial ecosystems	2.85	kg NO_x eq
Land use	Land use	0.198	m^2a crop eq a)
	Land transformation	0.198	m^2a crop eq a)
Fossil fuel depletion	Fossil fuel depletion	0.446	kg oil eq
(Other) non-renewable material depletion	(Other) non-renewable material depletion	0.225	kg Cu eq
Scarce water use b)	Scarce water use	1.29	m^3 scarce water use
Soil degradation c)	Soil erosion: water- and wind erosion		x
	Soil Organic Carbon (SOC) loss		x
	Soil compaction		x

a) See textbox 3.2; b) Water consumption is converted to scacrce water use by water scarcity factors of (Galgani et al., 2021b); c) Soil degradation is not presented in ReCiPe 2016 and can therefore not be included.
Sources: Galgani et al. (2021a); Galgani et al. (2021b); Galgani et al. (2023b); Huijbregts et al. (2016).

3.2 Social capital is assessed with Social Life Cycle Assessment and desk study

The social impact of cultivated meat and conventional meat has been assessed with help of Social Life Cycle Assessment (S-LCA). S-LCA is a method to quantify the social impacts of a product or process, considering its complete life cycle (or part of it), covering multiple social problems. The S-LCA methodology is based on the UNEP guidelines (2020) (see Appendix 4 - Table A4.1 for the stakeholder groups and 'social impact categories' described in these guidelines). The social impact categories have been checked by expert views to determine whether impacts are to expected in conventional meat production but also in cultivated meat production. The result of this hotspot analysis and the resulting longlist have been discussed with the commissioner. In this step it was also checked whether data are available and whether TCA modules have been developed. Appendix 4 provides an overview of the longlist that was discussed with the commissioner (Table A4.2). S-LCA also includes animal health and welfare and animal health impacts on human health. These issues are discussed in the Sections 3.2.2 and 3.2.3 below. Although out of scope of this study, some supplementary information about the role of the farmer in the chain and about the relationship between general welfare, TCA and SBCA is provided in Appendix 5.

3.2.1 Social impact (not animal related)

Two 'social impact categories' have been selected for further research, i.e.: 'health and safety of workers' and 'social benefits-social security of workers'. In addition, a social risk assessment of feed was executed using the Social Hotspot Data Bank (SHDB).

Health and safety of workers (in the primary production and slaughterhouse stage)
There is a TCA module available on (fatal) accidents in the sector for monetisation. The number of accidents per FU is calculated and the monetisation value provided by Eco-costs[7] is then applied: 0.01% mortality is valued with 0.1075 euro per hour.[8] On occupational health the approach is qualitative. The safety and health effects on workers in cultivated meat production are assumed to be comparable to those in dairy farming. In the production of cultivated meat, issues in the slaughter/cutting stage are avoided.

Social benefits – social security of workers (slaughter stage)
The aim is to quantify the impacts, especially on housing conditions for migrant workers in the slaughter/cutting stage; monetisation is not possible. A desk study is executed to estimate the impact regarding these problems. They are avoided in the production of cultivated meat.

Risk assessment on social impacts of feed using the SHDB
This is a quantitative approach, but no monetisation is possible. The most important non-Western countries that supply feed ingredients for the three sectors have been determined from the Agri-footprint data (i.e., soy beans, corn, and oil palm fruits). The US dollar value (2011) of these ingredients is then input in the SHDB. SHDB calculates 'medium risk hours' related to the different values of the inputs used. These 'medium risk hours equivalents' are a sum of all risk hours. High risk hours are valued 10 times the medium risk hours. The SHDB includes data on most of the impact categories listed in the UNEP guidelines. These risk hours are largely avoided in the production of cultivated meat. The risk hours of cultivated meat have therefore been set to 0 in the comparison.

3.2.2 Animal welfare is assessed quantitatively for animal welfare conditions during the farming stage and qualitatively for the slaughtering stage

External costs related to the animal welfare impact are assessed quantitatively for animal welfare conditions during the farming stage and qualitatively for the slaughtering stage (including transport to the slaughterhouses) as currently no quantitative method is available.

The external costs related to animal welfare conditions during the farming stage are assessed by the abatement approach of valuation. The abatement costs reflect the increase in costs associated with a set of measures to achieve a level where animal welfare issues are minimised (Vissers et al., 2023; Vissers and Woltjer, 2022). External costs related to animal welfare issues have been assessed with help of the Welfare Quality Index score of the Welfare Quality Protocol (Welfare Quality Network, 2009a). A method for True Cost accounting based on this Protocol is described in (Vissers et al., 2023). The Welfare Quality Index score is an aggregated score on four welfare principles:

- good feeding
- good housing
- good health
- appropriate behaviour.

The external costs of each welfare principle is calculated based on the value of two to four underlying welfare criteria (see Table 3.4). These 12 welfare criteria are assessed by the underlying quantitative animal-based welfare measures (Vissers et al., 2023; Vissers and Woltjer, 2022; Welfare Quality Network, 2009a). See Figure 3.1.

---

7 https://www.ecocostsvalue.com/EVR/img/social%20eco-costs%20V3.3%20in%20Simapro.xlsx.
8 This amount was based on: https://www.ecocostsvalue.com/EVR/img/social%20eco-costs%20V3.3%20in%20Simapro.xlsx. The table on mortality (OHS) shows variation in value of 0.104 to 0.108 euro/hr per 0.01% mortality. We chose however to execute the monetisation step, to show the order of magnitude of external costs.

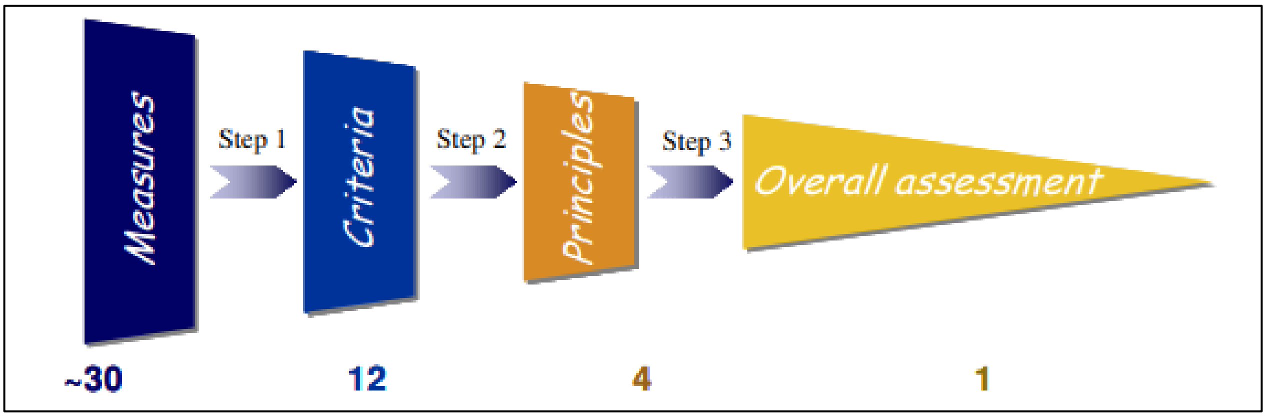


Figure 3.1 *Bottom-up approach for integrating the data on the different measures to an overall assessment of the animal unit (Welfare Quality Network, 2009b)*

Each of the four welfare principle scores is expressed on a 0 to 100 scale, where 100 corresponds to the best situation one can find in a farm. So, the theoretical best farm scores 4 x 100 = 400. The so-called 'excellence threshold' is defined for farms that score at least 80 on two principles and at least 55 on the other two principles (Vissers et al., 2023; Vissers and Woltjer, 2022). Higher scores on certain welfare principles can compensate lower scores on other welfare principles if the scores on the welfare principles are above certain thresholds defined by Vissers et al. (2023). If scores are below these thresholds, corrected scores must be calculated according to the formulars given by Vissers et al. (2023). Vissers et al. (2023) apply a minimum score threshold value of 20 points and a maximum compensation threshold of 35 points.

Table 3.4 *Animal welfare principles, criteria and measures*

Welfare principle	Welfare criteria	Measures chicken (broilers)	Measures fattening pigs	Measures dairy cattle
1. Good feeding	1. Absence of prolonged hunger	Emaciation	Body condition score	Body condition score
	2. Absence of prolonged thirst	Drinker space	Water supply	Water provision, cleanliness of water points, water flow, functioning of water points
2. Good housing	3. Comfort around resting	Plumage, cleanliness, litter quality, dust sheet test	Bursitis, absence of manure on the body	Time needed to lie down, animals colliding with housing equipment during lying down, animals lying partly or completely outside the lying area, cleanliness of flank/upper legs, cleanliness of lower legs
	4. Thermal comfort	Panting, huddling	Shivering, panting, huddling	*As yet, no measure is developed*
	5. Ease of movement	Stocking density	Space allowance	Presence of tethering, access to outdoor loafing area or pasture
3. Good health	6. Absence of injuries	Lameness, breast blister, hock burn, food pad dermatitis	Lameness, wounds on the body, tail biting	Lameness (loose housed animals), lameness (tier animals), integument alternations
	7. Absence of disease	On farm morality, culls on farm, Ascites, dehydration, septicaemia, hepatitis, pericarditis, abscess	Mortality, coughing, sneezing, pumping, twisted snouts, rectal prolapse, scouring skin condition, ruptures and hernias	Coughing, nasal discharge, ocular discharge, hampered respiration, diarrhoea, vulvar discharge, milk somatic cell count, mortality, dystocia, downer cows
	8. Absence of pain induced by management procedures	This criterion is not applied	Castration, tail docking	Disbudding/dehorning, tail docking
4. Appropriate behaviour	9. Expression of social behaviours	No measure is yet developed	Social behaviour	Agnostic behaviours
	10. Expression of other behaviours	Cover on the range, free range	Exploratory behaviour	Access to pasture
	11. Good human-animal relationship	Avoidance distance test	Fear of humans	Avoidance distance
	12. Positive emotional state	Qualitative behaviour assessment	Qualitative behaviour assessment	Qualitative behaviour assessment

Source: Welfare Quality Network (2009a).

Monetisation factors animal welfare farming stage

External costs related to the animal welfare impact during farming are assessed by the abatement approach. Currently, there is no valuation method available for the slaughtering stage. For conventional broilers and pigs (2030: Beter Leven 1 star), farmed in the Netherlands monetisation factors per kg live weight are provided by Vissers et al. (2023) (Table 3.5). Since 1 kg live weight will end up in various products (boneless meat and various co-products), the external costs of 1 kg live weight should be divided over the various co-products. It is chosen to apply economic allocation as recommended by Galgani et al. (2023a).
On average 1 kg live weight of broilers delivers 0.68 kg of meat and 0.32 kg of co-products (Blonk et al., 2022). Based on economic allocation (94.94% allocated to meat, 5.06% allocated to co-products (Blonk et al., 2022) the external costs of chicken meat is 4.11 euro/kg boneless meat (Table 3.5).

On average 1 kg live weight of fattening pigs delivers 0.57 kg of meat and 0.43 kg of co-products (Blonk et al., 2022). Based on economic allocation (97.6% allocated to meat, 2.4% allocated to co-products (Blonk et al., 2022) the external costs of pig meat is 1.29 euro/kg boneless meat (Table 3.5).

In this study, we chose to divide the external costs of animal welfare over the various products of the dairy systems, based on economic allocation, as recommended by Galgani et al. (2023a) and to stay methodologically consequent with the approach of valuing chicken meat and pig meat. For conventional dairy cows monetisation factors per kg milk (based on German farming system) are provided by Vissers et al., (2023). The study of Vissers et al., (2023) allocates the total animal welfare score to the milk the system delivers. If economic allocation was applied, 92.92% (Blonk et al., 2022) of the animal welfare score should be allocated to the milk, 4.19% to dairy cow live weight, and 2.89% to other co-products (calves). Based on economic allocation 94.58% of the impact of dairy cow live weight is allocated to boneless meat. This resulted in external costs of dairy cow meat of 0.004 euro/kg boneless beef (Table 3.5) (Galgani et al., 2023a). Since the amount of animals needed to produce cultured meat is 0.002% of the amount of (cattle) animals needed to produce conventional (beef) meat (Melzener et al., 2021), it is assumed that per kg cultivated meat external costs related to animal welfare is negligible.

Table 3.5 *External costs due to impact on animal welfare*

	External costs in Euro/kg live weight	**Allocation factor**	**External costs in Euro / kg boneless meat**
Chicken meat (BL 1)	4.33	94.94%	4.11
Pig meat (BL 1)	1.32	97.6%	1.29
Dairy cow meat	0.10/kg milk (all costs allocated to milk)	4.19% x 94.58% = 3.96%	0.004
Cultivated meat	negligible	100%	negligible

Sources: Vissers et al. (2023); Blonk et al. (2022).

3.2.3 Animal health is assessed qualitatively

For animal health and animal diseases related human health, the impact of antibiotic use, infectious animal diseases and more specifically zoonoses has been assessed. For zoonoses, the focus is on: bird flu, salmonellosis and campylobacteriosis and two infectious animal diseases from the EU category A list: swine fever and foot-and-mouth disease.

Monetisation factors animal health
No monetisation factors are available since there is currently no quantitative assessment method. Therefore, animal health impacts have been assessed qualitatively.

3.3 Human capital is assessed qualitatively

Diet-related consumer health is the main indicator for Human capital within the True Price methodology. Note that risks for human health due to zoonoses and animal antibiotic resistance/ESBLs is assessed in social capital – animal health (Section 3.2.3).

Monetisation factors human health
No monetisation factors are available since there is currently no quantitative assessment method. Therefore, diet-related consumer health impacts have been assessed qualitatively.

4 Data inventory based on primary and secondary data

Data of cultivated meat and conventional meat are collected from primary and secondary data sources. In this chapter an overview per capital of the data collection is given.

4.1 Natural capital: data from RESPECTfarms, from LCI databases and scenario studies

To assess the potential environmental impact of the various meat products we collected data of materials and other resources, energy use, emissions and losses during the cradle-to-gate value chain of the various meat products.

4.1.1 Cultivated meat: primary data of RESPECTfarms

Data of the carbon balance of the cultivated meat product and the full list of inputs and data sources are contained in Appendix 1 and 2.[9] The sections below describe important modelling choices.

Data collection and limitations
Data about the process was collected from RESPECTfarms. The proof of concept was made using theoretical calculations based on literature. As an ex-ante theoretical assessment, the main limitations are related to data quality. There are no measured data from real-world large-scale production yet for both cultivated meat and production of some of the culture medium ingredients. Estimates are therefore based on literature and physicochemical relationships. In the model, culture medium efficiencies (conversion of feedstock into final product) approach theoretical optima. It could be that realised energy and culture medium efficiencies are different for the process at scale in 2030 than the estimates used, e.g., due to site-specific characteristics, cell culture dynamics at large scales, (absence of) technological developments, or process design choices.

Description of the product system
Key characteristics of RESPECTfarms' production facility are listed in Appendix 2. Production is fed-batch, in disposable bioreactor bags (located inside bioreactor jackets). Batch time is 681 hours, and 400 kg of product is produced per batch, before production losses. Production losses are included in the LCA (3,5%). 270 batches are produced per year. Facility size is 755 m^2. Annual production (after production losses) is 104 tonnes/year. It represents cultivated meat production from bovine stem cells. The full list of system characteristics and annual estimated in- and outputs can be found in Appendix 2.

Description of the product
The final product is meat with a dry matter content of 25%, made up of 80% (mass) muscle cells and 20% fat cells. RESPECTfarms aims to produce meat using bovine stem cells.

Nutritional composition
No nutritional studies have been done yet on RESPECTfarms' product. We assume that the product is nutritionally equivalent to conventional beef, given the dry matter content ration of muscle and fat cells. More information about nutritional composition is given in Section 4.3 and Section 5.3.

Electricity mixes for 2030
LCA models for 2030 energy mixes were made for the Netherlands and for EU-average (see Table 4.1). The Dutch electricity mix for 2030 is modelled using the Klimaat- en Energieverkenning (KEV)(PBL, 2021).[10] The

[9] In the public version of the report, data in Appendix 1 and 2 are not published since data are confidential.
[10] Table 14a and appendix 'PBL KEV 2021 emissie elektriciteit'.

EU-average electricity mix for 2030 is made using own calculations based on the REmap 2030 scenario from (EC and IRENA, 2018) and the targeted share of renewables specified in REPowerEU (EC, 2022).

Table 4.1 ***Composition*** *of the average electricity mixes in 2030 for the Netherlands and the European Union, %*

Technology	NL 2030	EU 2030
Coal	0.0	3.2
Oil	0.0	0.0
Natural gas	26.6	17.5
Blast furnace gas	0.4	0.0
Nuclear	2.3	10.3
Total non-renewable	29.3	31.0
Hydropower	0.0	11.4
Biomass	2.1	10.9
Solar PV	16.4	13.7
Wind	51.7	31.2
Geothermal	0.0	1.9
Total renewable	70.2	69.0

Further information about the composition and modelling of these electricity mixes is provided in Appendix 3.

Electricity production at the farms
A majority of farms in the Netherlands is expected to have PV panels installed on the roofs in 2030.[11] We assume here that all roofs of the farms (both conventional and cultivated meat) are equipped with PV panels. In the case of the conventional meat farms, the roof area provides ample area to generate electricity to power the process when the sun shines (even when it shines a little). In the RESPECTfarms' system, additional PV panels are placed on land so that a maximum amount of hours in a year the energy demand at the facility is covered directly by the PV panels. This leaves 68% of the hours in a year when there is not enough sunlight (during night or day) to cover the energy demand of the process. Therefore the LCA models for both conventional and cultivated meat include an electricity mix of 32% from PV panel generated on-site and 68% from the 2030 average grid electricity mix in the Netherlands. Further explanation of the modelling approach is provided in Appendix 3.

Energy use
Estimates for energy consumption from the facility are based on theoretical calculations by RESPECTfarms for their specific technology and scale, supplemented with calculations made by CE Delft using existing literature. Energy profile and assumptions are provided in Appendix 2.

Culture media
Data for the culture medium composition and quantity were provided by RESPECTfarms. The culture medium used is an adaptation of Beefy-R (Stout et al., 2023), with a combination of hydrolysates and single amino acids, instead of solely single amino acids. Beefy-R uses rapeseed protein isolate (RPI) as substitute with a similar function to albumin. Levels of amino acids from hydrolysate and glucose were elevated, following carbon mass balance calculations to check whether 25% dm content in output was feasible (see Appendix 1). Total culture medium consumption per kg of cultivated meat was 73 litres, of which 47 litres for proliferation and 25 litres for differentiation (does not add up to 73 due to rounding). The media composition and volumes used during 1 year of RESPECTfarms production are listed in Table 4.1.

