Pay as you eat dairy, eggs and meat

Internalising external costs of animal food products in France, Germany and the EU27

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Content

Summary

Animal products are a substantial ingredient of current European diets, but their production and consumption is associated with a wide range of environmental problems: global warming, eutrophication of soils and waters that lower biodiversity, emissions of ammonium that are formed into secondary aerosols harming human health and extensive land use that comes at the expense of nature and biodiversity. These effects impose 'external costs' on society as they are not (fully) reflected in the price of the animal products. The external costs form the unpaid bill of consuming animal products.

External costs to society

In this study, we estimated the external environmental costs of animal products: meat (both from beef, veal and dairy cows), pork, chicken, eggs and (hard) cheese. Results for conventional farming are shown in Table **1**. It reveals that external costs can be substantial, ranging between the € 0.34 for a litre of milk to over € 10 per kg of beef. These external costs are primarily caused by emissions of greenhouse gasses plus ammonia from manure handling and application as fertiliser (plus artificial fertiliser) for growing crops for feed. Ammonia has many health related impacts and puts the environment under stress (eutrophication and terrestrial acidification). It is therefore no surprise that cattle systems, which have high ammonia emissions, also have the highest external costs. The external costs of organic agriculture seem to be lower for beef and dairy products, higher for chicken and eggs and more or less equal for pork, although it is worth mentioning that some benefits of organic farming compared to conventional farming cannot yet be captured by current LCA methodology and databases.

Table 1 **- External cost estimates for meat, eggs, milk and cheese in EU27 (€/kg, conventional farming)**

Impact category	Unit	Beef Beef cattle (incl. veal)	Beef Dairy cattle	Pork	Chicken	Eggs	Milk	Cheese (Gouda)
Particulate matter formation	€/kg	3.66	0.74	0.56	0.39	0.33	0.11	0.88
Climate change	€/kg	2.38	0.63	0.47	0.44	0.23	0.10	0.76
Marine eutrophication	€/kg	1.61	0.28	0.13	0.07	0.06	0.04	0.33
Terrestrial acidification and eutrophication	€/kg	1.18	0.23	0.17	0.09	0.08	0.04	0.28
Agricultural land occupation	€/kg	0.65	0.13	0.16	0.10	0.07	0.02	0.16
Terrestrial ecotoxicity	€/kg	0.49	0.18	0.37	0.32	0.25	0.03	0.21
Human toxicity	€/kg	0.13	0.03	0.03	0.02	0.01	0.00	0.03
Photochemical oxidant formation	€/kg	0.04	0.01	0.01	0.01	0.01	0.00	0.01
Freshwater eutrophication	€/kg	0.01	0.01	0.01	0.01	0.00	0.00	0.01
Ionising radiation	€/kg	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Freshwater ecotoxicity	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marine ecotoxicity	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ozone depletion	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urban land occupation	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**€/kg**	**10.15**	**2.24**	**1.91**	**1.44**	**1.03**	**0.34**	**2.68**

In this study, we have only focussed on the environmental impact. Most likely the 'real' unpaid bills are higher because the sector receives considerable subsidies that are not being paid by the consumer of animal products, because the sector is the cause of numerous outbreaks of animal diseases (which are paid by taxpayers in many countries), because it has a severe impact on human health through zoonoses and resistance to antibiotics and because it has poor standards for animal welfare that can only persist by hiding them from the general public. However, we have not derived external cost estimates for those non-environmental categories in this research.

Policy options

External costs of consumption of animal products can be most effectively combatted by making the consumers pay for those costs. Only then will consumers take the environmental impact into account when deciding to consume animal products or one of the plant-based alternatives, and the sector can be steered towards cleaner production methods and alternatives for animal products. Pricing instruments are therefore most effective when addressing the issue of unpaid bills in the animal products sector.

In this study, we have investigated three policy measures:
1. An excise levy on animal products.
2. An emission trading scheme (ETS) for the sector.
3. Removal of the lower VAT tariff on animal products.

Each of these schemes is feasible from a legal perspective and can be implemented, although the levy and the EU ETS need more scrutiny with regard to practical design questions such as where the taxation point should be and how imports/exports should be addressed in the scheme. The easiest measure to implement would be the removal of the lower VAT tariff for animal products in EU Member States. Various countries, such as Bulgaria, Denmark and the three Baltic States, have not granted lower VAT tariffs for meat or dairy. Other countries could follow their lead. This would reduce meat consumption by about 10% for beef and 8% for poultry and pork.

Although easy to implement, a higher VAT rate for animal products would have the drawback that it does not fully cover the external costs of meat consumption. For that, additional measures could be considered on top of the VAT increase, or as a substitute. A suitable option could be an excise levy. The most straightforward way would be the introduction of an excise levy on meat sold to consumers by retail companies (supermarkets) and food services (catering, restaurants, etc.), irrespective of whether this meat is being produced in the EU or in another country.

Recycling of government revenues

As policy measures raise product prices, the costs for consumers still wanting to consume animal products will increase. It reduces their purchasing power. Consumers can be compensated by the recycling of government revenues. If all Member States across Europe abolish the lower VAT rate for meat, additional government revenues are about € 19 billion. These revenues can be evenly distribute over the population through a 0% VAT on vegetables and fruit or a (free food) voucher or healthy food gift card to be spent in supermarkets on fruit or vegetables, for example. In Italy this voucher would be worth € 60/capita, in Hungary € 55, the Netherlands € 46, Poland € 45 and Spain € 43.

1 Introduction

1.1 Background

The livestock sector contributes significantly to global anthropogenic GHG emissions. Direct emissions from the sector contribute to 11% of total anthropogenic GHG emissions (Llonch, 2017). Beef and dairy production account for the majority of these GHG emissions followed by pig and poultry production. There are also considerable GHG emissions involved in the value chain. (Twine, 2021) estimates that in total at least 16.5% of GHG emissions can be attributed to livestock farming. Numerous other environmental problems exist in which animal production plays an important role, such as eutrophication and acidification of soils, damage to human health due to air pollution and loss of biodiversity due to monocrops grown for feed. These damages represent a cost to society.

Yet animal products form an important element of European diets. From an economic point of view, the problem is in essence that animal products are priced too low because a large part of the total associated 'social' costs are not included in the price. Since a 'full' or 'fair' price is not paid for these products or services, the decision-making process about the way of producing or whether or not purchasing them is not optimal and results in more production and consumption of environmentally harmful goods than optimal. The costs to society are considered as 'external costs' by producers and consumers: yet society pays the bill in the form of a reduction of the overall level of welfare.

There are various government policies that aim to reduce the environmental footprint of animal products. Although prescriptions, norms and standards can be part of public policies, economic instruments are frequently used to provide financial incentives and to internalise external costs. Examples of economic instruments are the European Emissions Trading System (EU ETS), a CO_2-eq. tax for industry and energy taxes. Companies covered by these schemes pay for their greenhouse gas emissions and try to pass them on to their customers. As a result, the external costs are (partly) internalised. However, there are still many economic activities where still an 'internalisation deficit' occurs. For example, the difference between the consumer price and the 'real price' for animal products tends to be relatively large, as for example (CE Delft, 2018a), (CE Delft, 2019a) and (Funke, et al., 2022) have shown. Several policy options can be implemented to increase consumer prices so that it better reflects the actual costs to society. Ideally, this will take place on a European scale, as there will be a wider range and a level playing field for all farmers and consumers within the EU.

1.2 Project aim and approach

The aim of the project is to provide policy proposals that can be used to pass on the external costs via the price of meat, dairy and eggs. The overall project covers the following three parts:

- Calculate external costs for meat, dairy and eggs for France, Germany and the EU27 on average. If policy makers decide to implement financial incentives, these external costs estimates indicate what level of taxes/levies/VAT-shifts would be needed to cover the external costs.

- Identify policy options for Germany, France and at EU27 level to increase the price of meat, dairy and eggs and estimate the expected impact of two selected financial policy options on the environment.
- Describe how government revenues can be applied to create political and social support, including some quantitative examples.
- A Supervisory Committee provided us with useful insights and feedback on the analyses.

The members were:
- Pierre Marie Aubert and Nathalie Bolduc (L'Institut du développement durable et des relations internationales, IDDRI, France).
- Reinhild Benning (Deutsche Umwelthilfe e.V., DUH, Germany).
- Élodie Vieille Blanchard, Pauline Abela and Anna Lab (Association végétarienne de France, AVF, France).
- Joey Cramer (ProVeg, Netherlands).
- Siska Pottie (European Alliance for Plant-based Foods, EAPF, Belgium).
- Jan Paul van Soest (Food Transition Coalition (TCV), and De Gemeynt, Netherlands).
- Jeroom Remmers (TAPP Coalition, Netherlands).

This is the main report of the analysis and contains all technical details necessary for the calculations and results at the EU27 level. In addition, we have published specific results for France and Germany.

1.3 Scope and research boundaries

In this research we have estimated the external costs associated with the following animal products: meat (chicken, pork and beef), dairy (standardised milk and cheese) and eggs. The environmental impact of these products have been estimated over the value chain of production and cover cradle to gate: the whole production chain up to the moment that the meat is sold to retail. The environmental impact has been calculated using Life Cycle Assessment (LCA). In total fourteen environmental impact types have been covered in this research (see Table 2).

Table 2 - Environmental impact covered in this research

Environmental impact categories	
Climate change	Freshwater eutrophication
Ozone depletion	Marine eutrophication
Human toxicity	Land use - urban
Photochemical oxidant formation	Land use - agricultural
Particulate matter formation	Terrestrial ecotoxicity
Ionising radiation	Freshwater ecotoxicity
Acidification	Marine ecotoxicity

In addition, the following research boundaries have been defined:
- External cost estimates will cover environmental impacts of the current production characteristics in livestock farming and product industries only. In addition to environmental impact, animal production is associated with a wide range of societal problems: animal diseases (zoonoses), health damage caused by the consumption of meat, issues with animal welfare, desiccation, depletion of the soil or antibiotic resistance.

We also did not calculate possible positive 'external' effects of meat, dairy and eggs (e.g. nice landscape for recreation purposes). Although relevant, these impacts are outside of the scope of the present study and could be investigated in future research.
- The analysis will consider the situation of conventional (non-organic) farming 'today' and current information on policy initiatives and the existing policy framework in the countries/regions under consideration. For the EU we roughly estimated the external costs of organic farming as well. We did not perform this for individual countries due to data and methodological constraints.
- The environmental impact was valued with regard to damage to human health, natural capital (ecosystems) and man-made capital (buildings/materials) using a valuation scheme used in EU policy appraisals. The valuation is based on average prices for the EU27 (see Annex A.1).
- When figures are expressed in €/kg meat, we mean kilograms of meat sold (and thus excluding carcases unless they are part of the sold products), unless explicitly stated that it is in 'carcass weight'.

1.4 Environmental impact of livestock farming

The livestock industry has a profound and diverse impact on the environment. The first and most important subject is climate change. Through digestion and manure management, livestock produces high amounts of CH_4 and N_2O, two important Greenhouse Gas (GHG) emissions that have a greater warming potential than CO_2. In the EU, animal agriculture contributes 10% to the region's direct total GHG emissions (European Commission, 2020). The sector is responsible for the majority of methane (CH_4, 52%) and nitrous oxide (N_2O, 74%) emissions. The sector also contributes to climate change and other emissions and impacts outside of the EU, as it is a net importer of animal feed and animal feed cultivation and associated land use change (LUC) is a major driver for the carbon footprint in animal production systems.

In addition to global warming, the livestock sector has a very substantial impact on local air and water quality. Livestock production is responsible for 90% of all ammonia emissions in the EU. Ammonia is transformed in the air into secondary aerosols with serious adverse impacts on human health. Next to a reduction in life expectancy, secondary aerosols can cause adverse impacts on cardiovascular and respiratory diseases and increase hospitalisation rates and people diagnosed with COPD (WHO, 2013). The livestock sector is also responsible for an overload of nitrogen and phosphor onto lands and water through fertilizer and manure (Leip, et al., 2015). When nitrogen and phosphorus are carried in freshwater and marine waters, they can cause eutrophication, the overgrowth of algae. The algae may deplete oxygen from the water, creating a dead zone and reducing biodiversity and ecosystem's resilience.

North-Eastern Europe (the Netherlands, France, Germany, Denmark and Ireland) is the region with the highest concentrations of nitrogen-related emissions to the environment. Livestock farming is also associated with large impacts on land use, especially for growing feed and fodder for animals. While providing 20% of calories of an average person in the world, it takes up 80% of the available land for crop production (Ritchie, 2017). Growing global consumption of animal products drive transformation of natural areas into farmland with disastrous consequences for the status of world's ecosystems and biodiversity (Dasupta, 2021). In addition, growing food crops for animals uses substantial amounts of fertilizer (with toxic trace elements such as cadmium) and pesticides that intoxicate humans and other organisms.

1.5 Pricing instruments to internalise external costs

Despite the fact that the agricultural sector in the EU has reduced its environmental footprint per kilogram product in recent years, it still has a significant impact on the aforementioned environmental themes, both in the EU and elsewhere in the world, via imported feed and fodder (see also the analysis in Chapter 2). The environmental impact of livestock farming is currently not taken into account by both the producers and consumers of animal products. They sell and buy products at prices that do not include these costs and environmental impacts therefore barely play a role at decisions about investments or purchases. Economists are advocating pricing instruments to include those external costs into product prices, at every part of the chain, in order to stimulate behavioural change of both consumers and producers. These are called 'economic instruments'. According to the UNEP, economic instruments are fiscal and other economic incentives and disincentives to incorporate environmental costs and benefits into the budgets of households and enterprises (UNEP, 1997).

Pricing instruments have important advantages over other forms of climate and environmental policies, such as setting standards or granting subsidies.[1]
Pricing instruments, especially when adopted on an economy-wide scale, are:
- Effective: increased prices for non-sustainable goods ensure that producers and consumers consider the effects on the climate/environment in their decisions so that the composition of the consumption package or the production structure is directed towards a more sustainable, low-carbon economy.
- Efficient: higher cost prices drive innovations and investments in energy-efficient and low-emission technologies, making the transition to a more sustainable economy cheaper.
- Fair: higher prices create a sense of justice in society whereby the polluter pays for environmental damage that is caused and no longer passes it on to others or future generations.

While the advantages of pricing instruments have long been recognised in (environmental) economics, see e.g. (Baumol, 1988); (OECD, 1989), it has taken some decades before pricing instruments for environmental pollution have become widespread. Nowadays, pricing environmental pollution has become more common for politicians and consumers. For example, 68 carbon pricing schemes have been counted at the moment in the World (World Bank, 2022), among which the European Emissions Trading Scheme (EU ETS) and national carbon taxes in the Netherlands, France, Spain, etc.

In general, pricing instruments can be classified into two categories:
1. (Behavioural) taxation based on a fixed charge.
   Unlike other taxes, the main aim of a behavioural tax is not to generate government revenues, but to reduce consumption of particular products or lessen their environmental impact by making it more expensive. The amount of environmental impact is uncertain; it depends on the behavioural response to raising (cost) prices. The taxation rate can be based on a politically agreed decision, like a VAT increase, or based on the actual external costs per kg of product.

[1] One of them being the 'free rider'-problem, granting subsidies to those parties that would have taken the measures anyway, making the policy instrument quite expensive and inefficient.

2. Trading systems in which the maximum environmental impact is fixed by an annual ceiling (the cap) and permits are traded on the market. This means that the permit price is not fixed. A well-known example is the current European Emissions Trading System (ETS) system for greenhouse gas emissions. The CO_2(-eq.)-price that must be paid for emissions depends on the supply and demand on the market for emission rights.

Application of the polluter pays principle in animal products is still very limited, despite the academic world considering the application of taxes much more effective than labels or giving information, for example (Katare, 2020). Recently, there been initiatives to introduce economic pricing instruments in both categories with respect to food products. New Zealand is likely to be the first country to bring agriculture under an ETS system and Germany is currently developing a consumer tax on animal products (see Textbox **1**). In other countries, including the UK, US and Finland, Sweden and Denmark, 'meat taxes' are currently being considered. Also at the EU level it is starting to attract political attention (FAIRR collective, 2020). In 2022, the EU Commission announced a study how the polluter pays principle for GHG emissions can be applied at livestock, for example by introducing an ETS.[2] Some countries, such as the Netherlands, consider a meat tax part of a broader policy package to encourage consumers to buy affordable, and more healthy and sustainable food. A tax on meat could then, for example, be combined with a tax increase on soft drinks and recycling revenues by lowering (or scrapping) the value added tax on fruit and vegetables and a sugar tax. This is by no means a hypothetical situation. In 2020, at least 40 countries have some form of sugar tax in place, including France, the UK and Mexico (FAIRR collective, 2020). A number of European countries have an (extra) reduced VAT rate on fruit and vegetables, including Ireland (0%), Spain and Italy (4%) (European Public Health Alliance, 2019). Such initiatives increase the price difference between animal based food products and vegetables and fruits.

Textbox 1 - Examples of pricing instruments in other countries

Germany

From 2017, there has been discussion about the low VAT rate (7%) that applies in Germany not only to plant products, but also to animal products. This was considered an 'environmentally harmful subsidy' (FAIRR collective, 2020). In 2020, Minister of Agriculture Klöckner, on the basis of advice from the Borchert Committee, made a proposal to increase the price of meat and thereby finance a multi-billion dollar reform of German livestock farming. The aim is to increase animal welfare and reduce the impact on nature and the environment. in more detail: increase the price of animal products (including meat € 0.47/kg and dairy € 0.02/litre), increase VAT on animal products (to the standard rate of 19%) and a general tax increase. A feasibility study was carried out (Redeker, 2021). The intention is to return the tax revenues to the farmers so that they can make the necessary adjustments, provided this is legally possible within EU regulations (Tagesspiegel, 2021).

New Zealand

The agricultural sector is responsible for 48% of New Zealand's total greenhouse gas emissions. This mainly concerns dairy farms and sheep farms. New Zealand is one of the largest exporters of lamb, mutton and sheep's wool. Since 2019, the government has been working on pricing emissions in the agricultural sector. Initially, they wanted to introduce a tax on CH_4 and NO_2 emissions from livestock and fertilisers, with a discount for farmers who take sustainable measures. This proposal did not receive sufficient political support, but it did lead to a plan in which farmers work towards monitoring and pricing emissions at farm level by 2025. The plan, confirmed by the New Zealand government in October 2022, is to bring the agricultural sector under the New Zealand ETS from 2025 (FAIRR collective, 2020).

2 www.ted.europa.eu/udl?uri=TED:NOTICE:178793-2022:TEXT:EN:HTML

The details of policy design are crucial to ensure public and political support for price instruments. They related to the treatment of imports and export (level playing field for companies and avoiding carbon leakage) and the earmarking of the government revenues (subsidise ‘healthy food’, support lower income groups and/or help companies to invest in sustainability). Limiting undesirable (income) effects and conducting careful communication is crucial. Otherwise, social resistance might cause absence of political will to actually implement ‘unpopular’ financial policy measures.

1.6 Reading guide

Chapter 2 covers the methodology and results of our external costs estimates of meat, dairy and eggs for EU27, indicating what price increase would be needed to cover the external costs. Chapter 3 describes two pricing instruments that could be considered by the European Commission to increase the animal product prices and evaluates them. It includes an environmental benefit assessment and options for earmarking government revenues. Chapter 4 provides conclusions and recommendations. In the Annexes detailed results are available for the way we have derived external cost figures in this report.

This report contains analysis and results at the level of EU27. Results for Germany and France, using the same methodology, have been reported in separate documents:
- Pay as you eat dairy, eggs and meat. External cost estimates and policy options to internalise them in France (CE Delft, 2022b).
- Pay as you eat dairy, eggs and meat. External cost estimates and policy options to internalise them in Germany (CE Delft, 2022c).

2 External costs of animal products

2.1 Introduction

External costs of animal products are costs that matter to society but are not paid by those that produce and consume animal products. In economic terms this implies that total welfare is lower. In more popular terms, the external costs can be described as the unpaid bill from producing and consuming animal products.

In this chapter, we present our calculation of the external costs from animal products for food. We present the methodology and results of estimating the external costs caused by the production of meat, dairy and eggs. Section 2.2 introduces the methodology employed. In Section 2.3 we describe the concept of environmental prices and include the set of prices used to calculate the external cost figures presented in Section 2.4, both for the EU27, France and Germany. In Section 2.5 we compare our results to other sources found in the literature.

2.2 Methods

Environmental impacts have been determined using life cycle assessment (LCA, further explained below) and those impacts have been valued with so-called environmental prices. The external costs have be calculated by the following formula:

$$EC_j = \sum_{i=1}^{14} I_{i,j} * EP_i$$

Where *EC*=external costs of one kg of animal product *j*, $I_{i,j}$ is the environmental impacts on environmental theme *I* associated with one kg of animal products *j* and EP_i are the environmental prices for environmental theme *i*. There are in total 14 environmental themes that have been included in this research, as given in Table 2. The external costs of 1 kg of animal product j is then the sum of impacts multiplied by their environmental price for all themes.

The external costs are thus made up by an analysis on environmental impacts multiplied by the environmental price. Both elements will be described hereafter.

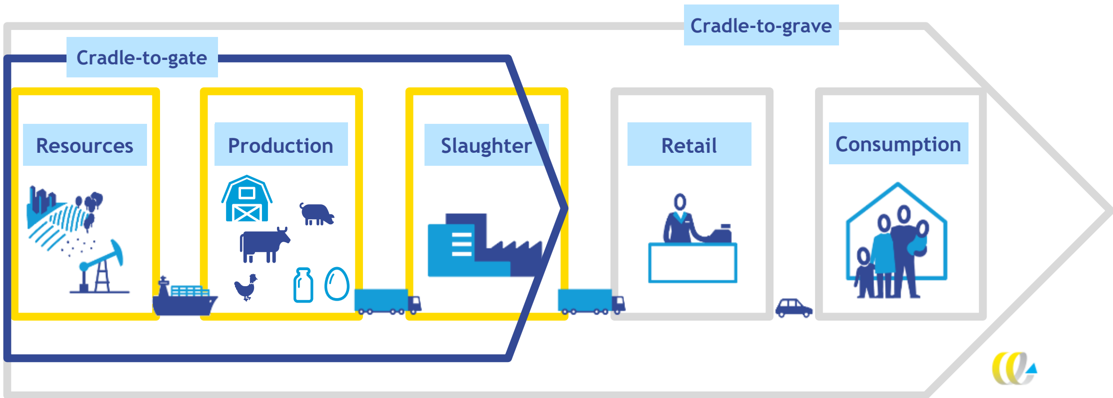
2.2.1 Calculating environmental impacts

We have used LCA to calculate the environmental impact of the following animal products in France, Germany and the EU27:
- beef from beef cattle including veal;
- beef from dairy cattle;
- pork;
- chicken;
- eggs;
- milk;
- cheese (Gouda).

Delineation (scope)

- The scope of the LCA is cradle-to-gate (see blue arrow in Figure 1 for graphic representation). Transport to retail and transport to consumers are out of scope (grey rectangles in Figure 1). These cover a very small share of total environmental impacts.[3]
- The analysis covers direct emissions at the farm level and indirect emissions in the chain, related to animal feed, energy mix and transport in the production chain. These aspects have an influence on the impacts of (the production of) the products on nature and the environment.
- The LCA models are based on LCA models of animal products in the Agri-footprint LCA database (v5.0)[4], with country-specific adjustments where data allowed. Data for France is provided by I4ce. Data for Germany was provided by Ecologic. Data for the EU is based on national inventories of emissions and weighted averages based on data available at CE Delft and EU market shares (see Annex A.1).
- Estimates are based on current average emissions for farming systems in the specified regions. This means that we implicitly take into account the fact that livestock farming production systems differ per region.
- Environmental impacts for organic agriculture are included, based on available animal-specific information and general EU regulation for organic agriculture.

Figure 1 - LCA scope



Study design

- Environmental models have been created for all animal products under study describing all processes that are required to produce animal products, including processes earlier in the value chain. These models are made using LCA methodology[5] and existing, public databases. The models are country-specific where possible and generic for European agriculture practices if no specific data was available. In Annex A more information on the models used can be found.

3 E.g. (Poore & Nemecek, 2018) report that the sum of emissions from packaging, transport, and retail contributes to 1 to 9% of total emissions. However, they do not provide details on each individual chain so their results cannot be used in the present analysis. Transport required to take feed to livestock is included in our analysis.

4 www.blonksustainability.nl/tools/Agri-footprint

5 LCA is the international standard method for determining comprehensive product footprints that include all steps in the product's life cycle, described in ISO 14044:2006.

- For organic farming, country-specific models were made for France and Germany. For the EU, weighted averages based on data available at CE Delft and EU market shares were used, in addition to some specific modelling (e.g. average EU energy mixes, average EU feed market mixes). The calculation steps, data and assumptions used for this are provided in Annex A.
- The environmental impact was assessed at the level of the final product, being 1 kg of animal product. For meat, this is boneless meat. For eggs, milk and cheese, this is 1 kg of product. Final packaging was excluded.
- Country-specific emission and production data is in many cases available per head (one animal) or at the level of carcass weight equivalent. Calculation steps taken to make these data suitable for inclusion in the LCA models or further analysis are described in Annex A.
- Allocation of co-products (e.g. meat from dairy cattle) is done on an economic basis. This means that environmental impacts are attributed to the various products on the basis of their economic value at which those products are sold on markets. Market prices for this are included in the databases used (see next section).
- The LCA modelling approach in this study differs from the previous study conducted by CE Delft for TAPP Coalition (CE Delft, 2019a). In the previous study, we used LCA models created internally within CE Delft – some of them being quite old. For this study, we used LCA models from a publicly available database (Agri-footprint) with some country-specific adaptations based on publicly available sources. This ensures that the models are more up to date with current technology and the approach is future proof, as both Agri-footprint and public sources such as emission inventories are regularly updated. Also, in this way the approach can be replicated for other countries, by other organisations.

Applied databases, software and impact assessment methods

Modelling takes place in the LCA software SimaPro. The LCA database Agri-footprint (Paassen, et al., 2019) version 5, economic allocation) is used as a resource to model the studied animal products. The impact assessment method (IAM) used is ReCiPe Midpoint (H) V.1.13 (see Annex A.2)[6]. ReCiPe includes seventeen environmental themes (midpoints). For fourteen of these, environmental prices are available (see Section 2.3).

Country specific modelling and parameters

Initial analysis and calculations revealed that the most important emissions for the external cost estimates are NH_3, CH_4, N_2O, CO_2 and NO_3. These explain over 75% of external costs in the various animal products. Therefore, we focused on these emissions, and related inputs, to make the LCA models country specific. The EU-specific models uses Agri-footprint models as a basis. Inventory data on farm level emissions of $NH_{3,}$ CH_4, N_2O was acquired from the EU National Inventory Report (European Environment Agency, 2021) and the Informative Inventory Report (IIR) (European Environment Agency, 2021). When emission data could not be divided between animal product group, the most conservative data from France, Germany or the original Agri footprint process card were used as proxy, in order to avoid omitted data and thus underestimation of emissions. Other (indirect) emissions were made country-specific by adapting inputs of the production system. As such, manure application

[6] This ReCiPe version has been replaced in 2016 by a newer version. However, environmental prices can currently only be applied to ReCiPe V.1.3 (e.g. the version of 2013). In 2023, CE Delft will publish a newer version of their environmental prices method that can be applied to more recent updates of the ReCiPe method.

rates and composition of feed was made country-specific where possible. For soy-based feed, direct land use was adjusted for the share of certified 'deforestation-free soy'. Finally, ammonia emissions from crop residues in grass and maize cultivation were recalculated according to the recent NEMA method (RIVM, 2021), which resulted in different (lower) emission values of feed throughout cattle production models than what is normally included in Agri-footprint.