[11] Currently this is already installed at around 75% of farms, see https://solarmagazine.nl/nieuws-zonne-energie/i35728/75-procent-boeren-heeft-zonnepanelen-optimisme-over-meervoudig-ruimtegebruik

Table 4.1 *Overview of culture media requirements*

Media component	Per litre culture medium (mg)	Per kg cultivated meat (g)	Per year of production (kg)
Amino acids	865	63	6,780
Lysate (BSY)	4,000	290	31,355
Sugars	4,722	343	37,019
Recombinant compounds	26	2	204
Rapeseed protein isolate (RPI)	400	29	3,136
Salts	10,158	737	79,634
Vitamins	34	2	267
Others	11	1	87
Total mass of dry ingredients	20,216	1,467	158,480
Medium requirements (litre)	1	73	7,839,522

The modelling of culture media ingredient production was done in line with (Sinke et al., 2023). For recombinant proteins we included estimates for 2030 production (scaled-up compared to current production). For all other ingredients, current production models were used (already at scale). The following adaptations to Sinke et al. (2023) were made:

- Updated versions of background LCA databases Ecoinvent and Agri-footprint are used.
- Carbohydrates are modelled as glucose (adaptation of Ecoinvent process), produced in the Netherlands, using NL market mixes for maize starch and NL electricity mix for 2030.
- Inorganic salts are modelled as 1/3 NaOH, NaCl, and $NaHCO_3$ (current production, Ecoinvent processes).
- Recombinant protein is modelled using EU-average electricity mix for 2030. 500 km transport to RESPECTfarms' facility assumed. As input the same glucose production model as is used for supplying the sugars to the RESPECTfarms' medium.
- The average LCA model for microbially produced amino acids is adapted to include 'Glutamate [CN]' (AGRIBALYSE database). It therefore represents the average of lysine, threonine, glutamine and glutamate. Energy mix used for the models is EU-average, 500 km transport to RESPECTfarms' facility assumed.
- The insulin LCA model represents a higher efficiency process (more recent data).
- Lysate from locally sourced brewer's spent yeast (BSY) is added.
- Rapeseed protein isolate is added following the modelling in Nikkhah et al. (2024) and considering NL market mix rapeseed meal and EU-average electricity mix for 2030.
- Energy and water use at the dry powder media formulation plant is included in the model (confidential producer data).

Lysate from brewer's spent yeast (BSY)

RESPECTfarms aims to use hydrolysate from BSY, or another sustainable feedstock (waste stream or co-product). An LCA model for BSY was made using the following sources and assumptions:

- The composition of dried yeast hydrolysate is 50% amino acids and 50% other substances (among which carbohydrates). Only the amino acids are used, and therefore the hydrolysate does not substitute glucose or other medium components.
- The amino acids profile of BSY is not optimal for cell cultures and therefore has to be supplemented with 865 mg/L single amino acids (data from RESPECTfarms).
- The BSY is received free of environmental burden, in line with the PEFCR for beer (Blonk Consultants et al., 2018). We assume this BSY is delivered as a liquid slurry.
- Assumed that processing of BSY slurry to hydrolysate takes place at the brewery in the Netherlands, with associated electricity mix and assumed 100 km of transport to RESPECTfarms.
- The yeast hydrolysate was modelled as two steps:
  - The liquid slurry of BSY is dried, modelled after (Kobayashi et al., 2023) following the steps to dry fermentation broth into dried single cell protein;
  - The dried yeast is hydrolysed according to a patent for the preparation of yeast peptone (Angel Yeast Co Ltd, 2013). It was assumed that 1 kg of dried yeast results in 1 kg dried yeast hydrolysate.

Utilities, consumables, chemicals and waste treatment

Data for utilities, consumables, and chemicals are received from RESPECTfarms and in some cases supplemented with data from CE Delft's cultivated meat database. Wastewater treatment is modelled according to (Sinke et al., 2023). No recycling of spent media (components) is included.[12] Facility water is recycled (75%).[13] Consumables and bioreactor bags waste treatment is modelled for the Dutch market. See Appendix 2 for specifics.

Losses during production

Expected production losses of the final product were assumed to be 3.5% (see Appendix 2).

4.1.2 Conventional meat: data from LCI databases and scenario studies

To assess the environmental impact of the three conventional meat products in 2030 scenario life cycle inventory data from Agri-footprint 6 (Blonk et al., 2022) have been used:

- Chicken meat, at slaughterhouse {NL} Economic, U
- Pig meat, at slaughterhouse {NL} Economic, U
- Dairy cow meat, at slaughterhouse {NL} Economic, U

The model has been adapted to a 2030 scenario according to the following assumptions:

- Herd dynamics in 2030 are equal to current herd dynamics
- Electricity use on (breeding and fattening) farms is based on solar energy generated by PV panels (modelled as 3kWp slanted-roof installation, multi-Si panel) on stable roofs (sufficient for about 32% of electricity needed) and purchased electricity from the grid (about 68% of electricity needed). In Appendix 3 an explanation about the assumed share of solar energy and grid energy is given. Also an explanation about the assumed electricity mix (based on (Planbureau voor de Leefomgeving (PBL), 2021)–2030 scenario) for 2030 is given in Appendix 3. Above Agri-footprint processes are adapted for on farm electricity use.
- Transport of living animals from breeding farm to fattening farm and from fattening farm to slaughterhouse is adapted from Euro IV trucks to Euro V trucks since it is expected that in 2030 Euro V is the mostly used standard in the Netherlands.
- Electricity mix at compound feed factory NL is adapted to market mix 2030 (based on Planbureau voor de Leefomgeving (PBL), 2021–2030 scenario),
- Energy use at slaughterhouses is adapted, according to sector ambitions (COV, 2024) to source 20% of their energy use from sustainable sources by 2030 and an improvement in energy-efficiency of 30% by 2030 compared to 2008:
  - Agri-footprint slaughterhouse processes are adapted to 30% energy-efficiency, since slaughterhouse processes are based on 2012 energy data and it is assumed that between 2008 and 2012 no reduction has been taken place since sectors ambitions were defined by 2012 (vlees.nl, 2024).
  - Agri-footprint slaughterhouse processes are adapted for electricity mix to 2030 grid mix (based on Planbureau voor de Leefomgeving (PBL), 2021–2030 scenario), which is already based on a mix of more than 20% from sustainable sources.

Other expected developments of the Dutch animal farming sector in 2030 -based on the current (January 2024) knowledge of existing and implemented policy and continuation of past behaviour- show trends that lead to both lower product footprints (e.g., feed additives) and higher product footprints (increased animal welfare) (Beldman et al., 2020; Hoste, 2023a; Van Horne, 2023). Since expected developments show both trends to higher and to lower footprints it is assumed that the net trend is zero. So, no modelling adaptions have been made for these expected developments. A non-exhaustive list of expected developments is given below. An exhausted inventory of expected developments is out of scope of this study.

- Potential reduction of livestock in 2030 (it is expected to have at most a minor impact for a 'per unit' comparison and therefore not taken into account for the environmental assessment)

---

[12] RESPECTfarms states that 25-50% of the solids in the media could in theory be recycled, but this is not included in the model as the exact configuration and feasibility is uncertain.

[13] Technically, the spent media is treated and clean water discharged to the environment. This results in a negative water footprint for the wastewater treatment stage. The net result is a largely reduced water footprint at the facility representative of water recycling (about 75% of facility water input is recycled).

- It is expected that by 2026, and thus in 2030, the vast majority (>80%) of broiler chickens are of a slower growing breed, while this share is now approximately 40%. This development results in lower feed conversion ratio, less soy per kg feed, more space per chicken, more phosphorus and nitrogen excretion per chicken (but less per m^2) (van Harn and Bikker, 2023; van Horne, 2023)
- Increase of animal welfare restrictions in pig farming systems, possibly resulting in a shift of environmental impact (Hoste, 2023a)
- Lower carbon footprints of pig feed due to higher share of co-products and waste products (Hoste, 2023a)
- More milk production per cow and more dairy cows per ha (Beldman et al., 2020)

Other future technological advancements for conventional meat are out of scope of this project.

4.2 Social capital: data from social databases and literature

4.2.1 S-LCA (not animal related): data from desk study

Health and safety of workers (in the primary production and slaughterhouse stage)
For safety issues, the data bases of the Nederlandse Arbeidsinspectie and Sazas/CBS are scrutinised on fatal accidents in the sectors and stages in the production chain, both in the primary sector as well as the slaughterhouse stage. The Nederlandse Arbeidsinspectie provides figures on accidents and fatal accidents in the industry in general and primary sector in general. There is an average of 4.6 fatal accidents per year over five years (2018-2022) in the agricultural sector and related services (see Table 4.3). In the industry, the number of average incidents per 100,000 is lower.

Table 4.3 *Number of fatal occupational accidents, 2018-2022*

	Average per year	Average per 100,000 jobs	Number of jobs/ labour volume
Average all workers	58.4	0.7	8,697,500
Agriculture, hunting and agricultural services	4.6	4.3	107,100
Industry	8.2	1.1	772,800

Source: Nederlandse Arbeidsinspectie (2023), per two-digit SBI.

The external costs related to fatal occupational accidents in the slaughterhouse can be based on the number of workers in Heyma and Luiten (2022). We assume that these workers have full time jobs. For the primary sector, we use the number of farms as a proxy for number of full time jobs in the primary sector (See Table 4.4).

Table 4.4 *Number of Farms in 2020*

Dairy Farms	Pig Farms	Chicken Farms	Cultivated meat farms
14,729	3,557	637	0

Source: Agrimatie.nl.

For fatal accidents no data is yet available for the cultivated meat production. The number of accidents may be lower than in the present agricultural sector as half of the fatal accidents number of accidents is related to driving machines.[14]

For health issues of workers limited data is available. On average, sick leave in the Netherlands is 4.4% (Website ziekteverzuim, vzinfo.nl, based on the CBS survey on absenteeism due to illness among employees). In agriculture, the absenteeism is lower (2.6%) and in industry (all sectors) it is higher (5.4%).

[14] https://www.boerderij.nl/in-2023-tien-dodelijke-ongevallen-in-landbouw

Occupational illness or disability among employees in the pig farming and chicken farming sector is both 0.5%, for dairy farming the figure is not known (Website: Dashboard Werknemers). Note, however, that these figures are also collected from employees, but there are relatively few employees in livestock compared to the horticultural sectors. Possibly, workers continue to work in the event of illness or illness has not been reported, because there are no company doctors at smaller companies such as livestock farms. So we conclude that no data is available to quantify occupational health in the primary sector.

However, it is known that respiratory health problems among more pig farmers exists. Prevalence of the respiratory problems among pig farmers in the province Limburg and Noord-Brabant was found to be 14% based on a questionnaire in the study by van der Gulden et al. (2002), and 5% of the respondents seems to have complaints indicating that they suffer from COPD. In an additional study Gulden et al. (200) showed that long functions grow worse with years of working as pig farmer. They conclude that long-term exposure in pig stables causes a decline in lung function and an increase in the prevalence of asthma. This is due to the use of wood shavings, disinfectants and inadequate ventilation and the use of a mechanical dry feeding system (van der Gulden et al., 2002).

For cultivated meat production no data is yet is available on health problems as far as we know. In the cultivated meat chain the slaughterhouse is not part of the chain.

Social benefits – social security of workers (slaughterhouse stage)
Under this impact category we report on housing problems for migrant workers/temporary workers, because these are more vulnerable to social issues than fixed workers. Particularly in the temporary employment sector, there are many opportunities for lucrative revenue models and fraudulent constructions, some of which cross Dutch borders (Kamerstuk, 2012). The Nederlandse Arbeidsinspectie (2020) checked 1,304 employment agencies for temporary workers and found non-compliances with regulations in two-third of them. The issues are not just housing, but also include withholding too much money from salaries for transport or housing, mistreating or exploiting employees, and paying incomplete wages (Kamerstuk, 2012). The number of temporary workers in the slaughterhouse stage can be derived from Heyma and Luiten (2022), Table 4.5. For the cutting stage, we cannot deduct the number of workers from their report. The report does not address the social security vulnerabilities.

Table 4.5 *Number and type of employees in slaughterhouses in 2020*

	Red meat slaughterhouses	Chicken meat slaughterhouses
Total number	7,400	7,700
Of which migrant worker	3,626	4,158
- directly employed	1,270	1,455
- through employment agencies	2,357	2,703

Source: deducted from Heyma and Luiten (2022).

In cultivated meat production the slaughterhouse stage is not part of the chain.

Risk assessment on social impacts of feed using the SHDB (feed production)
Based on 5-year averages (2014-2018), the number three non-western countries providing feed inputs are Brazil, Argentina, and Indonesia (see Table 4.6). The US dollar values (2011) that are input in the SHDB are calculated by dividing the gross value of the production of the raw material by their production volume per country (using FAOSTAT data), see Table 4.7. Oil palm fruits and soybeans are in the same crop category in the SHDB. The SHBD is both a data bank and a risk assessment tool. The data on social impacts in the SHDB is originally based on secondary data that is publicly available (such as ILO reports).

Table 4.6 *Quantity (g) of feed ingredient sourced from non-western countries per 1 kg of boneless meat*

Ingredient	Country	Pig meat	Chicken meat	Meat from dairy cows
Soybeans	Brazil	205	278	85
	Argentina	59	75	25
Corn	Brazil		49	29
Oil palm fruits	Indonesia	368		

Source: AgriFootprint Data.

Table 4.7 *Value (USD 2011) feed ingredients sourced from non-western countries per 1 kg of boneless meat*

Ingredient	Country	Pig meat	Chicken meat	Meat from dairy cows
Soybeans	Brazil	0,09	0,12	0,04
	Argentina	0,02	0,02	0,01
Corn	Brazil		0,01	0,01
Oil palm fruits	Indonesia	0,05		

Source: calculations, based on FAOSTAT (2011: Gross Production Value/production volume) and quantity of feed ingredients.

In the cultivated meat chain the feed production and feed input production and their accompanying risks are not part of the chain.

4.2.2 Animal welfare: data from literature

Data of animal welfare conditions of chicken, pigs and dairy cows during the animal farming stage are based on a quantitative animal welfare study published in 2023 (Vissers et al., 2023).

It is expected that animal welfare conditions for chicken will be improved by 2030 (van Harn and Bikker, 2023; van Horne, 2023). It is expected that by 2026 60-80% of the Dutch chicken farms meet the requirements of Beter Leven 1 star and the other 20-40% will develop to meet the criteria of the European Chicken Commitment (ECC). The requirements that are imposed on ECC are less far-reaching than those of Beter Leven 1-star (van Harn and Bikker, 2023). We assume that by 2030 all Dutch chicken meat meets the BLK 1 star requirements. Animal welfare scores of chickens are based on Dutch broiler production system BLK 1 star as reported in (Vissers et al., 2023) (Table 4.8).

It is expected that animal welfare conditions for pigs will improve in the future as well. European legislation is one of the drivers for animal welfare improvement (van Horne, 2023a; Hoste, 2023b). We assume that by 2030 all Dutch pig meat meets the Beter Leven 1 star requirements. Animal welfare scores of pig meat are based on Dutch pig production system Beter Leven 1 star as reported in (Vissers et al., 2023) (Table 4.8). No significant animal welfare improvements are expected for dairy cows in 2030 (Beldman et al., 2020). It must be noted that recently (February 2024) research has been done to the economic costs of animal welfare improvement measures for dairy cattle in the Netherlands (Backus and Jongeneel, 2024). Since at the moment of writing it is still very uncertain if and which measures will be implemented, we did not take the suggested measures into account in the TCA of dairy meat. Animal welfare scores of dairy cow meat are based on German conventional dairy farming systems as reported in (Vissers et al., 2023), since no accurate studies of Dutch conventional dairy farming systems are available. Note that dairy farming scores are based on welfare of dairy cows (milk producing animals), welfare of calves are not assessed (Table 4.8).

Background information about a comparison of the scores between the animal groups are given in Textbox 6.1 'Why are the external costs of chicken meat much higher than pig meat?'

Table 4.8 *Principle animal welfare scores*

	Good feeding	Good housing	Good health	Appropriate behaviour
1 star Beter Leven broiler production system	55.0	56.1	58.9	16.3
1 star Beter Leven pig production system	55.0	70.6	74.4	31.7
Conventional dairy farming system	42.0	64.7	44.8	50.4

Source: (Vissers et al., 2023)

For cultivated meat production, donor animals are needed. Currently, no studies about quantitative animal welfare scores are known. Melzener et al. (2021) report that the biggest source of discomfort for donor animals is the actual act of sedation and immobilisation in a cage. Ethical evaluations will have to be made to define the maximum number of biopsies taken per session, and the maximum number of sessions per animal (Melzener et al., 2021). Apart from biopsy conditions itself also the living conditions of the donor animals are relevant.

Although animal welfare issues play a role in cultured meat production, the amount of animals needed to produce a ton of meat is much smaller. Melzener et al. (2021) report that cultured beef could theoretically reduce the required number of cattle held globally from over 1 billion to less than 100, but due to genetic diversity an amount of 20,000 is recommended. So, a much smaller amount of animals is needed to produce cultivated meat and therefore a much smaller amount of animals would suffer from potential animal welfare issues.

Table 4.9 shows the outcome of the qualitative assessment on animal welfare during the slaughtering stage (including the transport to the slaughterhouses). Regulation related to animal welfare conditions during transport of living animals is laid town in the European regulation EU 2005/01. The EFSA, the independent scientific advisory body that advises the EC, identified the various welfare consequences that animals may experience during different stages of transportation (including transport to slaughterhouses), the hazards potentially causing them, and the animal-based measures (ABMs) by which they can be assessed (European Food Safety Authority, 2022). EFSA concluded that more space, lower temperatures and shorter journeys are needed to improve the welfare of farmed animals during transport. The Dutch animal protection organisation (Dierenbescherming, 2018) mentions that beside the issues mentioned by EFSA transport is also very stressful to animals due to noise and vibrations, unknown environment and grouping of unknown animals. They also warn for risks on injuries due to rough treatment by people during catching of the animals and slippery floors.