Annex A.1 shows the data used for this study, its handling and elaboration of country-specific changes to Agri-footprint processes per product.

Organic agriculture modelling

By organic agriculture, we mean agriculture that is labelled as organic under the EU organic agriculture label.[7] This label has strict rules, and farmers and other food producers are controlled by authorised bodies. Rules and regulations are the same throughout the EU. Inspection regimes are organised at the national or regional level and these regimes are checked by the European Commission. Legislation is laid down in Council regulation (EC) No 834/2007 of 28 June 2007, and Commission regulation (EC) No 889/2008 of 5 September 2008. The structure of governance of organic agriculture in the EU guarantees to a high degree that organic produce complies to the regulations.

There are many rules in organic agriculture, and for adaptation of the LCA models we selected the most relevant. As feed production has the highest environmental impacts among the total value chain, we focused on modelling organic versions of the most important feed crops.

Additionally, there are some characteristics of organic animal production systems that result in higher or lower external costs, such as e.g. longer life span (and increased feed use) for broiler chickens or increased outdoor grazing for dairy cows. Both the method for creating organic feed LCA models and adaptations to animal farming systems are discussed in Annex A.2.

It is important to note that not all aspects of organic agriculture are captured completely by the LCA methodology deployed in this study. In fact, some of the benefits of organic agriculture are not captured at all by LCA because the method and databases simply are unable to capture these at this point. Examples of this are positive ecosystem services such as support of pollinators, improved soil quality and improved animal welfare levels. This should be considered while interpreting LCA results, and especially comparisons between conventional and organic agriculture. We further discuss the limitations of LCA in relation to organic agriculture in Annex A.2.3.

2.3 Using environmental prices to calculate external costs

The external costs per environmental theme (midpoint) are estimated by using so-called 'environmental prices'. Environmental prices are prices that have been constructed by CE Delft for environmental quality and expressed as € damage per kg of pollution to air, water and soils (CE Delft, 2018b). Environmental prices calculate damage of pollution and land use occupation on human health, natural capital (ecosystems services) and man-made

7 www.agriculture.ec.europa.eu/farming/organic-farming_en

capital (buildings, machines and materials) and reflect the loss of welfare for society that occurs if an extra unit of a pollutant ends up in the environment.

Environmental prices can be given on substance level (individual substances like CO_2, SO_2, etc.), or at midpoint level. For use in LCA, the midpoint level is preferred, as the LCA presents environmental impacts at the level of midpoints. CE Delft has developed the Environmental Prices methodology that has frequently been used to determine the external costs from LCA-analysis (see e.g. (Costantini, 2020), in cost-benefit analysis (see e.g. (UNEP, 2020)) or by companies in reporting about their Environmental Profit and Losses (see e.g. (Philips, 2018)). Environmental prices form the basis of the European Handbook of valuing external costs of Transport for DG Move (CE Delft et al., 2019) and are frequently used in European policy analysis.

Environmental prices are average prices. They will vary by country and region due to differences in climate and geography, general health situation of the population, state of ecosystems, income levels and population density. CE Delft developed a consistent set of environmental prices for both the Netherlands (CE Delft, 2017) and the EU27+UK (CE Delft, 2018b). For lifecycle impacts, where we often do not know in which country the impacts over the value chain occur, the EU27+UK values are commonly used.[8] Therefore, we apply EU27+UK prices for all countries in this analysis. The environmental prices have been updated to reflect 2021 price levels.

Table 3 shows the average environmental prices for the fourteen environmental impact categories that are used to determine the external cost estimates. The impacts on human health, ecosystems and buildings/materials are included in the estimates per environmental midpoint category (see for further explanation Annex C.1).

Table 3 - Environmental prices used in this research (€/kg, 2021)

Environmental categories (midpoints)	Average external costs (value, unit)	
Impact on climate change	0.08	€/kg CO_2-eq.
Ozone depletion	33.05	€/kg CFC-eq.
Acidification	5.75	€/kg SO_2-eq.
Freshwater eutrophication	2.15	€/kg P-eq.
Marine eutrophication	3.59	€/kg N
Human toxicity	0.11	€/kg 1,4-DB-eq.
Photochemical oxidant formation	1.26	€/kg NMVOC-eq.
Particulate matter formation	42.67	€/kg PM10-eq.
Terrestrial ecotoxicity	10.04	€/kg 1,4-DB-eq.
Freshwater ecotoxicity	0.042	€/kg 1,4-DB-eq.
Marine ecotoxicity	0.009	€/kg 1,4-DB-eq.
Ionising radiation	0.050	€/kg kBq U235-eq.
Land use occupation	0.022	€/m^2a

Source: (CE Delft, 2018b) adjusted to price level of 2021. These are average EU27+UK prices, also used for Germany and France.

8 In addition, developing a consistent set of environmental prices for France and Germany would take a considerable amount of time and thus lays outside the scope of the present project.

For the acidifying emissions of NH_3, NO_X and SO_2, a separate calculation has been made, to reflect the dominance of these substances in agriculture, and as an important precursor for secondary aerosols causing damage to humans by air pollution. Resulting prices are: 11.5 €/kg SO_2; 14.8 €/kg NO_X and 17.5 €/kg NH_3.

2.4 External costs estimates

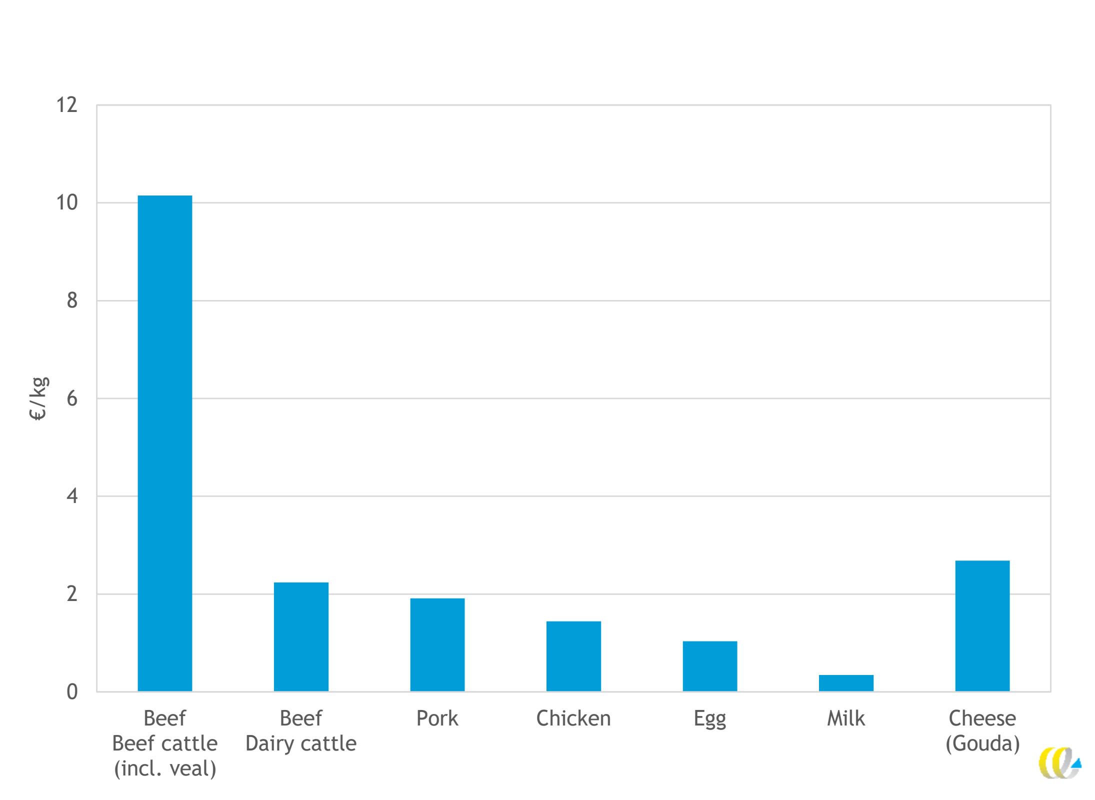
2.4.1 External costs estimates for EU27

Conventional farming

Combining the quantified environmental impacts (see Section 2.2 and Annexes A and B) with the environmental prices (Section 2.3) yields the external cost estimates for the various animal products. These are shown in Figure **2**. Beef (from beef cattle, incl. veal) production causes the highest external costs (10.15 €/kg), followed by cheese (2.68 €/kg)[9], beef (from dairy cattle, 2.24 €/kg), pork (1.91 €/kg), chicken meat (1.44 €/kg), eggs (1.03 €/kg) and full fat milk (0.34 €/kg).

[9] These results are for Gouda cheese, which is a hard cheese. For softer cheeses less milk is needed per kg (because of the higher moisture content). The amount of milk needed for 1 kg cheese caries considerably, from around 4 l (very fresh and soft cheese) to 12l (very old and hard cheese) per kg cheese. For the Gouda cheese in this study, 7.8 l milk is needed. For an average softer (cowmilk) cheese such as St. Paulin, around 5.5 l milk is needed (Kosikowski, 1985). To calculate the external costs of soft cheeses we therefore recommend multiplying the value for Gouda cheese with a conversion factor of 5.5/7.8 = 0.7. This leads to 1.87 €/kg external costs.

Figure 2 - Total external costs of conventional meat, eggs, milk and cheese in EU27 (€^{2021}/kg)



The comparatively high external costs of beef from beef cattle result for the largest part from high particulate matter (PM) emissions, followed by climate change impact, marine eutrophication, and terrestrial eutrophication and terrestrial acidification (Table 4). These are in turn mostly caused by ammonia from manure handling and application and artificial fertilizer application for feed. Ammonia has many effects on human health (PM-formation) and the environment (eutrophication and terrestrial acidification) and it is therefore no surprise that cattle systems, which have high ammonia emissions, have the highest external costs.[10]

Next to particulate matter, beef from beef cattle has a relatively high climate impact due to methane emissions during its lifetime, and impacts related to feed production (beef cattle needs a lot of feed to produce 1 kg of meat, much more so than pigs or chickens).

Beef from dairy cattle has a significantly lower impact than beef from beef cattle because most of the impact related to the lifetime of a dairy cow is allocated to the milk, and not the meat. Milk has a relatively low impact as a cow produces a lot of milk over a lifetime, which causes less impact per kg product. The external costs of 1 kg (Gouda) cheese are relatively high; almost as high as beef from dairy cattle. This is due to the fact that around 8 kg of milk is needed to produce 1 kg of cheese.

[10] Please recall that environmental prices are averages for an average emission at an average location. The question to what extent an emissions in agriculture fits in this concept of an 'average emission' has not been investigated in this research.

The external costs of pork and chicken meat are lower than beef meat and cheese. Chickens have the best feed conversion efficiency of all animals in this study and therefore the external costs associated with chicken products are relatively low. Pigs have a more diverse diet with less soy (which has high associated external costs) and therefore the impact per kg of pig feed are lower than a kg of chicken feed. The net external costs of chicken meat however are still lower due to more efficient feed conversion.

Table **4** shows the external costs of the animal products, attributed to the different environmental impacts and as totals. The importance of the environmental impact categories in the total external costs are quite similar for most animal products.
Impact categories associated with ammonia emissions (PM, marine and terrestrial eutrophication, and terrestrial acidification) are dominant in the total external costs, followed by climate change, toxicity categories and agricultural land occupation.
These latter three impacts are strongly related to feed production for all animal systems (in addition to methane emissions in cattle systems).

Table 4 **- External cost estimates for meat, eggs, milk and cheese in EU27 (€/kg, conventional farming)**

Impact category	Unit	Beef Beef cattle (incl. veal)	Beef Dairy cattle	Pork	Chicken	Egg	Milk	Cheese (Gouda)
Particulate matter formation	€/kg	3.66	0.74	0.56	0.39	0.33	0.11	0.88
Climate change	€/kg	2.38	0.63	0.47	0.44	0.23	0.10	0.76
Marine eutrophication	€/kg	1.61	0.28	0.13	0.07	0.06	0.04	0.33
Terrestrial acidification and eutrophication	€/kg	1.18	0.23	0.17	0.09	0.08	0.04	0.28
Agricultural land occupation	€/kg	0.65	0.13	0.16	0.10	0.07	0.02	0.16
Terrestrial ecotoxicity	€/kg	0.49	0.18	0.37	0.32	0.25	0.03	0.21
Human toxicity	€/kg	0.13	0.03	0.03	0.02	0.01	0.00	0.03
Photochemical oxidant formation	€/kg	0.04	0.01	0.01	0.01	0.01	0.00	0.01
Freshwater eutrophication	€/kg	0.01	0.01	0.01	0.01	0.00	0.00	0.01
Ionising radiation	€/kg	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Freshwater ecotoxicity	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marine ecotoxicity	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ozone depletion	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urban land occupation	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**€/kg**	**10.15**	**2.24**	**1.91**	**1.44**	**1.03**	**0.34**	**2.68**

Organic livestock products

The most important drivers for the differences between conventional and organic livestock are the external costs of feed, the difference in feed conversion ratios due to longer animal lifetime and different breeds in organic animal production, and the amount of direct emissions associated with different production systems.

Organic feed production has a number of significant differences compared to conventional feed (see Annex A.2). Organic agriculture does not use pesticides and artificial fertilizer, which causes a decrease in external costs, but often uses more animal manure and often has lower yields, which increase external costs per kg of product. Thus there is a trade-off, resulting for organic feed in e.g. lower external costs for climate change and toxicity, and higher costs for impacts related to ammonia. For most crops, the net external costs of organic feed are lower. In a few cases the yield gap is sufficiently big that the net external costs for organic are higher (e.g. for wheat). Fodder crops (e.g. grass) are very heavily fertilized with both animal manure and artificial fertilizer in conventional agriculture. This results in increased yields, but a lot of extra nutrients are needed for only a little yield increase. We therefore see that the external costs of organic fodder crops are much lower than their conventional counterparts.[11]

The external costs of organic agriculture per kilogram of meat are lower for beef and dairy products, higher for chicken meat and eggs and more or less equal for pork (Table 5), although it is worth mentioning that some benefits of organic farming compared to conventional farming cannot yet be captured by current LCA methodology and databases (see Annex A.2).

The lower external costs for beef are mainly caused by the lower costs associated with fodder. For dairy cattle this is also the case, but there are also a few other factors at play. Increased grazing in organic dairy systems results in lower ammonia emissions.

Table 5 - External costs of conventional and organic animal agriculture in EU27 per kg

System	Beef Beef cattle (incl. veal)	Beef Dairy cattle	Pork	Chicken	Eggs	Milk	Cheese (Gouda)
Conventional	€ 10.15	€ 2.24	€ 1.91	€ 1.44	€ 1.03	€ 0.34	€ 2.68
Organic	€ 8.41	€ 1.85	€ 1.97	€ 1.74	€ 1.07	€ 0.30	€ 2.32
Difference	-17%	-18%	3%	21%	4%	-14%	-14%

In pig systems, the net external costs are more or less the same. The impact of feed on average is lower, but more feed is needed to produce the same amount of meat. Also, wheat is an important part of the compound feed and the external costs of organic wheat are higher due to a large yield gap compared to conventional wheat.

In chicken systems (both for meat and eggs), there is a rather large difference in feed conversion between organic and conventional systems. Among others, this is due to longer life span of organic broiler chickens due to minimum slaughter age regulation. Also, wheat is quite important. Therefore the net external costs of organic chicken products are higher, despite the lower external costs of other feed (among which soy).

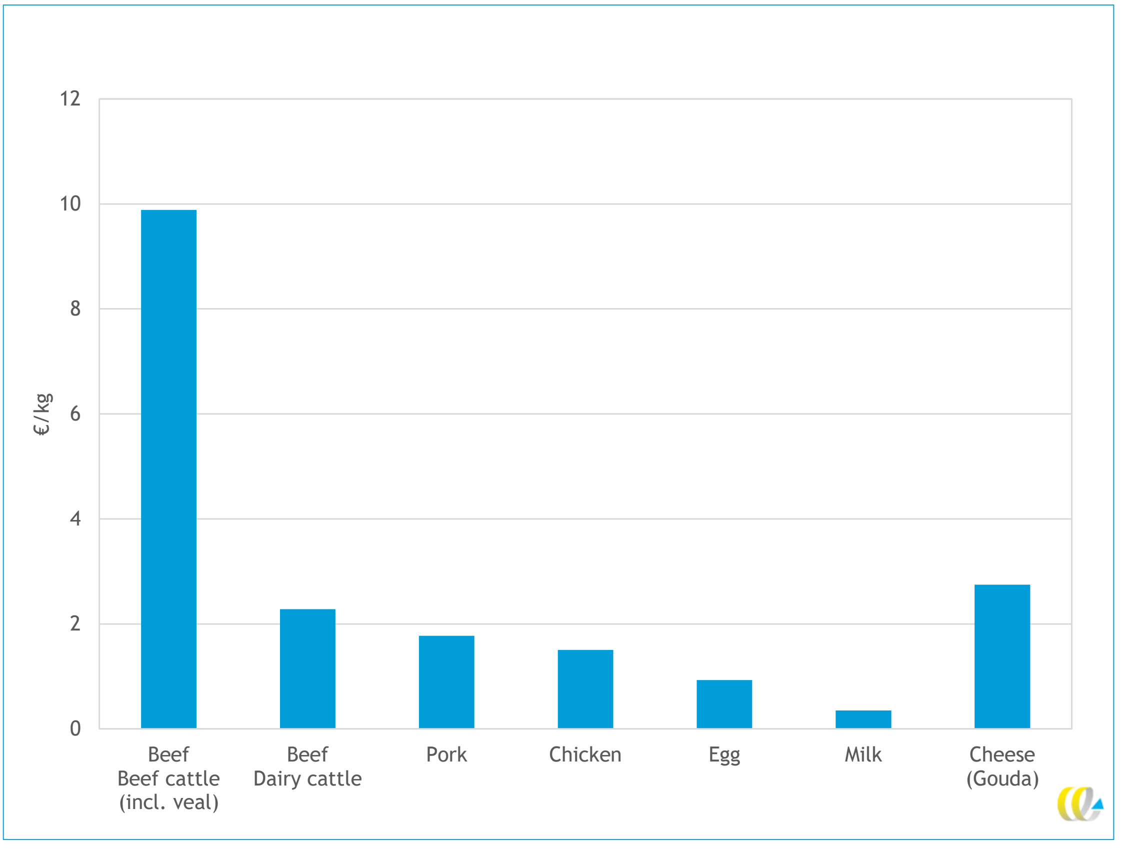
Organic farming is also more expensive and prices paid by consumers are considerably higher compared to conventional meat products. Therefore, per euro consumption, the environmental costs are still lower for all organic products considered in this study. A detailed analysis per euro consumption falls outside the scope of the present study.

[11] This is especially the case in countries that avail of derogation (such as the Netherlands), where up to 250 kg nitrogen from animal manure/ha/year can be applied on many soils, instead of the EU limit of 170 kg N/ha/y. Organic agriculture limits N-application to 170 kg N/ha/y.

2.4.2 External cost estimates for France

Figure 3 shows the external cost estimates from animal food products in France. Beef (from beef cattle, incl. veal) production causes the highest external costs (9.89 €/kg), followed by cheese (Gouda, 2.75 €/kg)[12], beef (from dairy cattle, 2.28 €/kg), pork (1.77 €/kg), chicken meat (1.50 €/kg), eggs (0.93 €/kg), and milk (0.29 €/kg). In general external costs per kg of animal product in France are slightly lower than the EU average due to higher production efficiency.

Figure 3 - Total external costs of conventional meat, eggs, milk and cheese in France (€/kg product)



The differences between the various animal products follows the same reasoning as in the EU27 (read Section 2.4.1). Table 6 shows the external costs of the animal products, attributed to the different environmental impacts and as totals. The importance of the environmental impact categories in the total external costs are quite similar for most animal products. Impact categories associated with nitrogen and ammonia emissions (i.e. PM, marine and terrestrial eutrophication, and terrestrial acidification) are dominant

[12] These results are for Gouda cheese, which is a hard cheese. For softer cheeses such as common in France, less milk is needed per kg (because of the higher moisture content). The amount of milk needed for 1 kg cheese caries considerably, from around 4 l (very fresh and soft cheese) to 12 l (very old and hard cheese) per kg cheese. For the Gouda cheese in this study, 7.8 l milk is needed. For an average softer cheese such as St. Paulin, around 5.5 l milk is needed (Kosikowski, 1985). To calculate the external costs of soft cheeses we therefore recommend multiplying the value for Gouda cheese with a conversion factor of 5.5/7.8 = 0.7.

in the total external costs, followed by climate change, toxicity categories and agricultural land occupation. These latter three impacts are strongly related to feed production for all animal systems (in addition to methane emissions in cattle systems).

Table 6 - External cost estimates for meat, eggs, milk and cheese in France (€/kg animal product)

Impact category	Unit	Beef Beef cattle (incl. veal)	Beef Dairy cattle	Pork	Chicken	Eggs	Milk	Cheese (Gouda)
Particulate matter formation	€/kg	3.78	0.75	0.51	0.47	0.28	0.12	0.91
Climate change	€/kg	2.05	0.58	0.42	0.42	0.22	0.09	0.71
Marine eutrophication	€/kg	1.59	0.34	0.13	0.08	0.06	0.05	0.40
Terrestrial acidification + terrestrial eutrophication	€/kg	1.23	0.24	0.16	0.12	0.07	0.04	0.29
Agricultural land occupation	€/kg	0.63	0.15	0.15	0.10	0.07	0.02	0.18
Terrestrial ecotoxicity	€/kg	0.42	0.16	0.35	0.29	0.21	0.03	0.19
Human toxicity	€/kg	0.11	0.03	0.03	0.02	0.01	0.00	0.03
Photochemical oxidant formation	€/kg	0.04	0.01	0.01	0.01	0.00	0.00	0.01
Freshwater eutrophication	€/kg	0.02	0.02	0.01	0.01	0.01	0.00	0.02
Ionising radiation	€/kg	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Freshwater ecotoxicity	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marine ecotoxicity	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ozone depletion	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urban land occupation	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**€/kg**	**9.89**	**2.28**	**1.77**	**1.50**	**0.93**	**0.35**	**2.75**

2.4.3 External cost estimates for Germany

Results for Germany are given in Figure 4. Beef from beef cattle (including veal) production causes the highest external costs (10.16 €/kg), followed by cheese (2.25 €/kg), beef (from dairy cattle, 1.87 €/kg), pork (1.89 €/kg), chicken meat (1.36 €/kg), eggs (0.97 €/kg), and milk (0.29 €/kg). These figures are slightly lower than the EU average due to higher efficiency in Germany.

Figure 4 - Total external costs of conventional meat, eggs, milk and cheese in Germany (€/kg meat product)

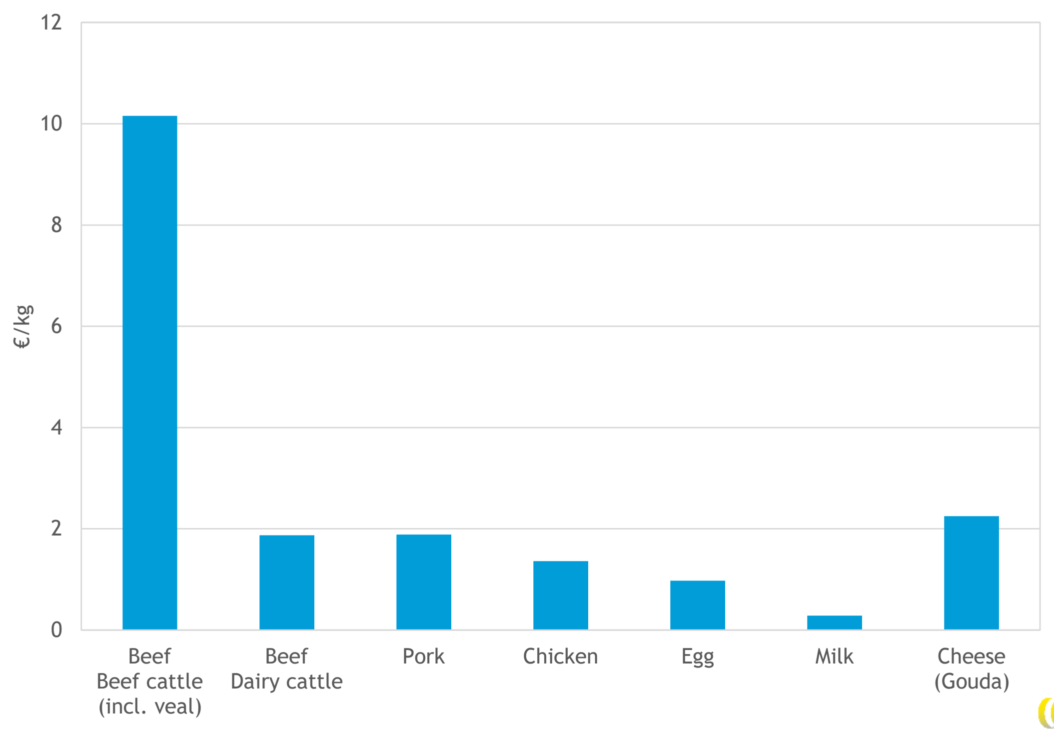


Table 7 shows the external costs of the animal products, attributed to the different environmental impacts and as totals. The importance of the environmental impact categories in the total external costs are quite similar for most animal products. Impact categories associated with ammonia emissions (PM, marine and terrestrial eutrophication, and terrestrial acidification) are dominant in the total external costs, followed by climate change, toxicity categories and agricultural land occupation. These latter three impacts are strongly related to feed production for all animal systems (in addition to methane emissions in cattle systems).

Table 7 - External cost estimates for meat, eggs, milk and cheese in Germany (€/kg)

Impact category	Unit	Beef Beef cattle (incl. veal)	Beef Dairy cattle	Pork	Chicken	Eggs	Milk	Cheese (Gouda)
Particulate matter formation	€/kg	3.65	0.54	0.57	0.35	0.27	0.08	0.66
Climate change	€/kg	2.21	0.56	0.41	0.38	0.21	0.08	0.68
Marine eutrophication	€/kg	1.60	0.22	0.13	0.07	0.06	0.03	0.26
Terrestrial acidification + terrestrial eutrophication	€/kg	1.18	0.17	0.17	0.08	0.06	0.03	0.20
Agricultural land occupation	€/kg	0.66	0.12	0.14	0.08	0.06	0.02	0.14
Terrestrial ecotoxicity	€/kg	0.68	0.21	0.41	0.36	0.29	0.03	0.26
Human toxicity	€/kg	0.12	0.02	0.03	0.02	0.01	0.00	0.03

Impact category	Unit	Beef Beef cattle (incl. veal)	Beef Dairy cattle	Pork	Chicken	Eggs	Milk	Cheese (Gouda)
Photochemical oxidant formation	€/kg	0.04	0.01	0.01	0.01	0.00	0.00	0.01
Freshwater eutrophication	€/kg	0.01	0.01	0.01	0.00	0.00	0.00	0.01
Ionising radiation	€/kg	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Freshwater ecotoxicity	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marine ecotoxicity	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ozone depletion	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urban land occupation	€/kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**€/kg**	**10.16**	**1.87**	**1.89**	**1.36**	**0.97**	**0.29**	**2.25**

2.5 Comparison with other studies

Compared to earlier studies by CE Delft on this subject ((CE Delft, 2018a); (CE Delft, 2020)) the external costs for the products are different. This is due to the different approach followed for the LCA models (see Section 2.2.1) and due to different external costs for impact categories. The previous study used environmental prices for direct emissions in the Netherlands and the present study uses such prices at the level of the EU27+UK. As the Netherlands is much more densely populated than the European average, air pollutants cause much higher damage to human health.