Regulation related to animal welfare conditions during slaughtering is laid town in the European regulation Slaughter & Stunning. The legislation aims to minimise the pain and suffering of animals through the use of properly approved stunning methods. EFSA identified animal welfare issues during slaughtering (European Food Safety Authority, n.d.). In general they identified risks on consciousness following stunning. For chicken EFSA identified a number of hazards that give rise to welfare issues – such as pain, thirst, hunger or restricted movement. For pigs EFSA identified heat stress, thirst, prolonged hunger and respiratory distress mainly due to inadequate staff skills and poorly designed and constructed facilities.

Since no slaughtering is needed to produce cultivated meat, animal welfare conditions during transport to slaughterhouses and during slaughtering are not applicable and therefore assessed as zero.

Table 4.9 *Animal welfare conditions during slaughtering stage*

Sector	Animal welfare during transport to slaughterhouses	Animal welfare during slaughtering
Chicken meat production	Improvement needed on more space, lower temperatures and shorter journeys; Risks on stress and injuries	risks on consciousness following stunning; number of hazards that give rise to welfare issues – such as pain, thirst, hunger or restricted movement
Pig meat production	Improvement needed on more space, lower temperatures and shorter journeys; Risks on stress and injuries	risks on consciousness following stunning; heat stress, thirst, prolonged hunger and respiratory distress
Dairy cow meat production	Improvement needed on more space, lower temperatures and shorter journeys; Risks on stress and injuries	risks on consciousness following stunning
Cultivated meat production	Not applicable -> 0	Not applicable -> 0

4.2.3 Animal health: data from literature

Table 4.10 shows the outcome of the qualitative assessment on animal health due to chicken, pig and dairy cattle farming. A division has been made between the risks for animal health and for human health due to animal diseases and zoonoses. Although current and historical data are available for animal diseases, no quantitative data are available for the future scenario 2030. The Dutch government published the 'Nationaal actieplan versterken zoönosenbeleid' (2022-2026) that describes how to further reduce the risk of zoonotic diseases emerging and spreading in the future, and to ensure that we are prepared for possible outbreaks. The action plan focuses on prevention, detection and response.

Table 4.10 *Risks of animal diseases and zoonoses due to chicken, pig and dairy cattle farming*

Animal disease/zoonosis	Animal health risk		Human health risk	
	Sector	***Main vector***	***Sector***	***Main vector***
Bird flu	Chicken farms	Transmissible from animal to animal, animal to human and human to animal through direct contact	Chicken farms	Transmissible from animal to human and from human to animal through direct contact with animals
Swine fever	Pig farms	Transmissible from animal to animal		
Foot-and-mouth disease	Dairy cattle farms (and lower risk pig farms)	Transmissible from animal to animal. Pigs are less sensitive to the virus than cows		
Salmonellosis	Low to zero risk for animals		Chicken farms Pig farms Dairy cattle farms	Consumption of raw/undercooked meat and their preparations, also due to cross-contamination
Campylobacteriosis	Low to zero risk for animals		Chicken farms Pig farms Dairy cattle farms	Consumption of raw/undercooked meat and their preparations, also due to cross-contamination
Antibiotic resistance/ESBLs			Chicken farms Pig farms (lower risk) Dairy cattle farms	Consumption of raw/undercooked meat Environmental risks of soil and water

Sources: CLO (2021); NVWA (2024); RIVM (2024a, 2024b, 2024c); WUR (2024a, 2024b,) Bestrijding van dierziekten - WUR).

For cultivated meat no animal health assessment has been done since the amount of donor animals needed to produce 1 kg meat is negligible compared to the amount of animals needed to produce conventional meat (Melzener et al., 2021). Therefore, it is assumed that risks of animal health due to diseases and zoonoses are negligible.

Currently studies about the human health risks of cultured meat consumption are very limited. The U.S. Food and Drug Administration (FDA) ruled that

> 'foods comprised of or containing the cultured cellular chicken based material resulting from [some specific production processes] are as safe as comparable foods produced by other methods and would not contain substances that adulterate the food.'

The UK Food Standard Agency identified potential hazards in meat products manufactured from cultured animal cells (Food Safety Agency, 2024). EFSA, the independent scientific advisory body that advises the EC on novel foods, has not yet been asked to evaluate any food derived from cultured animal cells (European Food Safety Authority, 2023)(European Food Safety Authority, 2023). Therefore, it is not yet permitted to sell cultivated meat on the Dutch (or EU) market.

In literature we find that cultivated meat produced from animal cells could cause bacteria related risks for human health (McNamara and Bomkamp, 2022). If introduced to a cultivated meat production process, fast-growing bacteria such as E. coli would rapidly out-compete the animal cells. Such contamination is more likely to result in batch failures than food safety hazards. However, slow-growing mycoplasma bacteria may go undetected without active testing, and some species may be human pathogens (McNamara and Bomkamp, 2022). They did not mention about the possible impact of a salmonella or campylobacter contamination.

The overuse or misuse of antibiotics is a common global phenomenon, which substantially increases the levels of antibiotics in the environment and the rates of their spread. The resulting growth in pathogen infections and the problem of antibiotic-resistant bacteria have higher mortality and morbidity rates than those of HIV and prostate and breast cancers combined (Serwecińska, 2020). Absence or reduced use of antibiotics could make a positive contribution to further reducing the occurrence of antibiotic-resistant bacteria or Extended-spectrum beta-lactamases (ESBLs) (Delsart et al., 2020). Globally, the conventional livestock farming system uses antibiotics. However, in the Netherlands (and EU), livestock farmers are not allowed to use antibiotics other than for medical treatment. Antibiotic use in Dutch animal husbandry has been strongly reduced since 2007. Antibiotics could also be used in cultivated meat production. However, if the cultivated meat production plant is sterilised well and if the production process is monitored well on microbacterial contaminants, antibiotic use could be very limited.

4.3 Human health: data from literature and RESPECTfarms

Meat contains essential nutrients such as proteins, iron, vitamins B1 and B12. However, the consumption of red meat and especially processed meat is associated with increased risks for human health. The Dutch health council (Gezondheidsraad) concludes that it is plausible that the consumption of red meat and processed meat is associated with a higher risk of stroke, diabetes, colorectal and lung cancer (Kromhout et al., 2016). The Dutch Nutrition Center (Voedingscentrum) advises to consume 0-500 grams of meat per week with a maximum of 300 gram red meat and as little as possible processed meat (Voedingscentrum, 2024).

Currently, little research has been done to the nutritional properties of cultivated meat. Based on the available state of the art regarding cultivated meat production processes, some nutritional properties of cultivated meat could differ from conventional meat (Fraeye et al., 2020). Although both cultivated meat and conventional meat consist of muscle cells and fat cells, conventional meat also contains compounds that are accumulated in the muscle but are not produced in the muscle itself (e.g., vitamin B12). These compounds are derived from animal feed components which have been digested and modified by non-muscle organs. If these compounds are not added to the culture medium and taken up by the cells, cultivated meat will not contain these compounds (Fraeye et al., 2020). Nutritional additives can also be added during post-production processing activities to come to comparable nutritional values (Ramírez López and (RESPECTfarms), 2024).

Meat is a protein supplier. According to (Fraeye et al., 2020) it is currently not clear to what extent the protein content and composition of cultivated meat cells resemble that of conventional meat. Neither it is clear for the essential fatty acids content (Fraeye et al., 2020). According to Ramírez López (RESPECTfarms, 2024), their cultivated meat product developments are currently focusing on the protein: fat ratio, aiming to come to a product with sufficient proteins and less saturated fats without losing flavour (Ramírez López and RESPECTfarms, 2024).

Meat is also a supplier of minerals, such as iron, zinc, and selenium. Cultivated meat cells contain iron, but the concentrations of zinc and selenium in basal cells are zero or very low and should be added to meet conventional meat concentrations (Fraeye et al., 2020). Currently, RESPECTfarms focuses on macro-nutrients. In the future they will probably add additives to their cultivated meat products to come to comparable values of micro-nutrients as conventional meat (Ramírez López and RESPECTfarms, 2024). It must be noted that the addition of additives could increase the external costs on the natural capital. In the LCA of this study these additives were not taken into account, beyond standard culture media composition (which includes a range of salts and vitamins, but not all that are included in conventional meat).

Studies about the health risks associated with a stroke, diabetes, colorectal and lung cancer are not known.

5 Impact assessment is conducted quantitatively and qualitatively

Quantitative assessments have been done for the externalities in the natural capital and for some in the social capital. Externalities in the social capital that could not be assessed quantitatively a qualitative assessment has been done. Qualitative assessment has also been done for the human capital. No assessments could be done in the economic capital since currently there is no economic TCA module available.

5.1 Natural capital: cultivated meat is more environmental friendly than conventional meat for some impacts, but less friendly for other impacts

The impact of the various meat products on natural capital has been assessed with help of Life Cycle Impact Assessment (LCIA) method ReCiPe 2016 (Huijbregts et al., 2016), since this LCIA method matches with the True Cost Accounting method of Echte & Eerlijke Prijs (Galgani et al., 2023a). Table 5.1. and Figure 5.1 show the ReCiPe 2016 midpoint results of chicken meat, pig meat, dairy cow meat and cultivated meat. Note that impact assessment data of the conventional meats are based on current Dutch average data, adapted for electricity use (PV panels on stable roofs and grid mix 2030) and cleaner truck transport (Euro IV to Euro V). No adaptions have been made for animal feed ingredients and the environmental effects of improved animal welfare conditions (see Section 4.2.2).

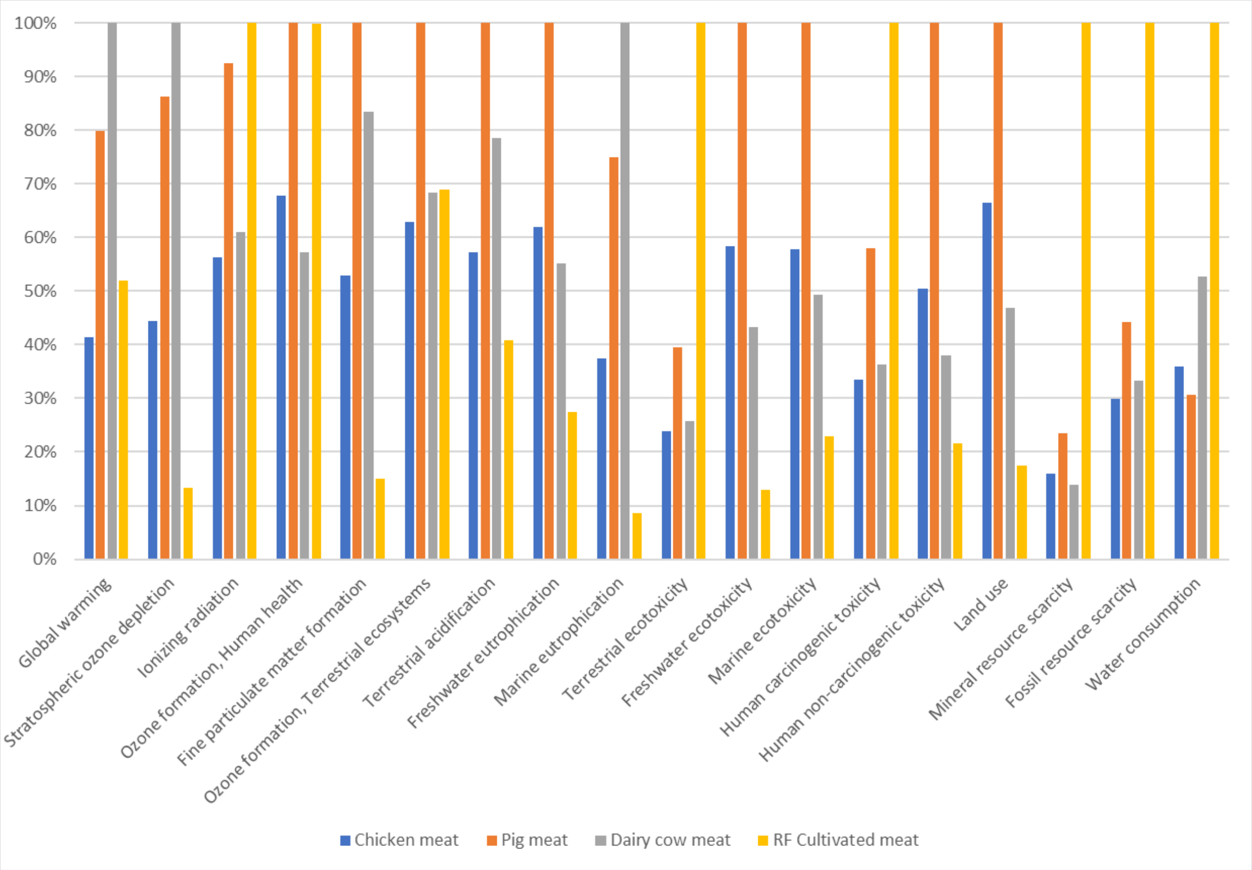


Figure 5.1 *Comparison of assessed environmental impact of conventional chicken, pig and dairy cow meat and RESPECTfarms' cultivated meat, scenario 2030*
The meat product with the highest impact on an environmental issue gets the score of 100%. The scores of the other meat products are relative scores related to the product with the highest impact: e.g., per kg boneless meat, dairy cow meat has the highest contribution to global warming, the contribution of pig meat to global warming is 80% of the contribution of dairy cow meat.

Table 5.1 *ReCiPe 2016 (H) midpoint results*

True Price impact category	True Price footprint indicator	ReCiPe 2016 midpoints	Chicken meat	Pig meat	Dairy cow meat	Cultivated meat	Unit
Contribution to climate change	GHG emissions	Climate change	3.36	6.49	8.13	4.22	kg CO_2-eq
Air pollution	Toxic emissions - Human toxicity	Human carcinogenic toxicity	0.025	0.044	0.028	0.076	kg 1,4-DCB
		Human non-carcinogenic toxicity	4.31	8.55	3.25	1.85	kg 1,4-DCB
	Particulate matter formation	Fine particulate matter formation	0.021	0.039	0.033	0.006	kg $PM_{2.5}$ eq
	Photochemical oxidant formation	Ozone formation, human health	0.0066	0.010	0.0056	0.0097	kg NO_x eq
	Acidification	Terrestrial acidification	0.022	0.039	0.031	0.016	kg SO_2 eq
	Ionising radiation	Ionising radiation	0.024	0.039	0.026	0.042	kBq Co-60 eq
	Ozone layer depleting emissions	Stratospheric ozone depletion	2.09×10^{-5}	4.06×10^{-5}	4.71×10^{-5}	6.29×10^{-6}	kg CFC11 eq
Water pollution	Toxic emissions - Freshwater ecotoxicity	Freshwater ecotoxicity	0.237	0.407	1.759	0.053	kg 1,4-DCB
	Toxic emissions - Marine ecotoxicity	Marine ecotoxicity	0.077	0.133	0.065	0.030	kg 1,4-DCB
	Freshwater eutrophication	Freshwater eutrophication	0.0010	0.0016	0.0009	0.0004	kg P eq
	Marine eutrophication	Marine eutrophication	0.0035	0.0071	0.0094	0.0008	kg N eq
Soil pollution	Toxic emissions - Terrestrial ecotoxicity	Terrestrial ecotoxicity	6.011	9.951	6.495	25.254	kg 1,4-DCB
	Photochemical ozone formation - terrestrial ecosystems	Ozone formation, terrestrial ecosystems	0.0097	0.0154	0.0106	0.0106	kg NO_x eq
Land use	Land use	Land use – occupation	5.25	7.897	3.697	1.375	m^2a crop eq a)
	Land transformation	Land use - transformation					
Fossil fuel depletion	Fossil fuel depletion	Fossil resource scarcity	0.351	0.524	0.393	1.177	kg oil eq
(Other) non-renewable material depletion	(Other) non-renewable material depletion	Mineral resource scarcity	0.0033	0.0049	0.0029	0.0208	kg Cu eq
Scarce water use	Scarce water use	Water consumption x scarcity factor b)	0.010	0.009	0.015	0.029	m^3
Soil degradation c)	Soil erosion: water- and wind erosion	x	x	x	x	x	x
	Soil Organic Carbon (SOC) loss	x	x	x	x	x	x
	Soil compaction	x	x	x	x	x	x

a) The True Price Footprint indicator Land use is expressed as mean species abundance * ha (MSA*ha), while the ReCiPe 2016 Midpoint category Land use is expressed in m^2a crop-eq. A converting calculation has been done to monetise land use; b) Water consumption (ReCiPe2016) is converted to scarce water use by water scarcity factors of Galgani et al. (2021b); c) Soil degradation is not presented in ReCiPe 2016 and can therefore not be included.

The environmental comparison between cultivated meat and the conventional meats is ambiguous. For nine out of the eighteen environmental indicators, cultivated meat has a lower impact than the three conventional meats under study, for seven indicators cultivated meat has the highest impact, and for two indicators some conventional meats have lower and others have higher impact than cultivated meat.

Cultivated meat has a low impact compared to the meat products on indicators that are strongly related to agricultural (crop) production, such as land use and the nitrogen-related indicators fine particulate matter formation, terrestrial acidification and marine eutrophication. Also the phosphorous-related indicator freshwater eutrophication is lower, and a few toxicity indicators. The reason for this is that cultivated meat has an improved feed conversion efficiency and therefore a lower biotic resource demand (crops).

At the same time, both the production of cultivated meat itself and of many inputs from its supply chain (culture medium ingredients, consumables, etc.) have a higher energy use and a higher demand for fossil and other non-renewable resources compared to conventional meat and its supply chain. This is reflected in the higher environmental impact of cultivated meat than the other meats under study on indicators related to this, such as fossil and mineral resource scarcity,[15] some toxicity indicators,[16] and ozone formation.
The scarce water use of cultivated meat is higher than that of conventional meats. The reason for the high scarce water use is the industrial (bioprocessing) nature of the cultivated meat supply chain, compared to a more agricultural (rainwater-fed, and therefore not included in the blue water use) nature of the conventional meat systems. The majority of water use in the life cycle of cultivated meat takes place in its supply chain (mainly the culture media ingredients production). Optimisation and recycling of water at bioprocessing facilities could reduce the water footprint in cultivated meat supply chain, but this is producer-dependent and not considered in this study. Since for all products under study, both cultivated meat as well as the conventional meats, water consumption mainly takes place in regions without high water scarcity, cultivated meat has also got the highest scarcity-weighted blue water use.