When comparing the results with the previous analysis, we observe that especially the external costs of pork are much lower. This is mainly because this study uses more recent data from efficient pig production systems, which are more representative of average large-scale pork production. To a lesser extent the differences are explained by differences in external costs.

When compared to other literature on this subject, external costs are more or less in line. (Funke, et al., 2022) calculated, on the basis of data from (Poore & Nemecek, 2018), the external costs for beef between US$ 5.75–US$ 9.17 per kg (the higher range for beef from meat cows and the lower range for beef from dairy cows), US$ 1.94 per kg for pork, and US$ 1.50 per kg for poultry. These estimates are slightly lower than our results. However, they state that they did not include a valuation for biodiversity loss or the health effects from livestock-related air pollution. The latter impact is in our estimate the largest category of external costs through the impact in the particulate matter formation. So all in all the costs estimated by us and (Funke, et al., 2022) are probably in line.

Other estimates exist. These results are interesting to mention, even though not directly comparable to the results of our study, given differences in methodologies, selections of environmental aspects and data sources. (Pieper, et al., 2020) report external costs for greenhouse gasses and land use changes only. The environmental price of greenhouse gasses emissions is 180 €/ton CO_2-eq. versus 80 €/ton used in our study. Other environmental impact categories are not included. The analysis results in external costs for beef in Germany of 6,65 €/kg, for poultry 2,85 €/kg, for pork 1,72 €/kg, and for milk 0,24 €/kg (all conventional, non-organic). (Michalke, et al., 2022) calculated German external costs for minced meat ((9,67 €/kg), gouda cheese (4,38 €/kg) and milk (0,89 €/kg)(all conventional), based on external costs for energy, greenhouse gas emissions, nitrogen and land use. This is also more or less comparable with results we found in our study. (Michalke, et al., 2020) also calculated external costs for organic products. In their study, all external costs per kg animal product (organic) were higher compared to conventional animal products. In our study, organic dairy and beef have lower external costs compared to conventional dairy and beef, for pork external costs are similar, only for chicken meat and egg, external costs for organic products are higher.

Older research on valuation of external costs of meat exist (see e.g. (IVM, 2010)), but these studies used quite some older data on impacts and valuations that the results are hardly comparable.

3 Economic instruments to internalise external costs

3.1 Policy context

Agriculture has always been at the cornerstone of EU policies. The Common Agricultural Policy (CAP), introduced already in 1962 gives income support for European farmers and promotes rural development through subsidies and regulates other interventions in the market through, e.g. import tariffs. Internalising external effects was never implemented. In 2021, the EU reformed the CAP, a reform that merely continued existing developments. Lack of alignment of the CAP proposal from the Commission with the Green Deal was even criticised by vice-president Timmermans – an element that has barely been resolved in the final trialogues.

Paying for environmental impacts and internalising external costs is currently not a goal in the CAP. By giving subsidies, the CAP works exactly the other way around: it lowers the price of food products in the EU including animal products. It is difficult if not impossible to calculate exactly to what extent animal products have a lower price through CAP. (Greenpeace, 2019) tentatively suggests that between 69-79% of the CAP direct payments is directed to producers of fodder for animals or goes directly to livestock producers as coupled support, which would create subsidies worth of € 28.5 billion-€ 32.6 billion according to Greenpeace.

However, as part of the European Green Deal, the Farm to Fork Strategy has been published in 2021. The Commission has announced that to enable and accelerate the transition to a fair, healthy and environmentally-friendly food system, research and innovation, advisory services and financial instruments can guide the European Agricultural system towards a more sustainable future. The Commission will publish a Framework for sustainable food systems in the 4th quarter of 2023. The question how to internalise the substantial externalities of the EU food production system will be a major challenge in this framework.

So far, little has happened in individual EU Member States (MS) to internalise external costs through pricing instruments. In France, so far, no taxation schemes exist or are proposed for the French agricultural sector[13] or for French food products, although the government implemented a tax on sugary drinks (I4CE, 2022). In the additional French report we go deeper into the political landscape of France at the moment. Also in Germany, vested interests and lobbying at work have so far avoided application of the polluter pay principle in German livestock farming, as in many other countries and sectors. Instead, meat products have been indirectly subsided by the Common Agriculture Policy (CAP) and reduced VAT prices because they are considered as basic food. It is unpopular to making meat more expensive, and getting the state involved - even more so than for car fuels (Ecologic, 2022). However, recently the low VAT rate for meat products was considered an ‘environmentally harmful subsidy’ (FAIRR collective, 2020) and a redesign of the VAT system

[13] Except for a pesticide tax since 2018 (PAN website) and a nitrogen fertilizer tax proposal in 2021.

is currently discussed in Germany and the European Parliament. More information on the political status can be found in our separate report on Germany specifically.

3.2 Policy reforms considered in this study

In this study we will consider three types of policy reforms that could assist the sector to internalise the external costs. These systems are:
- higher VAT rates for meat products (Section 3.3);
- a separate EU emission trading scheme (ETS) for agriculture (Section 3.4);
- a levy somewhere in the value chain (Section 3.5).

Hence, we solely focus on economic instruments in this study to internalise (part of the) external costs. The levy and VAT rates will be considered for both France and Germany. For the EU we will describe the system of a minimum VAT rate and an ETS and briefly touch upon the options to install a levy.

In the calculations of the effects of pricing instruments we will base our analysis on the prices and results for conventional production. A small part of animal products consumed in Europe are based on results for organic farming. However, as information on consumer demand, prices and price sensitivity of organic farming are largely missing in Europe and the member states, and the differences in external costs are relatively small, we have not attempted to collect information on that in this study.

3.3 Higher VAT rates for animal products in retail and food services

The policy measure to investigate in this section is a higher VAT rate for retail so that the lower VAT rates applicable for animal products will be abolished in each MS.

3.3.1 Description of the measure

A Value Added Tax (VAT) means that a percentage is added to the retail. It is paid when products are sold to the customer. There is considerable difference in VAT rates across Europe, especially when it comes to animal products, as is evidenced in Table 8.

Table 8 - Existing VAT rates in EU member states for meat and dairy compared to standard VAT rates

Member state	Code	Meat	Milk/dairy	Standard
Austria	AT	10%	10%	20%
Belgium	BE	6%	6%	21%
Bulgaria	BG	20%	20%	20%
Croatia*	HR	13%	13%	25%
Cyprus	CY	5%	5%	19%
Czech Republic	CZ	15%	15%	21%
Denmark	DK	25%	25%	25%
Estonia	EE	20%	20%	20%
Finland	FI	14%	14%	24%
France	FR	5.5%	5.5%	20%
Germany	DE	7%	7%	19%
Greece	EL	13%	13%	24%
Hungary	HU	5%	5%	27%
Ireland	IE	0%	0%	23%

Member state	Code	Meat	Milk/dairy	Standard
Italy	IT	4%	4%	22%
Latvia**	LV	21%	21%	21%
Lithuania	LT	21%	21%	21%
Luxembourg	LU	3%	3%	17%
Malta	MT	0%	0%	18%
Netherlands	NL	9%	9%	21%
Poland***	PL	5%	5%	23%
Portugal	PT	6%	6%	23%
Romania	RO	9%	9%	19%
Slovakia	SK	10%	10%	20%
Slovenia	SI	9.5%	9.5%	22%
Spain	ES	10%	4%	21%
Sweden	SE	12%	12%	25%
Population weighted average^	EU27	7.8%	7.2%	21.1%

Source: CE Delft. Based on European Commission (EC, 2021). Rates were applicable in the beginning of 2021.

Notes: * Temporary reduction to 5%.

** In Latvia temporarily reduced rate of 5% may be given.

*** Poland has a temporary reduction tariff of 0% in 2022.

^ Population weighted average, population as of 1-1-2022 (Eurostat).

In the EU, the population weighted average standard rate is just above 21% and the reduced rate for meat is 7.8% and for dairy 7.2%. Such reduced rates are motivated from the idea that basic food items should contain a lower VAT tariff to lower taxes for poorer people that spend a larger share of their income on basic food.

There are substantial differences between MS in their treatment of VAT for animal products. Two countries (Ireland and Malta) do not levy any VAT on animal products. On the other hand, Bulgaria, Denmark, Estonia, Latvia and Lithuania did not provide lower rates for meat products – at least until the end of last year. Various countries have now temporarily lowered VAT rates for animal products in order to combat impoverishing of the population because of the unprecedented high levels of inflation.

Because of the considerable environmental impacts associated with animal production chains, some authors have labelled the lower VAT Tariff as an example of an ‘environmental harmful subsidy’ (see e.g. (FAIRR collective, 2020)). Phasing out environmentally harmful subsidies has often been vowed in policy documents, such as the EU Roadmap for a Resource Efficient Europe or more recently the G7’s Climate, Energy and Environment Ministers’ Communiqué in Berlin, May 27, 2022.

One way to eliminate such harmful subsidies would be to abolish the lower tariff for animal products in all EU MS. Such a proposal could come from the European Commission but would ultimately be tested by the unanimity rule in the European Council. However, as no new instruments are being introduced, we regard this still as a more feasible policy initiative compared to an European-wide levy on meat. In this section we will analyse what a phase out would mean in terms of meat consumption and revenue raising.

3.3.2 Generalised impacts

A VAT increase for animal products through abolishing lower tariff exemptions will have various impacts:

1. It will reduce demand for the animal products in itself. Lower demand for animal products in general will entail a lower environmental footprint of human consumption. The environmental gains from a reduced demand in animal products will partly be offset by increases in consumption of alternatives, that also have environmental impacts. So part of the environmental impacts will be shifted from the animal products sector to the alternatives. However, as the alternatives have (much) lower environmental impacts, total external costs will be lower.
2. There may be a shift within the animal products sector towards meat from 'cheaper products' like chicken. However, as all animal products become more expensive we expect this impact to be very small.
3. The VAT increase will raise income for the government that can be recycled back to consumers/taxpayers (see Section 3.7). One of the options discussed there is to lower VAT tariffs for 'healthy food'.
4. A fourth impact path leads through reformulation of product compositions by food manufacturers in order to keep the price increase as low as possible. The less animal products are included, the lower the price increase due to the VAT increase. This impact is not quantitively included in the analysis.

3.3.3 Environmental impact

In this section, we present the global impact of a minimum VAT on meat products[14]. This is assuming that all EU countries raise VAT on beef, pork and poultry to the standard VAT rate. The effects on consumption, VAT revenues and total external costs are noted in Table 9. The price increase for each product varies for each EU country, depending on the current VAT rate and the standard VAT rate. Given the weighted average price increase, total consumption of beef, pork and poultry decreases by almost 6 kg per capita across the EU, with the highest absolute decrease for pork and lowest for beef. This is equivalent to a reduction of 10% in the case of beef and almost 8% in the case of pork and poultry. VAT revenues across all member states increase by around € 19.3 billion in total. Moreover, due to decreased consumption of meat, the total external costs decrease by over € 8.3 billion. The shift in VAT rates means that a larger part of the total external costs are internalised in the taxes over the meat products. Given current VAT rates, about 8% of external costs for beef, 20% for pork, and 17% for poultry are internalised in the consumer price. After the VAT raise, these internalisation rates increase to 23% for beef, 55% for pork and 47% for poultry. The revenues of such a system will be discussed in Section 3.6.

[14] Milk, cheese and eggs are not included in this analysis due to a lack of data on the EU level. The effects for milk, cheese and eggs in Germany and France are discussed in Section 3.3.4.

Table 9 - Impact on consumption, VAT revenues and external costs of minimum VAT on meat in EU27

	Unit	Beef	Pork	Poultry^
External cost, average EU27	€/kg	8.61	1.91	1.44
Price elasticity of demand		-0.8	-0.6	-0.6
Weighted average product price*				
Before VAT raise	€/kg	10.3	5.3	3.5
After VAT raise	€/kg	11.5	6.0	4.0
Consumption**				
Before VAT raise	kg/capita	12.9	33.7	24.9
After VAT raise	kg/capita	11.6	31.1	23.1
VAT revenues				
Before VAT raise	€ bln	4.2	5.8	2.7
After VAT raise	€ bln	10.4	14.6	7.0
External costs				
Before: total external costs	€ bln	49.7	28.8	16.1
Rate of internalisation in VAT	%	8%	20%	17%
After: total external costs	€ bln	44.6	26.6	14.9
Rate of internalisation in VAT	%	23%	55%	47%

* Weighted by total consumption. Prices are an estimation based on (Global Product Prices, 2022). A factor based on detailed prices for France and Germany was applied to estimate prices in 2019 for all three products. Malta is excluded due to lack of data (Malta represents less than 0.2% of total meat consumption in EU).

** Consumption data for 2019 is taken from Our World in Data (Our World in Data, 2019).

^ We assume that all poultry has the same external costs as chicken. As chicken meat is very dominant in the consumption of poultry, this is not an unrealistic assumption.

3.3.4 VAT tariff changes in individual Member States

In the European Union, VAT rates are decided by Member States (MS). Each individual MS can thus decide to increase the VAT on animal products. In the reports for France and Germany, the impacts of a VAT increase for all animal products (including milk, cheese and eggs) are analysed in depth. Table 10 summarises the analysis for France from increasing the VAT level for animal products from the current 5.5 to 20%. It shows that applying a uniform VAT for animal products similar to the general VAT level, increases the price of meat with 13.7%. Higher prices will induce a reduction in demand (determined on the basis of price elasticities) of 8% for all products except for beef cow that will lower demand by 11%. The reduction in consumption will most likely be one-to-one translated into a reduction of external costs.

Table 10 - Price details VAT increase in France

	Beef	Pork	Chicken	Milk	Eggs	Cheese
Price increase retail	13.7%	13.7%	13.7%	13.7%	13.7%	13.7%
Consumption reduction (%)	-11%	-8%	-8%	-8%	-8%	-8%
Part of external costs covered by VAT increase	21%	61%	66%	36%	59%	49%

One of the drawbacks of tackling all animal products with a uniform tax tariff is that not all external costs are being covered through this. The higher VAT increase covers around 60% of external costs for eggs, pork and chicken and around 50% for milk. For meat from dairy cows, the external cost coverage lowers to 36% and is only 21% for beef cows.

Yet, the measure would entail substantial benefits. In the French Report (CE Delft, 2022b), the reduction in CO_2-eq. emissions is calculated to be about 5.5 Mton. The total welfare gain due to less environmental effects would be around € 1,800 million per year of which € 400 million is related to climate change benefits and € 1,400 million to other environmental impacts. Most welfare gains arise due to the reduction in health impacts from particulate matter formation and land occupation. Per inhabitant, the annual total welfare gain is € 27 on average, which involves € 6 on climate-related issues and € 21 related to other environmental themes.

In Germany, see (CE Delft, 2022c), excluding animal products from the lower VAT rates would imply an increase in VAT rates from the present 7 to 19%. The impacts are given in Table 11. It shows that applying a uniform VAT for animal products similar to the general VAT level, increases the price of meat with 11.2%. These higher prices will induce a reduction in demand (determined on the basis of price elasticities) of 4.5% for all products except for beef cow that will lower demand by 5.6%. The reduction in consumption will be one-to-one translated into a reduction of external costs. The lower price increase in Germany compared to France also implies that over the entire value chain less external costs will be internalised, ranging between 41% for German-produced pork meat to 13% for meat from beef cow.

Table 11 - Price details VAT increase in Germany

Category	Beef	Pork	Chicken	Milk	Eggs	Cheese
Price increase	11.2%	11.2%	11.2%	11.2%	11.2%	11.2%
Change in consumption (%)	-5.6%	-4.5%	-3.4%	-4.5%	-4.5%	-4.5%
Part of external costs covered by VAT increase	13%	41%	22%	34%	27%	38%

As a result of the consumption decrease, pressure on the environment will be lower. With respect to climate change, a reduction of 3.4 Mton CO_2-eq. emissions would be realised (indicative estimate). The total welfare gain due to less environmental effects would be about € 1,170 million per year of which € 280 million is related to climate change benefits and € 890 million to other environmental impacts. Most welfare gains arise due to the reduction in human health impacts from reduced particulate matter formation and less land occupation. Per inhabitant, the annual total welfare gain is € 14 on average, which involves € 3 on climate-related issues and € 11 related to other environmental themes.

3.3.5 Administrative and regulatory issues

Administrative and implementation costs are rather low as the measure relies on an already established VAT-system. For combined food products including meat, dairy and eggs (e.g. pizza's, bread with a hamburger) a decision has to be made in what kind of VAT tariff the product should be placed: the reduced or standard VAT rate? This can be part of a discussion and lead to difficult interpretations. It is inevitable that the regulator decides this on a product-by-product basis.

With respect to legal issues, particularly the principle of fiscal neutrality would have to be observed. According to a legal feasibility study for Germany (Karpenstein, 2021), VAT measures are feasible. This means that individual MS themselves can decide on implementing the measure. For decision making at the EU level, for example the rule that animal products no longer can benefit from lower VAT rates, the measure would require unanimity in the European Council.

3.3.6 Governmental revenues

Increasing VAT rates would imply additional governmental revenues. If all EU countries would abolish the lower VAT tariffs for meat products, total VAT revenues would increase by over € 19 billion across the EU member states. This is more than 2.5 times the VAT revenues from animal products before the increase.

Recycling of revenues is an important element for the design of economic instruments that will be analysed in Section 3.6.

3.4 An ETS system for agriculture

As the EU livestock sectors are important sources of (greenhouse gas) emissions, emissions could also be regulated by an emission trading system (ETS). An ETS is a financial instrument where, through a detailed system of monitoring and reporting, participants need to cover their emissions with an emission permit that can be traded on the market.
An EU ETS has been installed since 2005 for electricity producers and large industry and is in essence working, even though commentators have been critical towards its effectiveness to decarbonisation, especially in the industry sector (see e.g. (CE Delft, 2022a).

Over time, the EU ETS has been expanded to cover aviation (2012) and in the future it will include emissions from maritime shipping, transport and the built environment, where transport and built environment will be part of a separate system, called ETS2.
As agriculture is a large emitter of GHG as well, it is logical to investigate if an ETS for agriculture could be set up, either to be included in ETS1 or ETS2, or in a separate new system (ETS3).

3.4.1 Is an ETS system for agriculture feasible?

Until recently, inclusion of agriculture in an ETS has received little attention outside the academic world. At the European Commission there are no direct plans that develop the idea, except for inclusion of the fuel consumption in agriculture as part of ETS2 (as was discussed in the IA of the 2030 Climate Target Plan (SWD(2020) 176 final).[15] However, fuel consumption is only a minor source of GHG emissions in agriculture – most of them are related to NO_2 and CH_4 emissions.

A real-life debate on including agriculture in an ETS is currently playing out in New Zealand, where agriculture will be included in the NZ ETS in 2025 unless a different system is accepted. If agriculture is included in the NZ ETS, agricultural livestock emissions will be priced at farm level, and fertiliser emissions at processor level, i.e. the manufacturer or importer rather than the user. However, the system is also debated on effectiveness and feasibility. A counterproposal to the inclusion of agriculture in the ETS is being discussed, called He Waka Eke Noa. This plan consists of a separate pricing mechanism which revolves around a farm-level split-gas levy. This split-levy approach applies different levy rates to

[15] Things may be shifting in the long run as in April 2022, DG CLIMA has published an open call for a study to assess the application of the polluter-pays principle to agricultural emissions. The Commission included this study in the action plan for carbon farming in their Communication on Sustainable Carbon Cycles. With this study DG Clima aims “to look at different ways to apply the polluter-pays principle to agriculture, including a sectoral ETS or a carbon tax. They also want to explore how the revenues from the application of this principle can be effectively channelled to land managers that provide carbon removals”.

short- and long-lived gas emissions, which are calculated at farm level through a centralised calculator (He Waka Eke Noa, 2022).

In the following we will discuss important design options for an ETS in agriculture. These included:
- the decisions which entities are being regulated (Section 3.4.2);
- the decision what type of ETS will be proposed: inclusion in present ETS, setting up a new ETS or piloting with national ETS systems (Section 3.4.3);
- the system of MRV that will be set up and which emissions will be regulated (Section 3.4.4).

3.4.2 Design options with respect to regulated entities

An important question in an ETS is who would be the regulated entities. Publications on the topic mainly consider the inclusion of individual farmers into the system, as opposed to slaughterhouses, dairy factories or retail or other more upstream entities in the agricultural chain. Inclusion of farmers has the advantage of a direct targeting at the point where most of the emissions occur. From a methodological point of view, this is the best point of regulation in an ETS.

In principle regulation can be organised along the following points in the chain:
- **Farm level** using a system of emissions monitoring. On the basis of fixed and harmonised rules, farmers can calculate their emissions based on e.g. type of cattle, type of feed, manure management practices, type of stable and efficiency in transforming feed into meat and other dairy products. On the basis of this system regulated entities must hand in emission credits to cover their emissions (see also Section 3.4.5).
- **Slaughterhouses and dairy factories** using a system of monitoring *animal* numbers. Slaughterhouses and dairy factories can keep track of the number of animals that are being slaughtered (and milk being processed), and this can form the basis of an emission trading scheme. Different type of animals could require different amount of emission credits, so basing the system on implicit GHG accounting.
- **Retail** using a system of sold kilograms of meat and dairy. Retail can be held responsible for administering and reporting the kilograms meat and dairy sold to consumers. Retailers would then have to hand in emission credits to cover emissions over the value chain. Different type of animals could require different amount of emission credits, so basing the system on implicit GHG accounting in which also organic farming could have their role.

Literature (see e.g. (Llonch, 2017) has identified various options to reduce GHG emissions from livestock. These fall apart into the following categories:
- Feed/digestibility management: measures related to alter the diet of animals so that less GHG are being formed. Especially used for beef and dairy cows.
- Manure management: measures related to processing or storing the manure so that less GHG are being formed – relevant for all types of animal products.
- (Eco-)Efficiency: measures related to the efficiency of, and conditions under which, animals are being raised into products (meat and dairy). A higher eco-efficiency means a higher yield with less environmentally harmful inputs.
- Reducing direct meat and dairy consumption or the use of meat and dairy in composite products.

It is important to realise that the point of entry impacts on the options available to reduce GHG emissions over the value chain, as shown in Table 12.

Table 12 – Regulation points possible for an ETS and options to reduce GHG emissions

	Farmer	Slaughterhouse	Retail
Feed/digestibility management	X		
Manure management	X		
Eco-efficiency	X	I	
Reducing direct meat and dairy consumption	I	X	X
Reducing indirect meat and dairy consumption	I	X	(x)

Note: I = indirect impact through higher costs; X= direct impact.

If the monitoring of the trading system is being placed at the farm level, the majority of GHG emissions in the value chain are directly regulated. All options to reduce emissions are thus covered by the scheme. Options to reduce CO_2 will increase costs at the farm level and through higher prices for meat and dairy, consumption can be (indirectly) reduced.

A trading system may also be placed at the level of slaughterhouses and meat importers where the *number* of animals will be capped (instead of emissions). The disadvantage of such a system is that options to lower GHG emissions during production through, e.g. feed and treatment of manure, are not covered by the scheme. Processed meat in other products would be reduced as well. There is a danger of unfair competition here where processed meat from factories outside the EU, would face a competitive advantage over processed meat from factories inside the EU. It should be investigated to what extent unfair competition would result in carbon leakage. If this is substantial, the scheme would have to be accompanied with a border mechanism taxing processed meat to assure fair competition at the market. A similar system can be developed for dairy processing factories and companies that import dairy to EU Member States, based on kg milk, or kg dairy products.

Finally, a trading system may be regulated at the level of retail. In principle such a system could achieve a similar efficiency as a system at the level of slaughterhouses but runs the risk of ending in difficulties defining which type of meat must be under the scheme. This is relatively straightforward for raw meat, but processed meat would pose a challenge.
If these would be left out of the scheme, there would be a shift towards products containing processed meat. If these would be included in the scheme, it may raise the administrative burden of the scheme as for every product the content of meat must be established and taxed. However, this must also be established in the border mechanism under the system of regulation at the slaughterhouse level.

3.4.3 Inclusion in the present ETS, a new system or national systems?

Another decision would be whether the ETS would be part of an existing ETS, whether it would be part of a newly formed ETS (e.g. ETS3), or whether it could be used as a blueprint for voluntary systems at the MS level.

Inclusion in the present ETS would imply that the existing ETS would be enlarged with emissions from livestock farming. The impact on the permit price from including farmers into the ETS depends on whether the marginal reduction costs (MRC) of the farmers are on average higher or lower than the marginal costs of entities currently in the system.
If farmers' MRC are on average lower, the permit price will tend to fall: overall, the average MRC will decrease. Conversely, if the farmers' MRC are on average higher, the permit price will tend to increase overall. According to research, marginal abatement costs in agriculture are estimated to be higher than in the sectors currently covered by EU ETS (De Cara & Vermont, 2011). However, including agriculture into the ETS can lead to savings on total abatement costs. This is because, as the researchers argue, the cheapest

abatement measures will replace the more expensive abatement measures in sectors already covered by ETS: there, the cheaper measures have already been taken. Researchers argue that farmers still have *relatively* lower marginal abatement costs compared to sectors already covered by ETS, and that inclusion in EU ETS should lead to positive effects on permit prices and technology (Brandt & Svendsen, 2011).

Agriculture could also be part of a separate system for livestock in the EU, a so-called ETS3. In that case, price formation in the agricultural sector can be different from that in ETS1 (electricity generation and industry) and ETS2 (transport and built environment). A separate system would, to some extent, also allow for more flexibility with respect to setting up separate rules for agriculture with respect to monitoring, reporting and verification.[16] The drawback is that a separate system may result in price differentials between the various ETS systems. From an economic perspective, such price differentials imply a loss of welfare as the total CO_2 reduction could be achieved at lower costs.

In principle, EU MS could also decide to implement a national ETS. However, also at the MS level, the idea is relatively underdeveloped. For example, in Germany emission trading in agriculture never made it past the stage of academic ideas. On the one hand this is remarkable, as the German and EU livestock sectors are important sources of (greenhouse gas) emissions. Besides, Germany acknowledges the benefits of emissions trading and recently set up a national CO_2 budget system for (road) transport and the built environment (see Textbox 2).

Textbox 2 - German national ETS for road transport and built environment

As of 2021, the German national CO_2 budget is effective. It caps the emissions of per year, based on the EU Effort Sharing Scheme. Air and ship traffic are not covered by this national ETS. In principle, the rights will be auctioned and mutual trade will take place. In the first phase (2021-2025) a fixed price has been set for which rights are sold; it increases from € 25/tonne CO_2 in 2021 to € 55/tonne CO_2 in 2025. An upstream system has been chosen in which energy suppliers must submit rights for (CO_2-causing) fuels that they have supplied to consumers and businesses. The costs for these rights are then passed on to end users[17]. To compensate for these price increases, the commuting allowance will be increased, a mobility premium has been introduced and reducing the surcharge paid via the energy bill to stimulate renewable energy (EEG surcharge) is considered (Bundesregierung, 2020).