Comparing the impact on climate change (global warming) the current carbon footprint estimation of cultivated meat is higher than chicken meat and lower than pig meat and dairy cow meat. The carbon footprint of cultivated meat is mostly caused by CO_2 emitted in its (energy-intensive) supply chain, whereas for conventional meats this is more strongly related to agricultural emissions of N_2O and CH_4 (mainly due to enteric fermentation), and CO_2 from land use change. It must be noted that in theory it is well possible to further reduce the carbon footprint of cultivated meat by decarbonising its supply chain and own production process, while further reducing the carbon footprint of conventional meat is more difficult, due to the relatively optimised production efficiencies.

Across most indicators, the culture medium use is the main hotspot in RESPECTfarms' product system, followed by energy use at the RESPECTfarms facility. Within culture medium use, the main hotspots are hydrolysate, amino acids, and salts, followed by sugars, and additional processing and the medium formulation facility.

It must be noted that the dairy cow meat is a relatively low impact beef product, since the environmental impact of the dairy system is divided over the various products the dairy systems delivers (milk and meat). This division is done by economic allocation. Since milk is the economic driver of the dairy system most impact is allocated to milk. Beef from beef cattle has a much higher environmental impact since the beef is the economic driver of the beef cattle system. In the Netherlands the beef cattle sector is very small and no representative data of the Dutch beef cattle sector are available. Comparing the environmental impact of the current Dutch dairy cow meat to Irish beef, the impact of Irish beef is about 3 to 6 times higher for all environmental impact categories (Blonk et al., 2022). See Figure 5.2.

[15] More than 60% of fossil and mineral resource scarcity is caused by the culture media supply chain which is energy- and resource intensive (electricity, steam, heat, salts, metals and other minerals). Similarly, more than 20% of fossil and mineral resource scarcity is caused by energy consumption at the facility (via production of the renewable technologies and infrastructure, and in part via the average NL grid mix which still contains fossil fuels).

[16] For example, terrestrial ecotoxicity is driven by run-off and wastes from mining and the processing of minerals and metals for the energy- and resource-intensive cultivated meat supply chain.

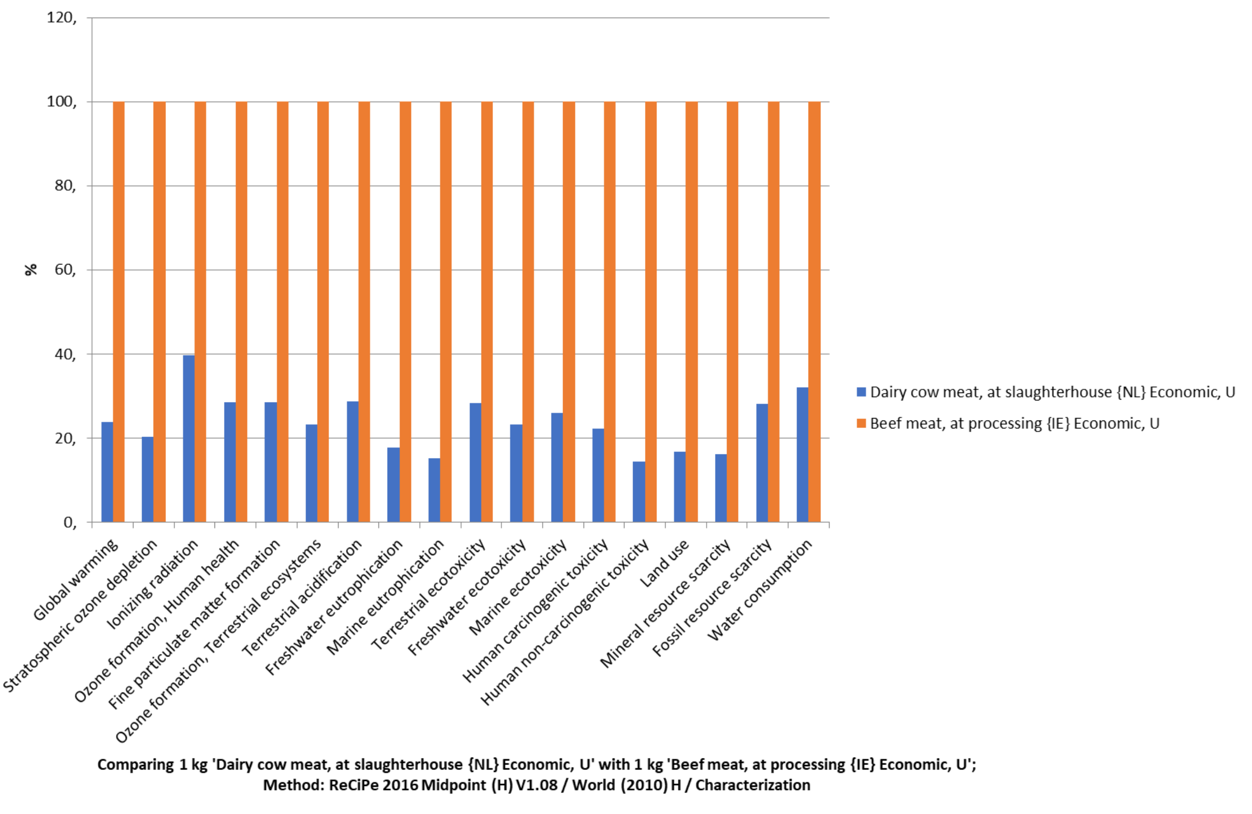


Figure 5.2 *Comparison of environmental impact of 1 kg meat from current Dutch dairy cows and 1 kg meat from Irish beef cattle*
Source: Agri-footprint 6 Blonk et al. (2022).
The meat product with the highest impact on an environmental issue gets the score of 100%. The scores of the other meat product are relative scores related to the product with the highest impact: e.g., per kg meat, Irish beef cattle meat has the highest contribution to global warming, the contribution of Dutch dairy cattle meat to global warming is 24% of the contribution of beef cattle meat.

5.2 Social capital: cultivated meat is expected to have a lower impact on social issues

5.2.1 Cultivated meat avoids social risks associated with feed production and the slaughterhouses stage, as well a health issues of farmers in intensive meat sectors

5.2.1.1 Cultivated meat avoids social risks in feed production (esp. compared to pig meat production)

Cultivated meat production is based on few animals providing cells for meat production. The need for feed and the growing of inputs for feed is reduced considerably in cultivated meat production. Figure 5.3 shows the results from the SHDB showing at the subcategory level. The risk hours appear to be related to almost all of the social impact subcategories. Pig meat has most social risk hours per kg boneless meat. Figure 5.4 shows that most of the social risks can be connected to country of origin Indonesia. In the SHDB, soybeans and oil palm fruits are in the same product category ‘oil seeds’, but from Table 4.6 we know that in pig feed palm fruits from Indonesia are used, therefore most risks are related to the oil palm fruits production.

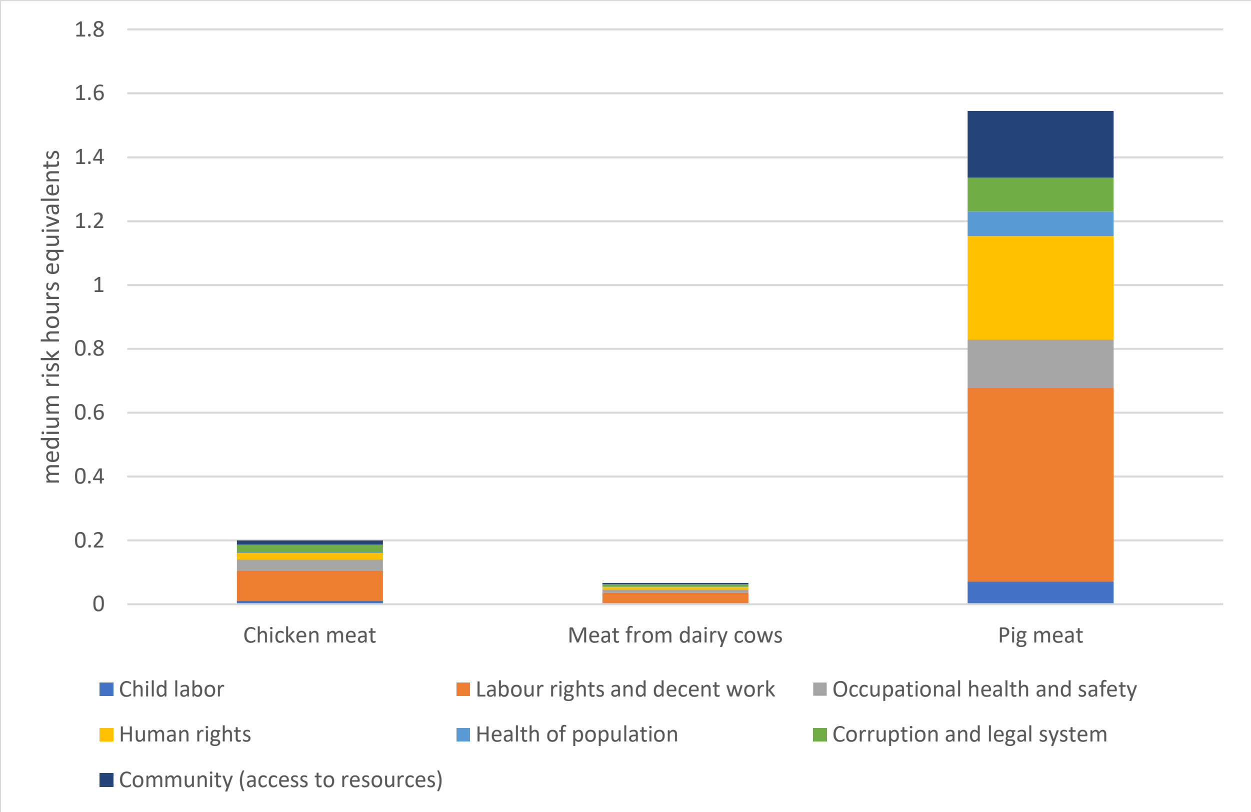


Figure 5.3 *Medium risk hours equivalents per social impact category per 1 kg of boneless meat in feed (for chicken meat, meat from dairy cows and pig meat). Numbers of the social impact categories are from SHDB*

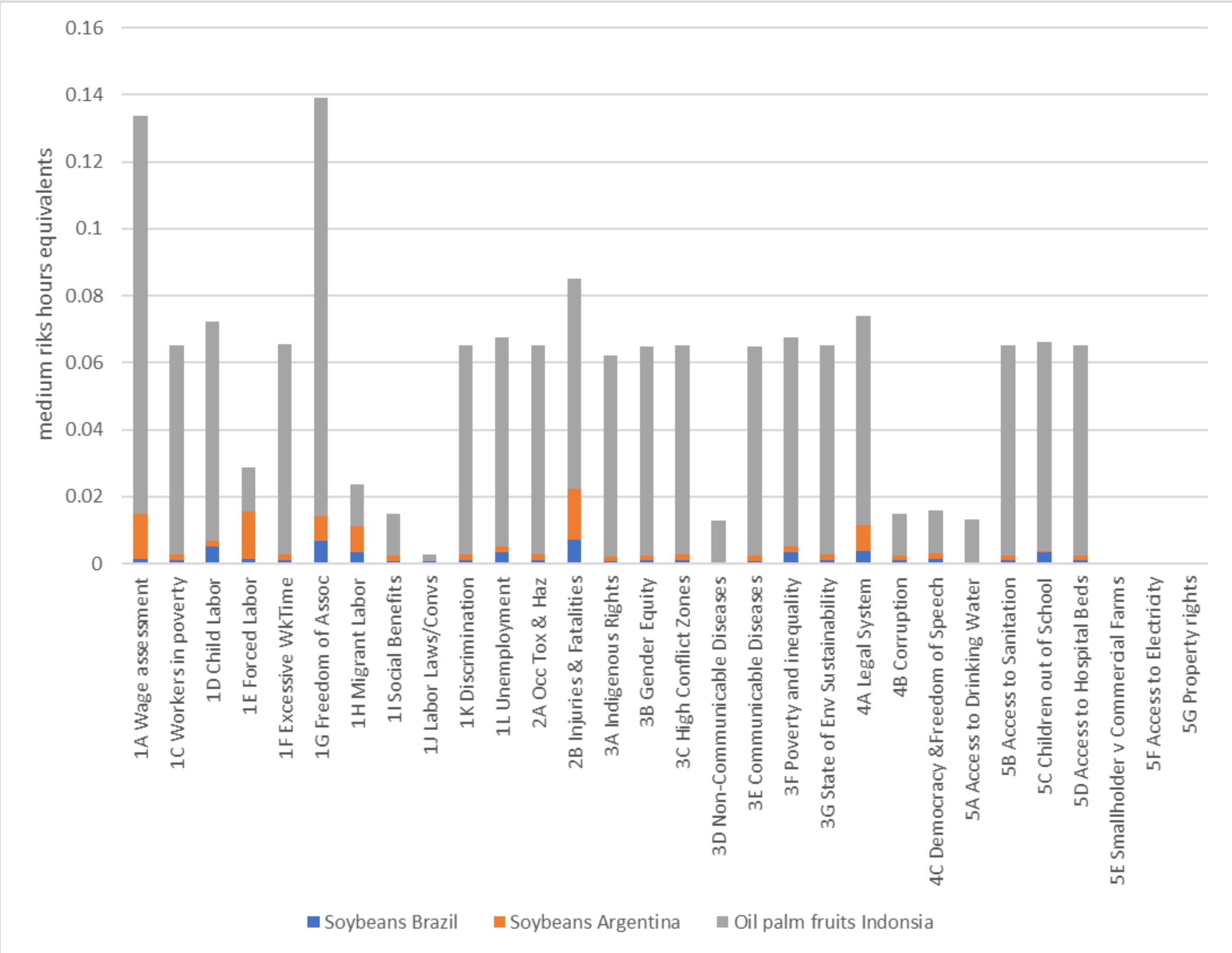


Figure 5.4 *Medium risk hours equivalents per social impact category and country (Brazil, Argentina and Indonesia) related to feed for 1 kg of boneless pig meat*

5.2.1.2 Cultivated meat avoids a considerable number of social risks hours in the slaughterhouse stage

Cultivated meat production is not based on fattening animals that need to be slaughtered. Though some animals needed for the production of cells will be slaughtered in the end. Under the assumption that the two-thirds of the non-compliances of the employment agencies (Section 4.2) involve risks for social impacts, the number of risk-hours can be calculated per kg boneless meat. The risks are not further defined and can range from small to large. In the calculation, the live slaughter weight of all red meat is averaged over the number of employees in the red meat slaughterhouses; no distinction is possible between pig and cattle slaughterhouses.

Table 5.2 shows the number risk hours by type of slaughterhouse. Table 5.3 shows the risk hours per kg boneless meat, by taking into account the different volumes of live carcass weight per kg of ‘boneless’ meat. The risks concern various but not identified aspects such as unfair wages and bad housing conditions. The social risk per kg boneless cultivated meat is considered negligible compared to the risk in the slaughterhouses.

Table 5.2 *Social risk hours (hrs) per slaughterhouse stage per year (2020)*

Red meat slaughterhouses	Chicken meat slaughterhouses
2,891,131	3,315,312

Source: Heyma en Luiten (2022) and calculations for this study.

Table 5.3 *Social risk hours (hrs) per slaughterhouse stage per 1 kg boneless meat*

Meat from dairy cows	Pig meat	Chicken meat	Cultivated meat
0.003	0.002	0.005	Negligible

Source: Heyma en Luiten (2022), Data Agri-footprint 6 and calculations for this study.

5.2.1.3 Cultivated meat will avoid accidents and health issues in the more intensive primary sectors

Based on the average number of fatal incidents in the industry and in the agricultural sector the number fatal incidents per kg boneless meat is calculated (see Table 5.4). Cultivated meat avoids accidents and health issues at the slaughterhouse stage. Compared to conventional meat production fatal accidents are unknown, but may be lower because half of the number is related to driving machines.

Table 5.4 *Fatal accidents per 1000 kg boneless meat*

	Meat from dairy cows	Pig meat	Chicken meat	Cultivated meat
Primary production	0.0002	0.0003	0.0001	Unknown
Slaughterhouse stage	0.0002	0.0001	0.0002	Not applicable

Source: Heyma en Luiten (2022), Agrimatie, Data Agri-footprint and calculations for this study.

Table 5.5 shows the sick rate leave per hour per 1000 kg boneless meat for the slaughterhouse stage, assuming that sick leave rates in the slaughterhouses are on the same level as the average of the Dutch industry (5.4%). For the primary sectors no data is available.

Table 5.5 *Sick leave (hour) per 1000 kg boneless meat*

	Meat from dairy cows	Pig meat	Chicken meat	Cultivated meat
Primary production	Unknown	Unknown	Unknown	Unknown
Slaughterhouse stage	0.84	0.59	1.08	Not applicable

Source: Heyma en Luiten (2022), and calculations for this study.

It was noted however that the prevalence of respiratory problems among pig farmers is 14% (van der Gulden et al. (2002). They conclude that long-term exposure in pig stables causes a decline in lung function and an increase in the prevalence of asthma. The health problems are caused by particulate matter, endotoxins and the use of disinfectants (van der Gulden et al., 2002). Similar problems are to be expected in the chicken sector. In the dairy sector, the issues are expected to be less relevant, because the sector operates more extensively and stables are open.

5.2.2 Cultivated meat has a relatively low impact on animal welfare since few animals needed

Aggregated corrected animal welfare scores during farming are given in Table 5.6. Since the amount of animals needed to produce cultured meat is 0.002% of the amount of (cattle) animals needed to produce conventional (cattle) meat (Melzener et al., 2021), it is assumed that per kg cultivated meat the impact of animal welfare issues during farming is negligible. It must be noted that although only a few donor animals are needed to produce the meat animal welfare conditions play a role for the donor animals themselves. Animal friendly biopsy conditions as well as good living conditions are important for the donor animals to undergo good animal welfare conditions.

Table 5.6 *Aggregated corrected animal welfare scores (expected for 2030)*

	Corrected total score*
Beter Leven 1 star broiler production system	170.3
Beter Leven 1 star pig production system	220.1
Conventional dairy farming system	201.9
Cultivated meat production system	negligible

a) Explanation about correction formulars is given in Vissers et al. (2023).
Source: Vissers et al. (2023); Vissers and Woltjer (2022).

Table 5.7 shows the outcome of the qualitative assessment on animal welfare during the slaughtering stage (including transport to slaughterhouse), if replacing Dutch conventional meat production by Dutch cultivated meat production.

Table 5.7 *Estimated change in animal welfare at slaughter issues if replacing Dutch conventional meat production with Dutch cultivated meat (CM) production*

Sector	Change in animal welfare issues at slaughter (incl. transport to slaughterhouses) *Increase (+), decrease (-), no difference (0), unknown difference (?) of risk*
Chicken meat production -> CM production	-
Pig meat production -> CM production	-
Dairy cow meat production -> CM production	-

5.2.3 Cultivated meat could cause a decrease of animal health risks, but little has been investigated yet

Table 5.8 shows the outcome of the qualitative assessment on animal health, if replacing Dutch conventional meat production by Dutch cultivated meat production. A division has been made between risks for animal health and for human health.

Table 5.8 *Estimated change in risks of animal diseases and zoonoses if replacing Dutch conventional meat production with Dutch cultivated meat (CM) production*

Animal disease/zoonose	Risk animal health		Risk animal related human health	
	Sector	*Increase (+), decrease (-), no difference (0), unknown difference (?) of risk*	*Sector*	*Increase (+), decrease (-), no difference (0), unknown difference (?) of risk*
Bird flu	Chicken -> CM	-	Chicken -> CM	-
Swine fever	Pig -> CM	-		
Foot-and-mouth disease	Dairy cattle and pig -> CM	0		
Salmonellosis		0	Chicken -> CM Pig -> CM Dairy cattle -> CM	? ? ?
Campylobacteriosis			Chicken -> CM Pig -> CM Dairy cattle -> CM	? ? ?
Antibiotic resistance/ESBLs			Chicken -> CM Pig -> CM Dairy cattle-> CM	- - 0

If Dutch cultivated meat production replaces Dutch conventional meat production and so reduces the amount of livestock, then the risk of spreading bird flu and swine fever between farms will reduce (Hagenaars et al., 2022). It must be noted that the amount of dairy cattle animals will likely not reduce due to cultivated meat production, since cultivated meat is not an alternative for dairy products.
The risk of spreading foot-and-mouth disease is mainly caused by import of meat. Current restrictions of meat import from high-risk countries have removed the risk of spreading foot-and-mouth disease (van Asseldonk et al., 2019). So, the replacement of Dutch conventional meat production with Dutch cultivated meat production will not have an effect in the reduction of foot- and mouth disease.
Risks of animal diseases related human health issues could decrease as well, although there is not much evidence from research yet. Since the use of antibiotics will decrease with reducing livestock, the shift from conventional meat to cultivated meat production in the Netherlands will likely reduce risks on antibiotic resistance.

5.3 Human health: cultivated meat is a protein supplier, but health risks are not yet investigated

Only few studies are done about the diet related consumer health effects of cultivated meat. Based on the study of Fraeye et al. (2020) and interview with Ramírez López (RESPECTfarms) (2024) the nutritional value of cultivated meat could be comparable to conventional meat if nutrients that are not present in the basal cells (e.g. vitamin B12) are added. To our knowledge, no studies exist about a difference in health risks between conventional meat and cultivated meat.

6 Valuing of impacts with TCA method PPP Echte & Eerlijke prijs

True cost accounting (TCA) is a method to value the impacts on natural, social and human capital. The valuation of cultivated meat and conventional meat has been done according to the TCA method of PPP Echte & Eerlijke prijs (Galgani, et al., 2023a). Monetisation factors are corrected for inflation up to 2021, since this is the most recent year factors are available of. Since price developments up to 2030 are very uncertain and out of scope of this study we chose to apply 2021 factors. Impacts are valued quantitively if possible and qualitatively for the externalities that are not yet included in the modules of PPP Echte & Eerlijke prijs.

6.1 Natural capital: A shift to cultivated meat causes a decrease of environmental external costs

The external costs of the environmental impact of the various meat products is shown in Figure 6.1 and Table 6.1.

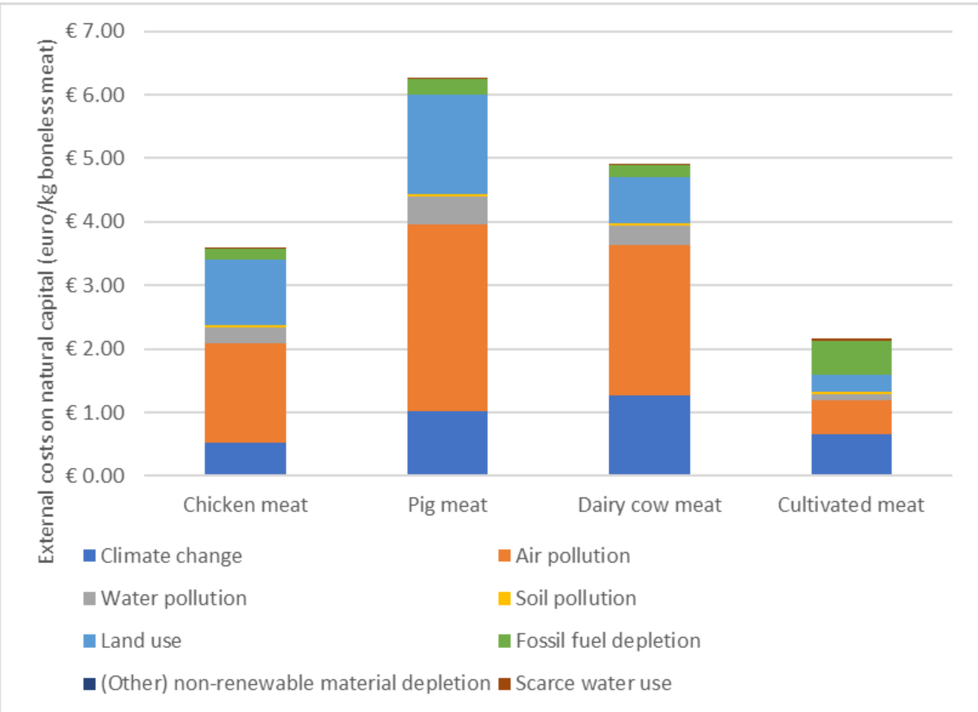


Figure 6.1 *Comparison of the estimated external costs on natural capital of cultivated meat and three conventional meats in 2030 (based on 2021 monetisation factors)*

Table 6.1 *Monetisation of natural capital (based on 2021 monetisation factors)*

True Price impact category	True Price footprint indicator	External costs in euro/kg boneless meat			
		Chicken meat	***Pig meat***	***Dairy cow meat***	***Cultivated meat***
Climate change	GHG emissions	0.527	1.020	1.277	0.663
Subtotal climate change		0.527	1.020	1.277	0.663
Air pollution	Toxic emissions - Human carcinogenic toxicity	0.009	0.015	0.009	0.026
	Toxic emissions – Human non-carcinogenic toxicity	0.099	0.197	0.075	0.042
	Particulate matter formation	1.344	2.543	2.122	0.381
	Photochemical oxidant formation	0.001	0.001	0.001	0.001
	Acidification	0.104	0.183	0.143	0.074
	Ionising radiation	0.000	0.000	0.000	0.000
	Ozone layer depleting emissions	0.001	0.002	0.003	0.000
Subtotal air pollution		*1.558*	*2.941*	*2.353*	*0.525*
Water pollution	Toxic emissions - Freshwater ecotoxicity	0.009	0.016	0.007	0.002
	Toxic emissions - Marine ecotoxicity	0.000	0.000	0.000	0.000
	Freshwater eutrophication	0.200	0.323	0.178	0.089
	Marine eutrophication	0.050	0.099	0.132	0.011
Subtotal water pollution		*0.259*	*0.438*	*0.317*	*0.102*
Soil pollution	Toxic emissions - Terrestrial ecotoxicity	0.002	0.002	0.002	0.006
	Photochemical ozone formation - terrestrial ecosystems	0.028	0.044	0.030	0.030
Subtotal Soil pollution		*0.029*	*0.046*	*0.032*	*0.037*
Land use a)	Land use	1.039	1.564	0.732	0.272
	Land transformation				
Subtotal Land use		*1.039*	*1.564*	*0.732*	*0.272*
Fossil fuel depletion	Fossil fuel depletion	0.157	0.234	0.175	0.525
Subtotal fossil fuel depletion		*0.157*	*0.234*	*0.175*	*0.525*
(Other) non-renewable material depletion	(Other) non-renewable material depletion	0.001	0.001	0.001	0.005
Subtotal (other) non-renewable material depletion		*0.001*	*0.001*	*0.001*	*0.005*
Scarce water use b)	Scarce water use	0.013	0.011	0.017	0.037
Subtotal scarce water use		*0.013*	*0.011*	*0.017*	*0.037*
Soil degradation c)	Soil erosion: water- and wind erosion	x	X	x	x
	Soil Organic Carbon (SOC) loss	x	X	x	x
	Soil compaction	x	X	x	x
Subtotal soil degradation		*x*	*x*	*x*	*x*
Total		***3.58***	***6.25***	***4.91***	***2.17***

a) See textbox Chapter 3.1; b) Water consumption is converted to water scarcity by water scarcity factors of Galgani et al. (2021b); c) Soil degradation is not presented in ReCiPe 2016 and can therefore not be included.

A shift from conventional meat to cultivated meat causes a decrease in external costs on the natural capital. It must be noted that the dairy cow meat is a relatively low impact beef product, since the environmental impact of the dairy system is divided over the various products the dairy systems delivers (milk and meat). This division is done by economic allocation. Since milk is the economic driver of the dairy system most impact, and so most external costs, is allocated to milk.

For all three conventional meat products, air pollution causes the highest external costs (almost 50%) in the natural capital, whereas air pollution contributes for 24% to the environmental external costs of cultivated meat. Climate change and land use do also have a great contribution to the external environmental costs of conventional meat. Climate change has also got a great (31%) contribution to the environmental external costs of cultivated meat. Fossil resource scarcity contributes to 24% of the environmental external costs of cultivated meat, whereas for conventional meat the external costs of fossil resource scarcity are relatively low (4%).

6.2 Social capital: a shift to cultivated meat could lower external social costs but not all issues could be valued

6.2.1 Cultivated meat avoids mortality costs in the slaughterhouse stage, other impacts could not be valued quantitatively

Health and safety of workers (in the primary production and slaughterhouse stage)
Results of the calculated value of fatal accidents are presented in Table 6.2. Per kg boneless meat these cost appear to be very low, due to very low mortality rates.

Table 6.2 *External costs due to fatal accidents per 1 kg boneless meat, in euro per kg, per sector*

	Meat from dairy cows	Pig meat	Chicken meat	Cultivated meat
Primary production	0.0003	0.0003	0.0001	Unknown
Slaughterhouse stage	0.0002	0.0001	0.0002	Not applicable

Source: calculations for this study.

Health costs may turn out to have more monetary impact, as health problems in intensive sector are prevalent and have long term effects. No valuation module, however, is available for monetising the risks of, for example, a decline in lung function and an increase in the prevalence of asthma during the work life of farmers in the intensive sector. Since cultivated meat avoids risks of a decline in lung function and an increase in the prevalence of asthma in the more intensive primary sectors, as well as the slaughterhouse stage we expect it likely that the external costs on the social capital will decrease when switching from conventional meat to cultivated meat.

Social benefits – social security of workers (slaughterhouse stage)
No valuation module is available. Since cultivated meat avoids a considerable number of social risks hours in the slaughterhouse stage, we expect it likely that the external costs on the social capital will decrease when switching from conventional meat to cultivated meat.

Risk assessment on social impacts of feed using the SHDB
No valuation module is available. Since cultivated meat avoids social risks in feed production (especially compared to pig meat production), we expect it likely that the external costs on the social capital will decrease when switching from conventional meat to cultivated meat.

6.2.2 A shift to cultivated meat causes lower external costs of animal welfare

External costs related to the animal welfare issues during farming are assessed by the abatement approach. The abatement costs reflect the costs associated with a set of measures to achieve a level where animal welfare issues are minimised (Vissers et al., 2023). Figure 6.2 and Table 6.3 present a comparison of the animal welfare related external costs per 1 kg of meat expected in 2030.

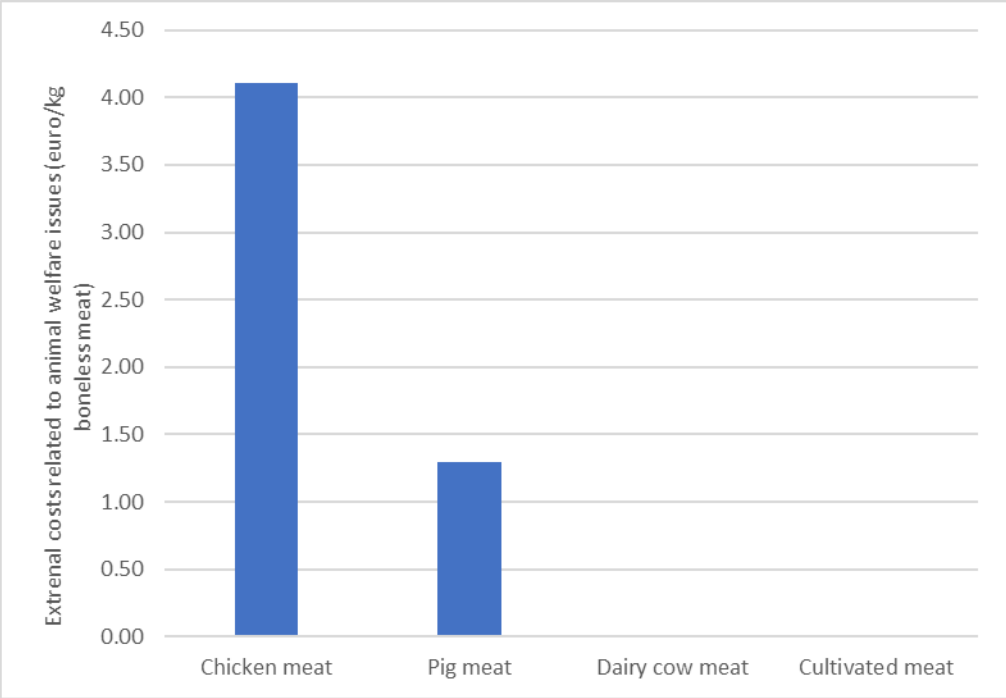


Figure 6.2 *Comparison of animal welfare related external costs during farming, per 1 kg of boneless meat (2030)*

Table 6.3 *Comparison of animal welfare related external costs during farming, per 1 kg of boneless meat (2030)*

	External costs in euro/kg meat
Conventional broiler production system	4.11
Conventional pig production system	1.29
Conventional dairy farming system	0.004
Cultivated meat production system	negligible

A shift from pig meat and even more from chicken meat to cultivated meat causes a decrease in external costs on animal welfare during farming. This is mainly caused by the reduction of animals needed to produce 1 kg of meat.

Textbox 6.1 Why are external costs related to animal welfare issues during farming of chicken meat much higher than pig meat?

The external costs of chicken meat are relatively high compared to the costs of pig and dairy cattle meat. This can mainly be explained by the fact that the welfare scores of the broiler production system are relatively low compared to the pig and dairy cattle production system (see Table 5.6). These welfare scores were obtained from (Vissers et al., 2023). The authors used the welfare scores and production costs of existing broiler production systems (conventional, 1-star Beter Leven and organic) to calculate the additional costs needed for each system to reach a level where adverse welfare effects are minimised (so-called excellence level). (Gocsik et al., 2016) found that animal welfare improvements that go beyond the requirements of the 1-star Better Life system are relatively cost-inefficient, i.e., are associated with a relatively high increase in production costs. Attributes of organic broiler production systems, such as a free-range area, add relatively small improvement to animal welfare but lead to a high increase in costs. Furthermore, the organic broiler production system scored worse on the welfare criteria 'incidence of injuries' compared to the 1-star Better Life system. Recent studies suggest that organic broilers score worse on footpad lesions than conventional broilers (Riber et al., 2020). This implies that welfare improvements on one aspect may cause a trade-off on other welfare aspects. Therefore, the high external costs of the broiler production system can be explained by the relatively high costs associated with animal welfare improvements that go beyond the 1-star Better Life system and the relatively low welfare score of the broiler production systems. The low external costs of dairy cattle meat is also caused by the allocation choices made: most impact is allocated to the milk and not to the meat as milk is the economic driver of the dairy system.

Table 6.4 shows the qualitative assessment of the change in external costs related to animal welfare issues at slaughter if replacing Dutch conventional meat production with Dutch cultivated meat (CM) production. Since no slaughtering is needed to produce cultivated meat, the external costs will decrease.

Table 6.4 *Qualitative estimation of change in external costs related to animal welfare at slaughter issues if replacing Dutch conventional meat production with Dutch cultivated meat (CM) production*

Sector	**Change in animal welfare issues at slaughter (incl. transport to slaughterhouses)** ***Increase (+), decrease (-), no difference (0), unknown difference (?) of risk***
Chicken meat production -> CM production	-
Pig meat production -> CM production	-
Dairy cow meat production -> CM production	-

6.2.3 A shift to cultivated meat could probably decrease the external costs of animal health, although a lot is still unknown

Table 6.5 shows the qualitative assessment of the change in external costs if replacing Dutch conventional meat production with Dutch cultivated meat (CM) production. It is assumed that a decrease of risks related to animal diseases and zoonoses results in lower external costs and vice versa. If Dutch cultivated meat production replaces Dutch conventional meat production and so reducing amount of livestock the external costs on animal health could probably decrease although a lot is still unknown.