3.4.4 MRV obligations and regulated emissions

A national ETS or ETS extension requires solving some serious issues with respect to accurate Monitoring, Reporting, Verification (MRV) and rigid enforcement. The fear of the carbon pricing/ETS community is that inclusion of agricultural activities and food consumption into the present EU ETS system might water down the high standards achieved thus far (Ecologic, 2022). For taxation, MRV systems must also be in place, but the required level of detail depends on the exact design and it is easier to include a development path to a differentiated system over time.

[16] In principle, separate rules for agricultural emissions MRV could also be part of the present ETS. However, in that case, there is always the risk that people may go to court over some underlying principles (e.g. definition of source streams) that are different in agriculture from industry and that the law does not properly provide argumentation for such differences. From a legal perspective it may thus be more easy to set up a new system.

[17] Delivery to companies that fall under the EU ETS is exempt, and where there is overlap with the EU ETS, refunds will be made.

The difficulties in integrating agriculture into the EU ETS are also recognised by (Isermeyer, et al., 2019). They argue that theoretically, the best policy concept would be to use an 'individual greenhouse gas balance' for each individual farm. However, in practice it is not possible to gather the necessary data for all farms in a reasonable manner. Instead, they consider measurements for the various greenhouse gases individually:

- Nitrous oxide emissions: not feasible for exact measurement. Instead, they propose the amount of reactive nitrogen to be the basis of CO_2-pricing.
- Methane emissions: for storage of farm manure it is assumed that regulations will provide the necessary emission reductions. For keeping of ruminants, the control parameter 'number of animals' remains as basis for the CO_2-pricing.
- Carbon dioxide: the authors focus on drained peat soils, of which the carbon reservoir can be preserved if it is completely rewetted, which could potentially be integrated into emissions trading.

A complicating issue with including agriculture in EU ETS is the matter of reporting. Annual emission estimates from farming know a confidence bound of -100 to +1,000% relative to the estimated mean. The most important reason for this is that most agricultural emissions arise from a complicated biological process, which can be heavily influenced by various parameters. To reduce such uncertainties in the monitoring of emissions from agriculture, Brandt and Svendsen propose a scheme in which the regulator proposes a list in advance of farming practices that can be used as valid reduction measures within the EU ETS system. Moreover, Tilburg University is currently undertaking a research project on developing a regulatory framework that allows agricultural greenhouse gas emissions to be included in the EU ETS, and to align the system with the Common Agricultural Policy. This project runs until 2023, results still forthcoming.[18]

It would be much easier if not the farm level, but slaughterhouses, dairy factories or retail would be the regulated entities. In that case, the GHG emission per type of animal and growing regime can be established. Such a system allows e.g. for differentiation towards conventional and organic farming. In theory, also other externalities could be tackled under such a system thereby increasing the extent to which externalities will be priced into the scheme.

3.4.5 Discussion and conclusions

The ETS is a viable policy option that should be investigated more in the future at the level of the EU. Currently agricultural emissions are being regulated through the Effort Sharing Regulation, but as emissions of transport and built environment will be placed in a separate ETS, it is needed to careful consider the necessity of other emitters to be kept under the ESR. An ETS has the advantage that it offers to agriculture an EU-harmonised approach to combat GHG emissions in the agricultural sector.

Design of an ETS is at this moment not possible without further study. There has been remarkably little done in this field. Our initial investigation showed that important elements are the point of regulation (farmer, slaughterhouse or retail), the GHG and other pollutants to be included in such a system and the design of a proper MRV system. However, an ETS in the agricultural sector should not be regarded as a holy grail.

[18] www.blog.uvt.nl/environmentallaw/?p=475

There is also concern about the effectiveness of an ETS in agriculture. This boils down to various points:

- Levelling the playing field through an ETS would be a challenge, given the subsidies that are provided to the agricultural sector under the Common Agricultural Policy (CAP). It is crucial to correct the existing incentive structures, by shifting potentially environmentally harmful agricultural support towards targeted environmental payments. Such CAP reforms might be more effective than adding another mechanism.
- Emission trading schemes are in essence political markets as supply of emissions permits is regulated by political laws. It may take a long lead times before the system becomes effective. The history of the ETS learns that it started already in 2005 and it lasted until 2018 until it started to work with prices that were approaching “optimal price levels” (CE Delft, 2022a).
- There is a genuine risk that an ETS for agricultural emissions will end other measures in the sector, as the sector can effectively limit further regulation by claiming that they are already regulated in emissions through the *animal number* system. In the EU ETS such a development had happened after introduction in which Swedish and Dutch industries have, effectively, lobbied against other regulations as they were already regulated by the ETS. For Swedish industry this implied abolishment of their existing carbon tax and for Dutch industry, companies would no longer participate in the Long-Term Agreements on Energy Saving. An evaluation in the Netherlands (CE Delft, 2010). showed that this had led to the situation that energy savings in industry were slowed down.
- If only GHG emissions will be regulated, the external cost coverage will be limited as over the value chain only 25-30% of the external costs are due to GHG emissions. If slaughterhouses, dairy processing companies and/or retail are being regulated, the scheme could in theory be adjusted easily so that more external costs can be taken into account. However, external cost figures used in this reflecting impacts on human health and eutrophication study reflect European averages and may differ greatly from location to location – which may be more difficult to take into account in a system that uses slaughterhouses or retail as the regulated entity.

3.5 A levy on meat products

An excise tax or levy on animal products is an instrument that could internalise the external costs effectively. Levies have traditionally been proposed by economists to correct for market failures (such as the existence of external costs). In the European Union a levy on meat products is unlikely to be realised due to the unanimity vote in the European council. In this study, the levy on meat products has thus only be considered in Germany and France.[19] We will only discuss the results here.

3.5.1 Design considerations of a levy

While a levy on external effects work perfectly in theory, the actual design of a levy is something that needs careful consideration.
This deals with:

- Type of levy: the levy can be designed like an excise duty at the moment of retail to consumers, or as a levy that is calculated on e.g. the value chain external costs.
- The taxation point: the levy could be place at the moment of the end-consumers, or earlier in the chain, for example at the slaughterhouses.

[19] In (CE Delft, 2019a) we have analysed a levy on meat products for the Netherlands.

- The height of the levy: the levy should ideally be made so high to cover all external costs. However, for political reasons, an increasing levy every year towards a full externalisation level in distant future (e.g. 2030) can be more acceptable.
- Revenue recycling and distributional impacts. The political support for a levy will greatly depend on what will be done with the revenues and how the levy will change income distributions.
- Efficiency and other considerations.

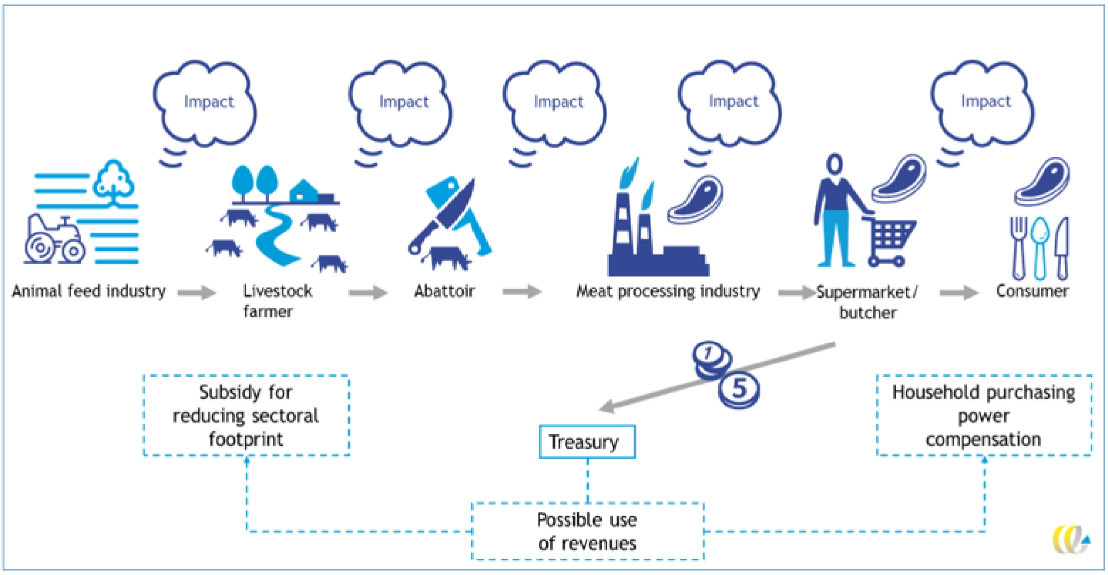
Some of the points will be elaborated in more detail hereafter.

3.5.2 Types of levy

We distinguish here a generic levy from a value chain levy. A generic levy will only differentiate towards the type of meat. In this sense the levy very much works likes an excise duty, similar to duties on alcohol or cigarettes. The tax is levied on the amount of meat, dairy and eggs (tax base) that is sold to end consumers. The advantage of this levy is that it is relatively straightforward and that similar levies have successfully been implemented in many countries worldwide. The disadvantage of this levy is that it stimulates less consumption of meat but does not necessarily stimulates cleaner production techniques in the value chain.

Another type of levy would be to base the levy on the external costs added in each production step. This is the basis of the External Cost Charge in which the added external costs in each production step are being taxed (CE Delft, 2020). The ECC aims to include the environmental impact during the entire supply chain up to the end consumer in the product prices. In each production step, ECC taxes the added external costs. Figure 5 provides an example for the meat production chain. Such approach would create the optimal price incentives for both producers and consumers to avoid/reduce the external effects. Hence, meat from livestock farmers who cause few external costs, a lower taxation rate is paid per kg of meat than when it comes from livestock farmers who cause high external costs.

Figure 5 - Ideal picture of excise levy based on ECC



This requires an extensive monitoring and reporting system on the external costs that are being added in each production step (CE Delft, 2018c). If only GHG is being monitored, it works like a Carbon (eq.) Added Tax (CAT). While such schemes do have great benefits in combining incentives for farmers with incentives for consumers, they are complex in monitoring and reporting regulations and so far they have not been implemented in any country in the world.

A simplified scheme in the end will boil down in an external cost charge for end consumers, which is similar to the excise duty above based on external costs. We will use this in this study: the height of the levy is then similar to the external costs.

3.5.3 Taxation point

A crucial question of a levy is where the levy should be paid. As with the EU ETS option, there are the same options: retail, slaughterhouses or farmers.

The first option is to introduce the levy when the product is sold to the consumer (retail). The seller then pays a rate based on the amount and type of product sold (beef, pork, chicken, dairy, eggs. This means that sellers have to report the amount of meat, dairy and eggs sold to end consumers and the meat, dairy, egg processing industries. The advance of this approach is that a significant amount of sales is covered by the excise levy.
For example, about 85% of the sales of meat (products) is to consumers (CE Delft, 2018a). The levy thus provides the incentive for consumers to switch to products with less meat, dairy and egg ingredients or animal products with lower environmental impact as they pay the levy.

If the levy would also apply to composite products containing animal products, food manufacturers may change their product compositions (less animal ingredients) to limit price increases. In addition, no import or export corrections are necessary as the tax is levied on products sold to consumers. Imports are then treated the same as domestically produced goods. A disadvantage is that the cost increase associated with environmental pressure is only ‘visible’ when sold to consumers. The price impact must be passed on in the chain, so the incentive for the livestock farmers to shift their production towards less animal products is only indirect. In case markets work efficiently, this should not be a problem. However, existing distortions in the market on e.g. land ownerships, subsidies through the CAP and monopsony in retail may distort the price signal to producers.

With a levy at the point of consumption, farmers have no incentive to use cleaner production methods as these will not be ‘rewarded’ with a lower levy. This could partially be circumvented by introducing labels or categories that would apply for a lower levy. Then, tariff differentiation is possible instead of an average tariff for each product category. Information requirements are high as reliable registration of environmental impacts in the product chain is needed and the risk of failing Monitoring, Reporting and Verification (MRV) is high.

A second option is to choose a taxation point more downstream in the chain. In that case, slaughterhouses, dairy and egg producers and meat, dairy and egg importers (mainly processing industries) are liable to pay the levy. Although it can be assumed that the tax will be (partly) passed through into consumer prices, it limits the number of actors directly under the scheme. Since the tax is levied on all products manufactured or imported into the country, exports would also be covered by the scheme. To maintain an international level playing field, a refund must be made for exports which makes administrative costs higher.

A third option is to place the taxation point at the livestock farmer level. As they are directly confronted with the taxation bill, it would give farmers the most direct incentive to use (new) techniques or methods that reduce external effects in the production of the good, or to switch on the production of other goods that have fewer externalities.
This particularly holds when the tariff is differentiated towards production methods. There is also a more direct incentive for the buyer of the meat to purchase meat from livestock farmers whose production causes less environmental impacts.

Under this latter option there is a potential risk of relocation of polluting activities abroad (leakage) due to a competitive disadvantage since only meat from EU-MS livestock farmers is taxed. To correct for this, cross-border adjustments for both imports and exports need to be made which may be difficult to monitor, inflict on existing trading agreements, run the risk of retaliation and be perceived as unfair towards developing countries. Therefore this point of taxation seems to be less promising.

3.5.4 Effects of a levy on meat

The exact effects of a levy on meat will depend on the type of levy that will be installed, the taxation point, the height of the levy and the possibility to differentiate the levy to different production types of meat (e.g. organic and conventional, or low-carbon).

In general, the following impacts can be expected:
1. Decrease in consumption of meat products.
2. Improvement in environmental quality through lower meat consumption.
3. Government revenues that can be recycled back to consumers.

In the studies for Germany and France we have shown that a levy equivalent to the external costs of meat, dairy and eggs, levied at the end-consumer, will reduce consumption and through that improve the environment. In addition, product compositions by food manufacturers may be reformulated to less animal products, in order to keep the price increase as low as possible.