Table 6.5 *Qualitative estimation of change in external costs of animal diseases and zoonoses if replacing Dutch conventional meat production with Dutch cultivated meat (CM) production*

Animal disease/zoonose	**Change in external animal health costs**		**Change in external animal related human health costs**	
	Sector	***Increase (+), decrease (-), no difference (0), unknown difference (?) of risk***	***Sector***	***Increase (+), decrease (-), no difference (0), unknown difference (?) of risk***
Bird flu	Chicken -> CM	-	Chicken -> CM	-
Swine fever	Pig -> CM	-		
Foot-and-mouth disease	Dairy cattle and pig -> CM	0		
Salmonellosis			Chicken -> CM Pig -> CM Dairy cattle -> CM	? ? ?
Campylobacteriosis			Chicken -> CM Pig -> CM Dairy cattle -> CM	? ? ?
Antibiotic resistance/ESBLs			Chicken -> CM Pig -> CM Dairy cattle -> CM	- - 0

6.3 Human health: Change in external costs in human capital unknown when shifting to cultivated meat

Since there is currently no quantitative monetisation method, impacts have been assessed qualitatively only (Table 6.6). It is assumed that the presence of qualifying nutrients (fibre, vitamins/minerals) leads to lower external costs of diet related consumer health costs, whereas the presence of disqualifying nutrients (energy, fat, saturated fat, salt, sugars) leads to higher external costs. No clear trend in external costs in the human capital can be made for a shift from conventional meat to cultivated meat, because impact studies are still limited.

Table 6.6 *Qualitative estimation of change in external costs of diet related consumer health if replacing conventional meat with cultivated meat (CM)*

Change in external costs	**Nutritional value (qualifying nutrients)** ***Increase (+), decrease (-), no difference (0), unknown (?)***	**Health risks (disqualifying nutrients)** ***Increase (+), decrease (-), no difference (0), unknown (?)***
Conventional meat -> cultivated meat	-/0 All suppliers of proteins and iron. Conventional meat: Supplier of vitamins B1 and B12 and zinc and selenium Cultivated meat: Supplier of vitamins B1 and B12 and zinc and selenium only if added	? Chicken meat: no diet related health risks Pig meat and dairy cow meat: red meat and processed meat is associated with a higher risk of stroke, diabetes, colorectal and lung cancer Cultivated meat: unknown, RESPECTfarms is working on a product with lower saturated fatty acid content

Source: Fraeye et al. (2020; Ramírez López and RESPECTfarms (2024).

7 Conclusion: A shift from Dutch conventional meat to Dutch cultivated meat will probably decrease the external costs in 2030

In this research project the external costs of a locally produced cultivated meat product and three conventional meat products are assessed. The locally produced cultivated meat product is produced according to the proof-of-concept (TRL7)[17] of RESPECTfarms. The three conventional meat products chosen for comparison are chicken, pig and dairy cow meat, produced in the Netherlands. All products are assessed for a 2030 scenario, where energy used is generated by PV panels at stable roofs and the rest is purchased electricity from the grid with the expected energy mix in 2030 (higher share of sustainable generated energy than currently).

In this study we applied the TCA methodology that has been developed in the PPP Echte en Eerlijke Prijs and the Horizon Europe project FOODCoST. Impacts for which valuation modules[18] have not yet been developed, have been assessed in a qualitative way. Figure 7.1 shows the external costs of the externalities that could be valued quantitatively. Table 7.1 gives a qualitative overview of the external costs development for all impacts when conventional meat is replaced by cultivated meat, including those for which no valuation method is yet developed.

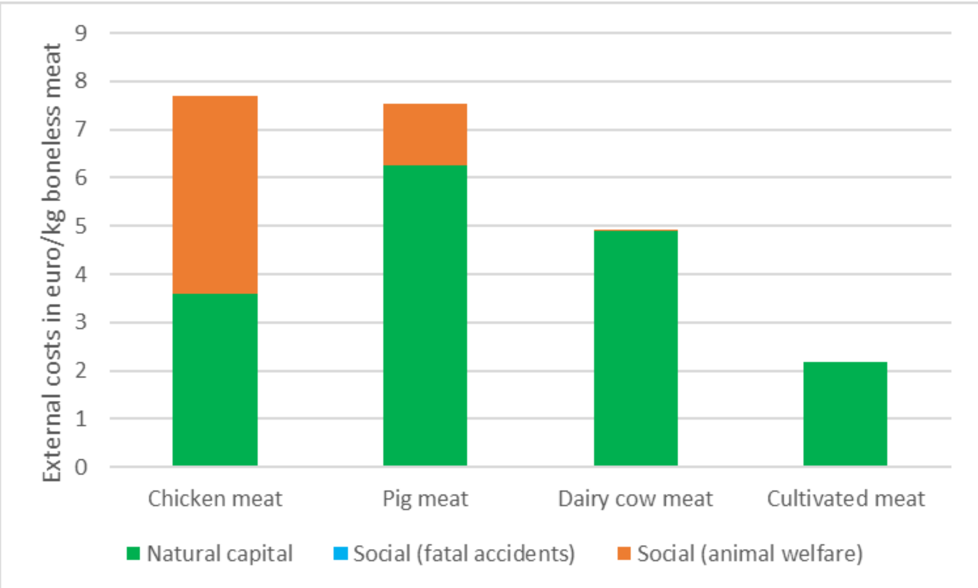


Figure 7.1 *Quantitative assessment of external costs on natural capital and social capital (fatal accidents and animal welfare) of three Dutch conventional meat products and Dutch cultivated meat (expected for 2030), in euro per kg boneless meat*

[17] While finishing this study TRL level expectations changed to TRL8/9 level. This study has been done at the TRL 7 level as expected at the start of the study.
[18] The modules can be found here: https://trueprice.org/natural-capital-modules-for-true-price-assessment/

__Table 7.1__ Qualitative assessment of change in external costs if Dutch conventional meat production is replaced by Dutch cultivated meat (expected for 2030): + = cost increase, - = cost decrease, 0 = no difference, ? = unknown

	Chicken meat -> cultivated meat	Pig meat -> cultivated meat	Dairy cow meat -> cultivated meat
Natural capital	-	-	-
Social capital - not animal related	-	-	-
Social capital – Animal welfare	-	-	-
Social capital – Animal related human health	-/?	-/?	-/?
Human health – Diet related consumer health	?	?	?

The external costs due to a shift from Dutch conventional meat production to locally produced cultivated meat in the Netherlands in 2030 are assessed to decrease, although a full quantitative assessment could not be made due to a current lack of valuation methods for some externalities.

Within the natural capital, external costs will decrease. This decrease is mainly caused by lower external cost of air pollution, water pollution and land use. The external costs of fossil resource scarcity and scarce water use will increase. The external costs of climate change will decrease if pig meat or dairy cow meat is replaced by cultivated meat, but will increase if cultivated meat replaces chicken meat.

Across most environmental indicators, the culture medium use is the main hotspot in RESPECTfarms' product system, followed by energy use at the RESPECTfarms facility. Within culture medium use, the main hotspots are hydrolysate, amino acids, and salts, followed by sugars, and additional processing and the medium formulation facility.

Within the social capital, non-animal related social issues are expected to decrease with a switch from conventional meat to cultivated meat, although quantification was not possible. A switch from conventional meat to cultivated meat avoids social risks in feed production (especially compared to pig meat production), avoids a considerable number of social risks hours in the slaughterhouse stage, and avoids risks on a decline in lung function and on an increase in the prevalence of asthma in the more intensive primary sectors. Switching to cultivated meat will decrease the external costs of fatal accidents in the primary sector and slaughterhouses, although the contribution to the total assessed external costs is low.

Within the social capital, animal related social issues are expected to decrease with a switch from conventional meat to cultivated meat, especially if cultivated meat replaces chicken meat. The decrease is a consequence of the very limited amount of (donor) animals needed for cultivated meat production as well as the lack of slaughtering activities in cultivated meat production. Still, animal-friendly living conditions should be ensured for these animals. Reducing the amount of livestock due to a switch to cultured meat will probably also decrease the external costs on animal health although a lot is still unknown.

Within the human health capital, no clear trend in external costs can be made for a shift from conventional meat to cultivated meat, because impact studies are still limited. Cultivated meat is a proteins and iron supplier and can be a supplier of vitamins B1 and B12 and zinc and selenium, if added. If so, it could match the nutritional value of conventional meat. Diet related consumer health risks (e.g. risks of stroke, diabetes, colorectal and lung cancer) of cultivated meat have not yet been investigated and therefore no external cost estimation could be done.

Discussion
Results of the TCA assessment must be seen in the context of some research limitations due to methodological choices, data accuracy issues and scenario analysis. In this study we had to deal with the fact that currently the production of cultivated meat is developed at lab-scale only, while the production of conventional meat is very well developed and optimised. The true cost assessment of cultivated meat is based on forecast data of a TRL7 production level. Assessments of all meat products are done for a 2030

scenario. Current models of conventional meat are adapted based on estimates of the situation in 2030. These adaptions are could only be based on policy reports, trends and expert opinions. Therefore some datapoints have a great deal of uncertainty. Some expected developments are not included in the analysis, because a robust analysis of the developments was beyond the scope of this study. This is the case for feed composition and feed conversion ratios, which are assumed to be unchanged in 2030.

Methodological limitations of this study are caused by limitations of the applied impact assessment methods and by limitations of the valuing methods. Applied monetisation factors are based on 2021 prices. Prices will probably be changed in 2030. Due to high uncertainty and because price development analysis was out of scope of this study, it was chosen to assess external costs for 2030 based on 2021 prices. A great limitation of the true cost assessment is the lack of true cost accounting modules for some social and human health issues. Therefore, only qualitative assessments have been done for these issues.

In this study we had to deal with allocation issues due to multi-functional processes in primary production, more specifically, in dairy cattle farming where milk and dairy cattle meat is produced. We chose economic allocation, which is the main applied allocation method in agrifood assessments and is also suggested by Galgani et al. (2023a). Other allocation methods could lead to other results. A sensitivity analysis on this was beyond the scope of this study.

The comparison of cultivated meat with beef was done for dairy cow meat, because no representative data of beef from Dutch beef cattle were available. The Dutch beef cattle sector is very small. Most beef produced in the Netherlands comes from the dairy sector. Since milk is the economic driver of the dairy sector, external costs of the sector are mainly allocated to the milk. Therefore the impact allocated to the meat is relatively small. Blonk et al. (2022) showed that the environmental impact of Irish beef was 3 to 6 times higher for all environmental impact categories than that of current Dutch dairy cow meat (Figure 5.2).

Limitations of the impact assessment methods in the natural capital are caused by limitations of the underlying life cycle impact assessment method ReCiPe2016. More information about these limitations can be found in (Huijbregts et al., 2016). The assessment on natural capital does not include local impacts as noise, odour and landscape disturbance, because currently there is no impact assessment method including these indicators nor the current TCA methods provide modules of these impacts. For the environmental externalities land use and scarce water consumption, a direct match between LCA results and monetisation factors was not possible. Instead, simplified conversion values were used to monetise land use and scarce water use, causing uncertainty in the results.

Methodological uncertainties on the social capital are caused by various issues. First, this study is limited because due to time restrictions; only a selected number of social (not animal related) impacts could be studied. Second, there is a lack of sector specific data on social issues such as occupational health and safety of the (self-employed) farmers, as well as a lack of data on working conditions in the slaughterhouse stage. Third, modules to calculate external costs are missing for impacts in social capital, except for animal welfare and occupational health and safety. So there is still a need both validated data and robust moduels to calculate social costs. But having said this, we can conclude that due to the very low mortality rates caused by fatal accicidents in both the industry as well as the primary sector in the Netherlands, the value of the related social costs are low, also most negligle. But occupational health issues have much higher prevalence and, especially in intensive meat farming, can be severe and might endure. Depending on their valuation these health impacts might show as non-negligible costs. Also, we expect that the social impact in the slaughterhouse stage, where a considerable number of issues happen, especially with respect to working conditions of migrant workers, costs might also turn out non-negligle.

The true cost assessment of animal welfare faces some limitations. The external costs are based on the Welfare Quality Protocol, which does not include all stages of the supply chain in which live animals are present, such as transport and slaughter. External costs of animal welfare will probably be higher if downstream activities were included in the Welfare Quality Protocol. The external costs of animal welfare are based on the additional costs needed to achieve the excellence level, i.e., the level where adverse animal welfare effects are minimised. Uncertainty in the external costs of animal welfare is also caused by the methodological definition choices of the ‘excellence’ level the minimum and maximum compensation thresholds (thresholds to limit compensation between welfare measures). Increasing or decreasing the excellence level and/or the minimum and/or maximum compensation thresholds will affect the external costs of animal welfare. In the study of Vissers et al. (2023) a sensitivity analysis was performed on the compensation threshold and excellence level. Results showed that particularly the external costs of the broiler production system were affected by these changes; the effect on the external costs of the pig and dairy production systems were limited. Therefore, particularly the external costs associated with broiler meat should be interpreted with caution. The number of studies that applied the Welfare Quality protocol is limited, which can be explained by the fact that the collection of data with the Welfare Quality protocol tends to be time consuming and costly. Application of the Welfare Quality protocol to other livestock production systems could provide better in the insight costs associated with animal welfare improvements and thus the costs needed to achieve the excellence level.

The monetisation factor for dairy cow meat was derived from the production costs (base year 2019) and welfare scores of conventional and organic dairy farming systems in Germany. The monetisation factor was calculated as the ratio of the change in production costs and the change in welfare score (see Vissers et al., 2023) and subdivided by economic allocation over milk and meat. The costs were obtained from The German Office of Agricultural Sociology and Agriculture (2019) and the welfare scores from Wagner et al. (2021). In Germany and the Netherlands, the production costs of the organic dairy farming system were on average 17 euro/100 kg milk higher than the conventional system in 2019 (Büro für Agrarsoziologie und Landwirtschaf, 2021; WUR, 2019). Using the production costs of Dutch conventional and organic dairy farming systems would therefore not affect the monetisation factor and thus the external costs of animal welfare. To date, there is no study that applied the Welfare Quality Protocol to Dutch dairy cattle. As welfare scores for Dutch dairy cattle are lacking, it is not known how these scores would affect the external costs of animal welfare.

Further it must be noted that in this study we assumed that the external costs of animal welfare of cultivated meat products are negligible, because only a very few donor animals are needed to produce cultivated meat. Although external costs are assumed to be negligible, animal friendly biopsy conditions as well as good living conditions are important for the welfare of these donor animals.

Sources and literature

AgriDirect BV (n.d.). Aanwezigheid alternatieve energie in de intensieve veehouderij. Angel Yeast Co Ltd. (2013). Yeast protein peptone and preparation method thereof (Patent CN103966290B).

Backus, G. and R. Jongeneel (2024). Quick scan financiële impact maatregelen 'Voorgenomen invulling regelgeving dierwaardige veehouderij.'

Beldman, A., J. Reijs, C. Daatselaar and G. Doornewaard (2020). De Nederlandse melkveehouderij in 2030 : verkenning van mogelijke ontwikkelingen op basis van economische modellering. https://doi.org/10.18174/532156

Blonk Consultants, Bocconi University and The Brewers of Europe (2018). PEFCR for Beer.

Blonk, H., M. van Paassen, N. Draijer, M. Tyszler, N. Braconi and J. van R. (2022). Agri-footprint 6 Methodology Report - Part 2.

Büro für Agrarsoziologie und Landwirtschaft (2021). Milk production costs in eight European countries, EU average costs and organic milk production costs What is the cost of producing milk? www.milcherzeuger.eu

CLO (2021). Gebruik van antibiotica en gemeten resistentie in de veehouderij, 1999 - 2020. https://www.clo.nl/indicatoren/nl056509-gebruik-van-antibiotica-en-gemeten-resistentie-in-de-veehouderij-1999-2020

Colland Arbeidsmarkt - https://collandarbeidsmarkt.incijfers.nl/dashboard/dashboard/werknemers--persoonskenmerken- – Sazas en CBS, 2019

COV (2024). COV - Duurzaam. https://www.cov.nl/themas/thema?dossierid=604504064&title=Duurzaam

Dagevos, H. and W. Verbeke (2022). Meat consumption and flexitarianism in the Low Countries. Meat Science, 192, 108894. https://doi.org/10.1016/j.meatsci.2022.108894

De Baan, L., R. Alkemade and T. Koellner (2013). Land use impacts on biodiversity in LCA: A global approach. International Journal of Life Cycle Assessment, 18(6), 1216–1230. https://doi.org/10.1007/s11367-012-0412-0

De Vries, M., Van Middelaar CE and De Boer, I.J.M. (2015). Comparing environmental impacts of beef production systems: a review of life cycle assessments. Livestock Science, 178, 279–188.

Delsart, M., F. Pol, B. Dufour, N. Rose and C. Fablet (2020). Pig farming in alternative systems: Strengths and challenges in terms of animal welfare, biosecurity, animal health and pork safety. Agriculture (Switzerland), 10(7), 1–34. https://doi.org/10.3390/agriculture10070261

Dierenbescherming (2018). Veetransporten. https://www.dierenbescherming.nl/werkzaamheden/dierenbeleid-beinvloeden/dossiers/veetransporten

EC. (2022). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS REPowerEU Plan. COM/2022/230 final.

EC and IRENA (2018). Renewable Energy Prospects for the European Union.

European Food Safety Authority (n.d.). Animal welfare at slaughter. Retrieved May 28, 2024, from https://www.efsa.europa.eu/en/topics/topic/animal-welfare-slaughter#:~:text=EU%20framework,It%20applies%20to%20farmed%20animals.

European Food Safety Authority (2022, September 7). More space, lower temperatures, shorter journeys: EFSA recommendations to improve animal welfare during transport. https://www.efsa.europa.eu/en/news/more-space-lower-temperatures-shorter-journeys-efsa-recommendations-improve-animal-welfare#:%7E:text=Providing%20more%20space%2C%20lowering%20maximum,recommendations%20published%20today%20by%20EFSA.

European Food Safety Authority (2023). The safety of cell culture-derived food – ready for scientific evaluation. https://www.efsa.europa.eu/en/news/safety-cell-culture-derived-food-ready-scientific-evaluation FAOSTAT: https://www.fao.org/faostat/en/#data

Food Safety Agency (2024). Identification of hazards in meat products manufactured from cultured animal cells: Hazards. https://www.food.gov.uk/research/identification-of-hazards-in-meat-products-manufactured-from-cultured-animal-cells-hazards#fn:1

Fraeye, I., M. Kratka, H. Vandenburgh and L. Thorrez (2020). Sensorial and Nutritional Aspects of Cultured Meat in Comparison to Traditional Meat: Much to Be Inferred. Frontiers in Nutrition, 7. https://doi.org/10.3389/fnut.2020.00035

Galgani, P., R. de Adelhart Toorop, A. de Groot Ruiz, E. Varoucha and G. Woltjer (2021a). Land use, Land use change, Biodiversity and Ecosystem Services: Impact-specific module of the true pricing method for agri-food products. www.trueprice.org

Galgani, P., B. van Veen, D. Kanidou, R. de Adelhart Toorop and G. Woltjer (2023a). True Price Assessment Method for Agri-food Products. https://www.wur.nl/nl/Onderzoek-

Galgani, P., G. Woltjer, D. Kanidou, R. de Adelhart Toorop and A. de Groot Ruiz (2021b). Scarce water use module True pricing method for agri-food products https://www.wur.nl/nl/Onderzoek-

Galgani, P., G. Woltjer, D. Kanidou, E. Varoucha, R. de Adelhart Toorop (2023b). Air, soil and water pollution module True pricing method for agri-food products

Gocsik, É., S.D. Brooshooft, I.C. de Jong and H.W. Saatkamp (2016). Cost-efficiency of animal welfare in broiler production systems: A pilot study using the Welfare Quality® assessment protocol. Agricultural Systems, 146, 55–69. https://doi.org/10.1016/j.agsy.2016.04.001

Goedkoop, M., A.G. Rossberg and M. Dumont (2022). Bridging the Gap Between Biodiversity Footprint Metrics and Biodiversity State Indicator Metrics Understanding the purposes and relationships between biodiversity metrics with a special focus on the Living Planet Index and PDF-based footprinting metrics. https://www.qmul.ac.uk/sbbs/media/sbbs/research/bsc-project/QMUL-

Gulden, J. van der, P. Vogelzang, C. van Schayck and H. Folgering (2002). Longaandoeningen en werkgebonden risicofactoren bij varkenshouders. In: Huisarts & Wetenschap 45(01) januari 2002.

Hagenaars, T., G.J. Boender, P. Hobbelen and A. Elbers (2022). Scenario's voor gebiedsgerichte aanpak van de inrichting van het landelijk gebied en het effect daarvan op transmissierisico's van dierziekten. https://doi.org/10.18174/571487

Heyma, A. and W. Luiten (2022). Aantal werkenden in de slachthuizen en overige vleessector – kwantitatieve verkenning van de sector. Eindrapportage. SEO.

Hoste, R. (2023a). Interview sector expert Pigs (WUR).

Hoste, R. (2023b). Varkenshouderij in 2043: blik in de toekomst. https://weblog.wur.nl/fnh-ri/varkenshouderij-in-2043-blik-in-de-toekomst/

Huijbregts, M., Z.J.N. Steinmann, P.M.F.M. Elshout, G. Stam, F. Verones, M.D.M. Vieira, M. Zijp and R. van Zelm (2016). ReCiPe 2016. National Institute for Public Health and the Environment, 194. https://www.rivm.nl/bibliotheek/rapporten/2016-0104.pdf

Jurkiewicz, E., U. Husemann, G. Greller, M. Barbaroux and C. Fenge (2014). Verification of a new biocompatible single-use film formulation with optimized additive content for multiple bioprocess applications. Biotechnology Progress, 30(5), 1171–1176.

Kamerstuk (2012). Bijlage 1. Beeld van de uitzendbranche. Dossiernummer 17050 - "blg-184090"- https://zoek.officielebekendmakingen.nl/blg-184090.pdf. Vergaderjaar 2011- 2012.

Kamerstuk (2022). Brief, nr. 1269, 29861 Arbeidsmigratie en sociale zekerheid. Vergaderjaar 2022-2023.

Kobayashi, Y., E.W. Mohammad, H. Guðmundsson, E.E. Guðmundsdóttir, Ó.H. Friðjónsson, E.N. Karlsson, M. Roitto and H.L. Tuomisto (2023). Life-cycle assessment of yeast-based single-cell protein production with oat processing side-stream. Science of the Total Environment, 873, 162318.

Kromhout, D., C.J.K. Spaaij, J. de Goede, R.M. Weggemans, J. Brug, J.M. Geleijnse, J.B. van Goudoever, A.W. Hoes, M.T.E. Hopman, J.A. Iestra, R.P. Mensink, H. Pijl, J.A. Romijn, A.M.W.J. Schols, J.C. Seidell, P.V.T. Veer, M. Visser and M.H. Zwietering (2016). The 2015 Dutch food-based dietary guidelines. In European Journal of Clinical Nutrition (Vol. 70, Issue 8, pp. 869–878). Nature Publishing Group. https://doi.org/10.1038/ejcn.2016.52

Leiden, A., F. Cerdas, D. Noriega, J. Beyerlein and C. Herrmann (2020). Life cycle assessment of a disposable and a reusable surgery instrument set for spinal fusion surgeries. Resources, Conservation and Recycling, 156, 104704. https://doi.org/10.1016/J.RESCONREC.2020.104704

McNamara, E. and C. Bomkamp (2022). Cultivated meat as a tool for fighting antimicrobial resistance. In Nature Food (Vol. 3, Issue 10, pp. 791–794). Springer Nature. https://doi.org/10.1038/s43016-022-00602-y

Melzener, L., K.E. Verzijden, A.J. Buijs, M.J. Post and J.E. Flack (2021). Cultured beef: from small biopsy to substantial quantity. Journal of the Science of Food and Agriculture, 101(1), 7–14. https://doi.org/10.1002/jsfa.10663

Mostert, P.F., I. Huisman, M. Maaoui, P.G. Rojas and W. Hennen (2023). Greenhouse gas emissions of pig production in the Netherlands: A trend analysis from 1990 to 2020 by using life cycle assessment. Wageningen Livestock Research.
Nederlandse Arbeidsinspectie (2020). Programmarapportage Uitzendbureaus 2020 -2022. Ministerie van SZW.
Nederlandse Arbeidsinspectie (2021). Monitor en arbeidsongevallen 2021. Ministerie van SZW.
Nederlandse Arbeidsinspectie (2023). Monitor en arbeidsongevallen 2022-2023. Ministerie van SZW.
Nikkhah, A., A.J. Stout, K. Trinidad, D.J. Kaplan and N. Tichenor Blackstone (2024). Life cycle assessment of Beefy-9 and Beefy-R serum-free culture media for cell-cultivated beef production. Preprint.
NVWA (2024). Klassieke varkenspest. https://www.nvwa.nl/onderwerpen/dierziekten/klassieke-varkenspest-kvp
PBL (2021). Klimaat- en energieverkenning (KEV) 2021.
Pishgar-Komleh, S.H. and A. Beldman (2022). Literature review of beef production systems in Europe. https://doi.org/10.18174/567148
Planbureau voor de Leefomgeving (PBL). (2021). Klimaat- en Energieverkenning 2021. www.pbl.nl/kev
Ramírez López, V. (RESPECTfarms) (2024). Interview Victoria Ramírez López.
Riber, A.B., L. Rangstrup-Christensen, M.S. Hansen, L.K. Hinrichsen and M.S. Herskin (2020). Characterisation of footpad lesions in organic and conventional broilers. Animal, 14(1), 119–128. https://doi.org/10.1017/S1751731119001551
RIVM (2024a). Campylobacter. https://www.rivm.nl/campylobacter
RIVM (2024b). Samonella. https://www.rivm.nl/salmonella
RIVM (2024c). Vogelgriep. https://www.rivm.nl/aviare-influenza
Serwecińska, L. (2020). Antimicrobials and antibiotic-resistant bacteria: A risk to the environment and to public health. Water (Switzerland), 12(12). https://doi.org/10.3390/w12123313
Sinke, P., E. Swartz, H. Sanctorum, C. van der Giesen and I. Odegard (2023). Ex-ante life cycle assessment of commercial-scale cultivated meat production in 2030. The International Journal of Life Cycle Assessment, 28(3), 234–254.
Stout, A.J., M.L. Rittenberg, M. Shub, M.K. Saad, A.B. Mirliani, J. Dolgin and D.L. Kaplan (2023). A Beefy-R culture medium: Replacing albumin with rapeseed protein isolates. Biomaterials, 296, 122092. https://doi.org/10.1016/J.BIOMATERIALS.2023.122092
UNEP (2020). Guidelines for Social Life Cycle assessment of Products and Organizations 2020.
Van Asseldonk, M.A.P.M., A.R.W. Elbers, T.J. Hagenaars, G.J. Boender and R.H.M. Bergevoet (2019). Onderbouwing DGF-plafonds 2020/2024. https://doi.org/10.18174/476589
Van Harn, J. and P. Bikker (2023). Omschakeling van reguliere vleeskuikens naar Beter Leven 1-ster vleeskuiken. https://beterleven.dierenbescherming.nl/over-de-dieren/alle-dieren/vleeskuikens/
Van Horne, P. (2023). Interview sector expert Poultry (WUR).
Van Rossum, C.T.M., E.L. Sanderman-Nawijn, H.A.M. Brants, C.S. Dinnissen, M. Jansen-van der Vliet, M.H. Beukers and M.C. Ocké (2022). Diet of the Dutch 2019-2021.
Vink, I. and A. Pieters (1999). Handboek huisvesting jongvee en melkvee. Praktijkonderzoek Rundvee, Schapen en Paarden.
Vissers, L.S.M., C.P.A. van Wagenberg and W.H.M. Baltussen (2023). A method for calculating the external costs of farm animal welfare based on the Welfare Quality® Protocol. Frontiers in Animal Science, 4. https://doi.org/10.3389/fanim.2023.1195221
Vissers, L. and G. Woltjer (2022). Farm animal welfare. https://www.wur.nl/nl/Onderzoek-
vlees.nl. (2024). Duurzame vleessector. https://www.vlees.nl/themas/duurzaam-vee-vlees/duurzame-vleessector/
Voedingscentrum (2024). Waarom is minder vlees eten beter voor je gezondheid en het milieu? En hoe doe je dat? https://www.voedingscentrum.nl/nl/duurzaam-eten/waarom-is-minder-vlees-eten-beter-voor-gezondheid-en-milieu.aspx
https://www.vzinfo.nl/ziekteverzuim/bedrijfssector - cijfers 2019
Wageningen Economic Research. (2022). Agrimatie.
Wagner, K., J. Brinkmann, A. Bergschmidt, C. Renziehausen and S. March (2021). The effects of farming systems (organic vs. conventional) on dairy cow welfare, based on the Welfare Quality® protocol. Animal, 15(8). https://doi.org/10.1016/j.animal.2021.100301
Welfare Quality Network (2009a). The Welfare Quality® Assessment Protocol. https://www.welfarequalitynetwork.net/en-us/reports/assessment-protocols/

Welfare Quality Network (2009b). Welfare Quality ® Assessment protocol for cattle.
WUR (2019). Kostprijs van melk (excl. BTW) - Melkveebedrijven. Agrimatie. https://agrimatie.nl/Binternet.aspx?ID=6&Bedrijfstype=1&SelectedJaren=2019%402018%402017%402016&GroteKlassen=Alle+bedrijven
WUR (2024a). Afrikaanse varkenspest. https://www.wur.nl/nl/onderzoek-resultaten/onderzoeksinstituten/bioveterinary-research/dierziekten/virusziekten/afrikaanse-varkenspest-2.htm
WUR (2024b). Mond- en Klauwzeer (MKZ). https://www.wur.nl/nl/onderzoek-resultaten/onderzoeksinstituten/bioveterinary-research/dierziekten/virusziekten/mond-en-klauwzeer-mkz.htm

Appendix 1 Carbon balance cultivated meat production process

The carbon balance for RESPECTfarms' production process is shown in Table A1.1. The carbon conversion efficiency (out in product/in) is around 47%.

Table A1.1 *Carbon balance for RESPECTfarms' production process*

	Substance	Qty IN in culture medium (g/kg meat), or OUT (g/kg meat)	Carbon content average (in dm ingredients), %	Carbon IN or OUT (g/kg meat)	Comment
IN	Amino acids (total)	c.d.	c.d.	c.d.	
	Lysate	c.d.	c.d.	c.d.	Assumed there is 50% amino acids in lysate and the sugars are not metabolised (therefore not counted as carbon in)
	Sugars (total)	c.d.	c.d.	c.d.	
	Recombinant compounds	c.d.	c.d.	c.d.	Not metabolised (therefore not counted as carbon in)
	Rapeseed protein isolate	c.d.	c.d.	c.d.	Not metabolised (therefore not counted as carbon in)
	Salts	c.d.	c.d.	c.d.	
	Vitamins	c.d.	c.d.	c.d.	Not metabolised (therefore not counted as carbon in)
	Others	c.d.	c.d.	c.d.	Not metabolised (therefore not counted as carbon in)
	Total	c.d.		c.d.	
OUT	Cell mass, meat (dry mass)	c.d.	c.d.	c.d.	
	Cell mass, fat (dry mass)	c.d.	c.d.	c.d.	
	CO_2	c.d.	c.d.	c.d.	Calculated by RF for their specific process.
	Lactate	c.d.	c.d.	c.d.	Calculated by RF for their specific process.
	Unused amino acids	c.d.	c.d.	c.d.	Assumed 10% (90% conversion)
	Unused lysate	c.d.	c.d.	c.d.	Assumed 10% (90% conversion)
	Unused sugars	c.d.	c.d.	c.d.	Assumed 10% (90% conversion)
	Total	c.d.		c.d.	

c.d.: Confidential data RESPECTfarms (data known by Wageningen Economic Research).

Appendix 2 Input data for the RESPECTfarms LCA model

Table A2.1 *General system characteristics*

Aspect	Data RF	Data CED	Data for LCA model	Unit	Comment
Facility size	c.d.		-	m^2	Capital goods (building) cut-off, to match scope of conventional animal production (Agri-footprint)
Batches per year	c.d.		-	p	
Amount of product produced per batch (kg) before downstream	c.d.		-	kg	
Total batch time (proliferation + differentiation) (hours)	c.d.		-	h	
Number of seeding lines	c.d.		-	p	Included estimates for stainless steel bioreactors in the LCA model, amortized over a 20 year lifetime
Number of bioreactors for main proliferation step	c.d.		-	p	Idem
Number of bioreactors for muscle differentiation step	c.d.		-	p	Idem
Number of bioreactors for fat differentiation step	c.d.		-	p	Idem
Assumption for COP of cooling water system		c.d.	-		Conservative assumption as no specifics on heat pumps were provided.

c.d.: Confidential data RESPECTfarms (data known by Wageningen Economic Research).

***Table A2.2** Outputs from 1 year of production*

Product	Data RF	Data CED	Data for LCA model	Unit	Comment
Cultivated meat at facility gate	c.d.		c.d.	kg	Including downstream processing losses
Cultivated meat before downstream	c.d.			kg	
Dry matter (dm) content	c.d.				
Meat cells	c.d.				
Fat cells	c.d.				
Wastes and emissions					
Spent medium, in which:	c.d.			l	Waste treatment: Wastewater from potato starch production {CH}| market for wastewater from potato starch production (proxy selected based on similarity of composition of organic carbon and nitrogen)
Lactate	c.d.			kg	Value from RF calculated for their specific process.
Ammonia	c.d.			kg	Value from RF calculated for their specific process.
Unused amino acids	c.d.			kg	Value from RF calculated for their specific process.
Unused lysate	c.d.			kg	Value from RF calculated for their specific process.
Unused sugars	c.d.			kg	Value from RF calculated for their specific process.
Process losses (cell mass)	c.d.			kg	3,5%. Assumed to be discarded with spent medium.
Used bioreactor bags	c.d.			kg	Waste treatment: Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration with fly ash extraction
Air filters			c.d.	p	Same as input. Waste treatment: Used air filter decentralized unit, 180-250 m^3/h {CH}| market for used air filter decentralised unit, 180-250 m^3/h
Liquid filters			c.d.	p	Same as input. Waste treatment: Used air filter decentralized unit, 180-250 m^3/h {CH}| market for used air filter decentralised unit, 180-250 m^3/h
Other consumables		c.d.		kg	Same as input. Waste treatment: Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration with fly ash extraction
CO_2, biogenic	c.d.			kg	Produced by cell metabolism, no climate change impact because biogenic CO_2
CO_2, fossil	c.d.			kg	From CO_2 added to bioreactor

c.d.: Confidential data RESPECTfarms (data known by Wageningen Economic Research).

Table A2.3 *Inputs for 1 year of production*

	Data RF	Data CED	Data for LCA model	Unit	Comment
Culture medium quantity					
Total medium requirements	c.d.		c.d.	l	Value from RF calculated for their specific process.
Medium per kg CM	c.d.		-	l/kg	Value from RF calculated for their specific process.
For proliferation	c.d.		-	l/kg	Value from RF calculated for their specific process.
For differentiation	c.d.		-	l/kg	Value from RF calculated for their specific process.
Culture medium composition					
Beefy-R serum-free growth medium (with RPI), in which:					
Amino acids	c.d.		c.d.	mg/l	Value from RF calculated for their specific process. See main text for additional information.
Lysate (BSY)	c.d.		c.d.	mg/l	Idem
Sugars	c.d.		c.d.	mg/l	Idem
Recombinant compounds	c.d.		c.d.	mg/l	Idem
Rapeseed protein isolate (RPI)	c.d.		c.d.	mg/l	Idem
Salts	c.d.		c.d.	mg/l	Idem
Vitamins	c.d.		c.d.	mg/l	Idem
Others	c.d.		c.d.	mg/l	Idem
Energy (electricity)					
Heating		c.d.	-	kWh	Value from Sinke et al. (2023): 0,03129 kWh/L for heating water from 10 to 37 ºC. Applied to all culture medium. COP 3 assumed.
Mixing	c.d.		-	kWh	Value from RF calculated for their specific process.
Filtration	c.d.		-	kWh	Value from RF calculated for their specific process.
Aeration	c.d.		-	kWh	Value from RF calculated for their specific process.
Agitation	c.d.		-	kWh	Value from RF calculated for their specific process.
Cooling	c.d.		-	kWh	Value from RF calculated for their specific process. Cooling water produced electrically on-site, COP 3 assumed.
Concentration	c.d.		-	kWh	Value from RF calculated for their specific process.
Freezing	c.d.		-	kWh	Value from RF calculated for their specific process.
Water demineralisation		c.d.	-	kWh	Proxy data from Ecoinvent LCA database (ultrapure water production in Europe)
Other		c.d.	-	kWh	To fill electricity demand data gap, e.g. HVAC of the facility, digital systems. Proxy data from HVAC consumption in non-sterile ointments production, as this is a biotech process but RESPECTfarms indicates that food-grade is more representative than pharma-grade environment: https://www.cleanroomtechnology.com/news/article_page/Saving_energy_in_cleanrooms/100623
Total			c.d.	kWh	Calculated value (total of all electricity use)
Energy use per kg CM			c.d.	kWh	Calculated value (electricity consumption / annual production)

	Data RF	Data CED	Data for LCA model	Unit	Comment
Utilities					
Freon	-		-		Cut-off, likely negligible when amortised over the lifetime of the system
Water (demineralized)	c.d.		c.d.	l	Assumed to be demineralised on-site
Air	c.d.		c.d.	kg	Assumed to be ambient air, energy use included in energy estimates
CO_2	c.d.		c.d.	kg	Assumed to be waste fossil CO_2
O_2	-		-		Probably not used in RF production system
N_2	-		-		Probably not used in RF production system
Consumables					
Air filters for air filtration before gas compression (10 m^3/hour)	c.d.		c.d.		Proxy data for air filters of 180 - 250 m^3/h (Ecoinvent)
Air filters for gas in and gas out for bioreactors (ranging from 8 L/hour up to 6 m^3/hour)	c.d.		c.d.		Idem
Filters for sterilisation of proliferation medium	c.d.		c.d.		Proxy data from CE Delft database, filter cartridges that can filter up to 3000 L, roughly 1 m^2 (folded) ultrafiltration membrane.
Filters for sterilisation of muscle differentiation medium	c.d.		c.d.		Idem
Filters for sterilisation of fat differentiation medium	c.d.		c.d.		Idem
Filters for downstream processing (m^2)	c.d.		c.d.		Idem
Single use bioreactor bags	c.d.		c.d.	kg	Composition modelled after Jurkiewicz et al. (Jurkiewicz et al., 2014). Gamma irradiation not modelled because of lacking information, approach from Leiden et al. (Leiden et al., 2020) followed to exclude this and to only model transport to radiation facility (500 km) and to RF (500 km).(Jurkiewicz et al., 2014). Gamma irradiation not modelled because of lacking information, approach from Leiden et al. (Leiden et al., 2020) followed to exclude this and to only model transport to radiation facility (500 km) and to RF (500 km).(Jurkiewicz et al., 2014). Gamma irradiation not modelled because of lacking information, approach from Leiden et al. (Leiden et al., 2020) followed to exclude this and to only model transport to radiation facility (500 km) and to RF (500 km).
Other consumables			c.d.	kg	See below
Other consumables per kg of CM		c.d.	-	kg/kg CM	Miscellaneous consumables (tubes, bottles, flasks, etc.), quantity from CE Delft CM database. Injection moulded LDPE with average 500 km transport from production to RESPECTfarms used as proxy.
Chemicals					
PBS	-		-		Probably not used in RF production system
HCL	-		-		Probably not used in RF production system
NaOH			c.d.	kg/kg CM	Maybe used, therefore added
NaOH per kg of CM		c.d.	-	kg/kg CM	Pure (no solution). Quantity from CE Delft CM database.
Other					
Starting cells	n.a.		-		Cut-off, negligible environmental impact over the product's life cycle

c.d.: Confidential data RESPECTfarms (data known by Wageningen Economic Research).

Appendix 3 Energy mix modelling

Netherlands and EU-average electricity mixes in 2030
The Netherlands-average electricity mix for 2030 was available at CE Delft and shared with WEcR for the purpose of this project. This LCA model is based on the Klimaat- en Energieverkenning (KEV) (PBL, 2021).[19]

An LCA model was made for the EU-average electricity mix. The average composition was calculated using EC and IRENA (EC and IRENA, 2018) and renewed targets specified by the EU in context of the REPowerEU plan[20] and associated communication (EC, 2022). The starting point for the calculations is the REmap 2030 scenario in EC and IRENA (EC and IRENA, 2018), which has been compiled in close collaboration with the EC and which resulted in 50% renewable electricity in Europe's supply. The climate targets of the EU have since been increased and therefore EU indicates share of renewables in electricity by 2030 will have to be 69% (EC, 2022). We assume the share of technologies in the grid mix in-/decrease proportionally to the in-/decrease as estimated in EC and IRENA (EC and IRENA, 2018) from 2010 to 2030 REmap. This means largest increase for solar PV, largest decrease for coal, and little change for natural gas.

Table A3.1 Electricity *production scenarios (EC and IRENA, 2018) and calculated scenarios for REPowerEU (EC, 2022)*

Technology	2010 (IRENA, 2018) (annual power generation in TWh)	2030 Reference (2018, IRENA) (annual power generation in TWh)	REmap (IRENA, 2018) (annual power generation in TWh)	Relative in- or decrease of REmap compared to 2010, %	REPowerEU 2030 (own calculations) b) (annual power generation in TWh)	Relative in- or decrease of REPowerEU 2030 compared to 2010, %	Calculated relative share in production mix in REPowerEU 2030, %
Coal	878	556	444	-49	118	-87	3,2
Oil	108	7	7	-94	0	-100	0,0
Natural gas	752	751	715	-5	648	-14	17,5
Nuclear	911	732	677	-26	380	-58	10,3
Total non-renewable	2,649	2,046	1,843	-30	1,147	-57	31,0
Hydropower	373	387	411	10	420	13	11,4
Biomass	128	286	324	153	403	215	10,9
Solar PV	23	188	281	1,122	506	2,101	13,7
CSP[a]	0	8	10	n.a.	0	n.a.	n.a.
Wind	151	544	783	419	1,153	664	31,2
Geothermal	6	13	44	633	70	1,072	1,9
Total renewable	681	1,426	1,853	172	2,553	275	69,0
Other a)	0	0	4	n.a.	0	n.a.	n.a.
Total	3,330	3,472	3,700	11	3,700	11	100,0
Share renewable	20%	41%	50%	n.a.	69%	n.a.	69
Share non-renewable	80%	59%	50%	n.a.	31%	n.a.	31

a) Not possible to calculate a relative in- or decrease as 2010 value is 0 TWh. Since these categories are nominal, we distributed these shares proportionally over the other technologies, taking into account the total shares of renewable versus non-renewable electricity; b) Calculated using $TWh_{REPowerEU} = TWh_{REmap} * (1 + \%_{relative\ in-\ or\ decrease})^x$, in which $TWh_{REPowerEU}$ = 31% * 3,700 TWh for the non-renewable and 69% * 3,700 TWh for the renewable technologies. Solving for x results in 1.94 and 0.24 respectively.

[19] Tabel 14a and appendix 'PBL KEV 2021 emissie elektriciteit'.
[20] See https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_nl

Electricity production at the farm
At the moment of study, already around half of the intensive animal agriculture stables has PV panels on their roof (AgriDirect BV, n.d.). It is plausible the majority of the stables will have PV panels in 2030. In order to create an equal comparison, we assume that all farms in this study have PV panels on the roof of their stables in 2030.

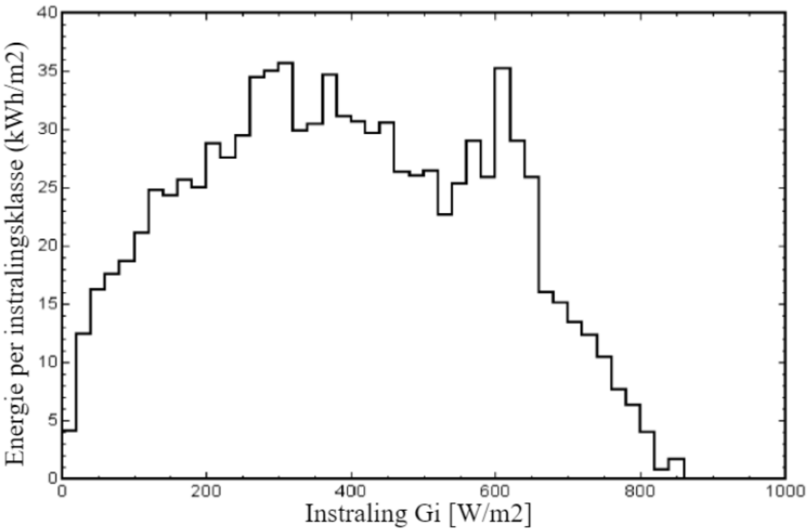
The PV panels partly provide the electricity for the production process in the stables. However, the sun does not always shine, and energy demand varies per meat production system. Part of the year, therefore, energy will be obtained from the grid. Here we calculate with a scenario where grid power is the average mix in 2030. A calculation was performed to:
1. Determine how the energy demand of the meat production systems relates to the installed capacity of the PV systems on the barn roofs;
2. Determine how that relates to the power supplied by the PV system during the year.

***Table A3.2 Calculation** of energy use and its relation to energy production capacity at different stables*

Type	Energy use (kWh/year)	Energy demand (continuous) (kW)	Stable floor space (m^2)	Roof area for PV panels (m^2) a)	Peak capacity (kW) b)	Energy demand (continuous) / peak capacity	Sources
Cultivated meat	636,670	73	800	419	84	87%	Stable floor space and energy use: Data RESPECTfarms
Chicken	90,000	10	5,000	2,621	524	2%	Stable floor space and energy use: Data WEcR
Pigs (fattening pigs)	87,949	10	2,636	1,382	276	4%	Energy use: Mostert et al. (Mostert et al., 2023). Stable floor space: Data WEcR.
Pigs (sows)	206,696	24	4,065	2,131	426	6%	Energy use: Mostert et al. (Mostert et al., 2023) Stable floor space: Data WEcR.
Dairy cattle	45,167	5	1,827	958	192	3%	Energy use: Agri-footprint. Stable floor space: Vink and Pieters (Vink and Pieters, 1999)(Vink and Pieters, 1999)(Vink and Pieters, 1999)(Vink and Pieters, 1999)

a) Roof area calculated as half of the stable area, at a 25% slope, of which 95% can be utilised to install PV panels; b) Peak power calculated using an average 200 Wp/m^2.

Figure A3.1 shows the average irradiance in Belgium, which is located next to the Netherlands and therefore considered representative. In Belgium, 50% of the hours in a year there is sunlight, 18% of the hours have an irradiance of <100 W/m^2 (<10% of the maximum irradiance), and 32% of the hours have an irradiance of >100 W/m^2 (<10% of the maximum irradiance). With an irradiance of >100 W/m^2, the power of the PV installation is proportional to the irradiance, with the maximum irradiance of 1,000 W/m^2 being equal to the peak power of the panels (e.g., with an irradiance of 500 W/m^2, the installation delivers 50% of its peak power). Thus, 32% of the hours in a year the PV system delivers >10% of its peak power. Table 5 shows that the energy demand of the meat production systems ranges from 2% - 6% of the peak power installed on the roofs (under continuous energy demand) at livestock farms, and 87% at the cultivated meat facility. Therefore, we assume that during 32% of the hours in a year there is (more than) sufficient solar power available to run the continuous production process on the livestock farms. For the cultivated meat facility, an additional 643 kW (3,215 m^2 or 0.32 hectares) of PV panels must be installed to ensure that the same 32% of the year sufficient power is available. For the remaining 68% of the hours, there may be insufficient power available to provide renewable power to the process. A more detailed calculation of power supply and demand is beyond the scope of this study, and so we use a factor of 0.32 for renewable power, and 0.68 for electricity from the grid.



Figuur 6.11 De verdeling op jaarbasis van de zonne-energie, opgewekt op een hellend vlak (30°) in België, wordt gegeven in functie van het instralend vermogen.

Figure A3.1 *Annual solar irradiation in Belgium*[21]

At times, both the cultivated meat facility and the livestock farms will have surplus solar power. We see this as a separate business activity and not as a multifunctional production system, and therefore this is not included in this LCA (via netting, substitution, or otherwise) beyond the fact that renewable electricity is guaranteed for part of the year. Producers usually receive compensation for this, and the activity is separated from meat production (in any case technically and often also economically). In addition, there is uncertainty about what happens to surplus electricity, due to grid congestion and the resulting contained connection capacities and curtailment of PV systems.

A possible solution for using the locally generated electricity would be to put batteries at the meat production sites. This is not attractive to everyone given the high investment costs, and so we have placed it outside the scope of this study. However, for the cultivated meat facility, this would be an interesting route to explore, given the substantial electricity demand.

[21] The publication was located at https://docplayer.nl/6635096-Hoofdstuk-6-dimensionering-van-een-fotovoltaisch-systeem.html. This is only one chapter of the book, author and other publication details could unfortunately not be located.

Appendix 4 S-LCA backgrounds and tables

Table A4.1 *List of stakeholder categories and impact subcategories*

Stakeholder categories	Worker	Local community	Value chain actors (not including consumers)	Consumer	Society	Children
Subcategories	1. Freedom of association and collective barganing 2. Child labour 3. Fair salary 4. Working hours 5. Forced labour 6. Equal opportunities / discrimination 7. Health and safety 8. Social benefits / social security 9. Employment relationship 10. Sexual harassment 11. Smallholders including farmers	1. Access to material resources 2. Access to immaterial resources 3. Delocalisation and migration 4. Cultural heritage 5. Safe and healthy living conditions 6. Respect of indigenous rights 7. Community engagement 8. Local employment 9. Secure living conditions	1. Fair competition 2. Promoting social responsibility 3. Supplier relationships 4. Respect of intellectual property rights 5. Wealth distribution	1. Health and safety 2. Feedback mechanism 3. Consumer privacy 4. Transparency 5. End-of-life responsibility	1. Public commitments to sustainability issues 2. Contribution to economic development 3. Prevention and mitigation of armed conflicts 4. Technology development 5. Corruption 6. Ethical treatment of animals 7. Poverty alleviation	1. Education provided in the local community 2. Health issues for children as consumers 3. Children concerns regarding marketing practices

Source: UNEP (2020).

Table A4.2 *Longlist 'social impact categories', data availability and TCA -module available*

	Regular meat			**Data availa-bility**	**Cultivated Meat**	**Data availa-bility**	**TCA-module**	**Remarks**
	Feed prodcution	**Primary production**	**Porcessing Verwerking**		**Production**			
Fair salary	x	x	x	Yes		nk	Yes	FADN (BIN) data on income (aje) and spread
Working hours	x		x	No			No	Combined with social benefits: risks hours workers
Health and safety workers	x	x	x	Yes, limited	x Comparable to Primary Dairy production	Yes	Yes	(Fatal) incidents (No data on occupational health)
Social benefits/ social security	x		x	Yes, limited		nk	No	Combined with working hours: risk hours of workers
Access to material resources	x	x	x		x	Yes	Yes	Wateruse: part of LCA
Safe and healthy living conditions		x		1. Yes 2. Yes			1. Yes 2. No	1. Particulate matter is part of LCA 2. Animal diseases qualitive description
Local emploment	x	x	x	Yes	x	nk	No	
Wealth distribution	x	x	x	No		nk	No	Information in ACM report (2022)
Ethical treatment of animals		x		No		Yes	Yes	

Appendix 5 Supplementary information about Position of farmer in the chain and Relationship general welfare, TCA and SCBA

From: Elsje Oosterkamp, Huib Silvis en Katja Logatcheva, 2023. Hoe True Cost Accounting bijdraagt aan het meten van Brede Welvaart; Begrippen True Pricing, True Cost Accounting, MKBA en Brede Welvaart toegelicht. Wageningen, Wageningen Economic Research, Rapport 2023-111.

The position of the farmer in the chain
Table 4.4 in the Agro-Nutri Monitor 2022[22] shows that the net margins for pig meat in the conventional chain are low for farmers, processors and supermarkets with 1, 2 and -4%, respectively. This is the average result over the years from 2017 to 2019. For the supermarket, pig meat is a traffic generator. The product is priced cheaply to attract store visits. The product is supposed to generate profits on other products bought in the shop.

Dairy cow meat and chicken meat have not been examined in the Agro-Nutri Monitor. For dairy farming, where an average of over 95% of farm income derives from milk, the net margin is -10%. Net margins for milk in the industry and supermarket are -4 and 8%, respectively. During these years from 2017 to 2019, world milk prices where on average level, before they dropped in 2020. Milk prices rocketed till the end of 2022 to stabilise at a more than average level. Meat prices stabilised at a higher level.

Table 4.5 in the same Monitor shows that where margins in the primary sector are good, there may be many factors underlying this. High concentration in processing does not seem to add to higher profits at the primary stage. Note that however in the dairy sector, the processor is a cooperative and in the pig meat sector farmers are still owners of the slaughterhouse company. In general it cannot be stated that the processing phase is at the expense of farmers. It can be stated that price risk lays primarily at farmers. The food industry has low margins (with the exception of drinks, for example).

General Welfare - TCA - SCBA
TCA is comparable to the General Welfare 'sustainable' (Brede Welvaart 'later') in that it describes sustainability based on four types of capital: economic, natural, human and social. TCA and the General Welfare 'sustainable' complement each other in that. TCA allows variations in these capitals to be described, while the General Welfare 'sustainable' records the current state of affairs. The change between two states is regarded as a trend. The goal of TCA is to monetise the externalities and reduce their effects, while the General Welfare 'sustainable' does not monetise. However, several TCA methodologies have been developed for specific contexts that do always not include economic capital, because they assume that the market price represents the economic capital. In these cases, TCA must be supplemented with an economic capital analysis if it is to be applied in a general way.

True Cost Accounting can be considered a variant of the social cost-benefit analysis (SCBA). Both monetise the total effects, but there is a difference. TCA focusses on the external effects of food production in relation to sustainability. The scope is often narrower than that of an SCBA. The scale of an SCBA is comparable level as the calculated effects of a project or policy option, while the scale of TCA is determined by the relevant sector or product, whether it is produced globally or regionally. Both reflect all relevant effects. In an SCBA, the alternatives are weighed against each other, while TCA calculates those effects relative to a baseline (although in practice not all external costs can be eliminated). True Cost Accounting could be seen as a variant on a social cost-benefit analysis (SBCA).

[22] Agro-Nuti Monitor 2022 – Hoofdrapport on https://www.acm.nl/system/files/documents/agro-nutri-monitor-2022.pdf

Wageningen Economic Research
P.O. Box 29703
2502 LS The Hague
The Netherlands
T +31 (0)70 335 83 30
E communications.ssg@wur.nl
wur.eu/economic-research

REPORT 2024-029

To explore the potential of nature to improve the quality of life

Wageningen Economic Research
P.O. Box 29703
2502 LS Den Haag
The Netherlands
T +31 (0) 70 335 83 30
E communications.ssg@wur.nl
wur.eu/economic-research

Report 2024-029

The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 7,700 employees (7,000 fte), 2,500 PhD and EngD candidates, 13,100 students and over 150,000 participants to WUR's Life Long Learning, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.