Table 13 - Annual consumption figures of animal products after introducing a levy

	Beef	Pork	Chicken	Milk	Eggs	Cheese
After introduction of levy						
Relative price increase	91%	29%	54%	35%	44%	31%
Estimated price elasticities	-0.5	-0.4	-0.3	-0.4	-0.4	-0.4
Change in consumption (%)	-46%	-12%	-16%	-14%	-18%	-13%
New consumption level (million tonnes, product weight)	0.5	2.4	1.1	3.7	1.0	1.8

Note: Current consumption figures based on (BMEL, 2021).

They show that consumption of beef can be reduced by 46% if the beef sector is fully paying for their external costs. Reductions between 12-18% will be achieved among the other animal products. Total CO_2 emissions will be reduced by about 17 Mt CO_2-eq.
Moreover, damage due to other environmental impacts (mainly air pollution) would accrue to over € 4 billion.

In the analysis for France and Germany, the levy accounted for 100% of the external cost estimate. In practice a growth patch might be chosen (e.g. starting a tax level at 25% of external costs and yearly increasing), due to political reasons or to allow parties to get used to the system.

Lower consumption of the taxed products, creates additional demand for alternative products. This will be partly a desired effect when people switch to plant-based proteins. Hence, it is also possible that they shift to other animal based products as they become relatively cheaper as they face lower tax tariffs[20]. This would be an undesired effect when demand increases for products that are worse for animal welfare (e.g. chicken meat), as the aim is fostering the transition towards the consumption and production of less and 'better' animal products.[21] An undesired shift from the perspective of animal welfare would occur when a lower rate on chicken compared to beef causes a consumption shift towards chicken. According to (CE Delft, 2020) it is expected chicken meat consumption will also be reduced, if chicken meat will be part of a meat tax levy, even if tax levels for pork and beef are higher.

3.6 Revenues and recycling of revenues

Pricing instruments, such as an ETS, a levy or a higher VAT rate, would imply higher prices for consumers and revenues for governments. On the one hand, the revenues can be used to compensate for a loss of purchasing power for certain groups. This may concern the sector itself, as it is confronted with a cost increase that can lead to a reduction of the profit margin (if the costs are not passed on one-to-one) and a loss of turnover (if demand decreases when costs are passed on). Famers could be compensated by providing subsidies from the revenues for, e.g., investments in products and methods of production that allow for lower environmental impacts. Such measures have not been investigated further in this research, as a compensating mechanism should carefully consider the amount of pass through of the costs to end consumers, and such lays outside the scope of the present research.[22]

If all costs are passed through to end consumers, or the pricing instruments directly target end consumers, they can be compensated for their loss in purchasing power because of the higher (meat and dairy) prices. This is regarded problematic especially for low income households as a larger share of their incomes may be spent on food products.

There are several ways to compensate consumers:
1. Through a VAT relief for fruit, vegetables and other products. In April 2022, Greenpeace Germany presented a report (Wiegmann, 2022) on VAT increase on meat, dairy and eggs in different EU countries, and proposed at the same time a reduction of VAT rates to 0% on vegetables, fruit, cereals and bread, allowing consumers a net benefit of around € 50/year (based on average diets). The advantage of a VAT relief is that it does not discriminate towards household income. Every household will benefit equally from this.
2. Through a reduction in other taxes, e.g. income taxes. Taxing environmental impacts and recycling money back to lower labor taxes has often been considered giving double dividends: lower pollution and lower unemployment (see e.g. (Topal, 2017)). Reduction of labor taxes could thus be a good idea, especially in countries that have a relatively high unvoluntary unemployment. On the other hand, the reduction in labor taxes will only benefit those who have a (paid) job while pensioners and unemployed

[20] Tariffs are highest for beef, followed by pork and chicken, in accordance with the environmental impact.

[21] Beef might be a worse product for environmental reasons, but better for animal welfare. Animal welfare is not included in the analysis, see Section 1.3.

[22] In a previous report (CE Delft, 2020) some proposals are developed however, like subsidies to buyout livestock units, manure processing (digestion or methane oxidation), feed supplements, soil measures (improving Soil Organic Matter, clover), organic dairy, etc.

people will pay for higher taxes but not reap any benefits. Therefore, this measure has distributional consequences which would have to be addressed through other policy measures. Distributional consequences will also appear if other taxes are being lowered such as profit or energy taxes.

3. Through giving a voucher to citizens free to spend on specific food product categories (e.g. vegetables and fruits) for each country inhabitant. Nowadays, many countries (e.g. Belgium, France) provide such food vouchers to low income groups to compensate for the higher costs of food.

For France and Germany, we will explore the VAT relief on fruit and vegetables in detail. Moreover, for all EU countries, we will consider the potential amount a voucher would entail.

3.6.1 Full return of VAT increase through vouchers for fruit and vegetables

A different manner to recirculate government revenues from a VAT increase on meat products, is to evenly distribute the revenues over the population through a voucher, to be spent in supermarkets on e.g. fruit or vegetables. The amount of additional VAT revenue for each MS depends on the current VAT rate on meat products (see Table 8 in Section 3.3.1). If the standard rate is already applied on meat products, there will be no additional tax revenues and thus there will be no vouchers. Table 14 shows, for each member state, the estimated additional VAT revenues (summing up to over € 19 billion in total), and its value per inhabitant. This last value would indicate the amount a personal voucher may entail to recirculate all additional VAT revenues on meat products to the consumer.

Table 14 – Recycling VAT revenues on meat products through vouchers for each member state

Member state	Additional VAT revenue (€ mln)	Voucher per person (€/capita)
Austria	308	35
Belgium	424	37
Bulgaria	0	0
Croatia	120	30
Cyprus	21	23
Czech Republic	163	15
Denmark	0	0
Estonia	0	0
Finland	161	29
France	4,660	69
Germany	2,538	31
Greece	251	23
Hungary	539	55
Ireland	261	53
Italy	3,607	60
Latvia	0	0
Lithuania	0	0
Luxembourg	29	46
Malta	-	-
Netherlands	808	46
Poland	1,706	45
Portugal	606	59
Romania	329	17
Slovakia	107	20

Member state	Additional VAT revenue (€ mln)	Voucher per person (€/capita)
Slovenia	69	33
Spain	2,043	43
Sweden	564	55

* Note: the additional VAT revenues include only the VAT revenues for meat products (beef, pork and chicken). Dairy products are not included in this analysis.

For France and Germany, we also know the potential additional VAT revenues for milk, eggs and cheese as well (see separate country reports). Table 15 shows the government revenues from a VAT increase for meat, dairy and eggs and an introduction of an excise levy.
The corresponding voucher amounts for France and Germany are provided as well.

Table 15 – Voucher amounts for France and Germany, including revenues from milk, eggs and cheese

	VAT increase		Excise levy	
Country	Government revenues (€ bln)	Voucher (€/capita)	Government revenues (€ bln)	Voucher (€/capita)
France	6.3	94	11.5	171
Germany	5.7	68	16	193

The voucher system would imply additional administrative efforts. Administrative costs will highly depend on the type of system that will be set up and will also depend on the number of people that can participate. An evaluation of the Italian scheme of a payment card for free purchases for poor people showed that the administrative costs can be expected to be around € 20 per card (EC, 2020). Other sources estimate that administration costs for food related vouchers can be between the 3 and 37% (United Nations, 2007).

3.7 Discussion: feasibility of the policy options

In this study we have investigated policy options to internalise external costs associated with animal products. Each of these policy options has the impact to increase the price of animal products so that consumers in the end will pay for (part of the) external costs.

The comparison of the pricing instruments one to each other is hampered by the fact that the devil is in the detail. The functioning of pricing instruments crucially hinges on the way they are designed: who is getting the pay check from the regulator, what external effects are covered by the scheme, how are imports and exports being treated, to what extent are impacts earlier or later in the value chain included in the analysis, to what extent are animal products included in composite products, etc. As we don't know these details yet, with the exception of the VAT increase, and cannot answer which type of design is to be preferred within the instrument, it is difficult to compare these instruments to each other.

Nevertheless, Table 16 provides some thoughts on the preference of each instrument. This immediately shows that there is no instrument that immediately is preferable compared to the others. A VAT approach scores high on administrative, regulatory and legislative issues, mainly due to the fact that a VAT system is already in place in each EU MS. In principle, the VAT increase measure is also effective in providing financial incentives for more sustainable consumption and production. However, not all external costs are covered through a VAT increase, especially not for meat from beef cows (which could form a cause for an additional excise duty for beef and veal). When designing an excise levy, the choice of the taxation point and taxpayer has a significant impact on the mechanism. It determines the number of actors that are covered by the scheme (and thus administrative and implementation costs), the effectiveness (which actor faces the main financial incentive) and the need to correct for cross border effects (to avoid relocation of polluting activities abroad). The scores on the ETS system are very provisional as more research needs to be undertaken before the feasibility and impacts of such a scheme can be sketched.

Table 16 -Tentative Scores of policy instruments to internalise external costs of meat, dairy and eggs

Issues/Instruments	Excise levy			VAT increase	ETS	
Taxation point	**Consumer level**	**Slaughterhouses, dairy factories and importers**	**Farm level**	**Consumer level**	**Farm level**	**Slaughterhouse Dairy factories**
EU wide policy measure	-	-	-	0	+	+
Options for individual MS	+	+	+	++	0	0
Possibility to include all external costs	++	++	++	-	-	0
Possibility to differentiate towards production methods	-/0	-/0	+	-/0	-/0	-/0
Prevention from carbon leakage without CBAM	++	-	-	++	-	-
Environmental impacts	+	+	+/++	+	+	+
Low administrative burdens	+	+	-	++		
Low implementation costs of governments	+	-/0	-	++	-	-/0

Note: Scores indicate the indicatively assessed relative performance of the policy instrument, so - = bad performance, 0 = modest, += good, ++=very good.

4 Conclusions

Animal products are an substantial ingredient of current European diets. Yet, the production and consumption of animal products is associated with a wide range of environmental problems: global warming, eutrophication of soils and waters that lower biodiversity, emissions of ammonium that are formed into secondary aerosols harming human health and extensive land use that comes at the expense of nature and biodiversity.

In this study, we estimated the external environmental costs of animal products: meat (both from beef, veal and dairy cows), pork, chicken, eggs and (hard) cheese. Our analysis shows that external costs are substantial, ranging between € 0.34 for a litre of milk to over € 10 per kg of beef. These external costs are primarily caused by emissions of greenhouse gasses plus ammonia from manure handling and its application as a fertiliser (plus artificial fertiliser) for growing crops for feed. Ammonia has many health related impacts and puts the environment under stress (eutrophication and terrestrial acidification). It is therefore no surprise that cattle systems, which have high ammonia emissions, also have the highest external costs.

These external costs form the unpaid bill of consuming animal products. In this study, we have only focussed on the environmental impact as part of the unpaid bills. Most likely the 'real' unpaid bills are higher because the sector receives considerable subsidies that are not being paid by the consumer of animal products, because the sector is the cause of numerous outbreaks of animal diseases (for which taxpayers pay in many countries), because it has a severe impact on human health through zoonoses and resistance to antibiotics and because it has poor standards for animal welfare that can only persist by hiding them from the general public. However, we have not derived external cost estimates for those non-environmental categories in this research.

External costs of consumption of animal products can be most effectively combatted by making the consumers pay for those costs. Only then will consumers take the environmental impact into account when deciding to consume animal products or one of the plant-based alternatives and the sector can be steered towards cleaner production methods and alternatives for animal products. Pricing instruments are therefore most effective when addressing the issue of unpaid bills in the animal products sector.

In this research we have investigated three policy measures:
1. An excise levy on animal products.
2. An emission trading scheme (ETS) for the sector.
3. Removal of the lower VAT tariff on animal products.

Each of these schemes is feasible from a legal perspective and can be implemented, although the levy and the EU ETS need more scrutiny with regard to practical design questions such as where the taxation point should be and whether imports/exports should be addressed in the scheme. The easiest measure to implement would be the removal of the lower VAT tariff for animal products in EU Member States. The lower VAT tariff for meat can be labelled as an 'environmentally harmful subsidy'. Phasing out environmentally harmful subsidies has been a commitment of the EU Roadmap for Resource Efficiency. Various EU Member States, such as Bulgaria, Denmark and the three Baltic States, have not granted lower VAT tariffs for meat or dairy. Other countries could follow their lead. This would reduce meat consumption by about 10% for beef and 8% for poultry and pork. If all EU countries would abolish the lower VAT tariff for meat, total VAT revenues would increase by over € 19 billion across the EU Member States.

Although easy to implement, a higher VAT rate for animal products would have the drawback that it does not fully cover the external costs of meat consumption. For that, additional measures could be considered, either on top of the VAT increase or as a substitute[23]. The most straightforward way of introducing a levy would be to implement an excise levy on meat sold to consumers by retail companies (supermarkets) and food services (catering, restaurants, etc.), irrespective of whether this meat is being produced in the EU or in another country.

Higher VAT rates and/or a levy would imply that costs of consumers still wanting to consume meat will increase which would lower their purchasing power. Consumers can be compensated by the recycling of government revenues from a VAT increase on meat products in order to evenly distribute the revenues over the population through a 0% VAT on vegetables and fruit or a (free food) voucher or healthy food gift card to be spent in supermarkets on fruit or vegetables, for example. In Italy this voucher would be worth € 60/capita, in Hungary € 55, in the Netherlands € 46, in Poland € 45 and in Spain € 43. In France and Germany, compensation for a VAT increase on meat alone would mean a voucher of € 69/capita respectively 31 €/capita. Where a VAT increase covers both meat, dairy and eggs, the voucher value increases to 94 €/capita in France and 68 €/capita in Germany. The latter measure would reduce GHG emissions by 5.5 Mton CO_2-eq./year in France and by 3.4 Mton CO_2-eq./year in Germany.

[23] For France and Germany, we investigated the possibilities of a levy equivalent to the external costs of meat. Such a levy would raise € 11.5 and 16 billion of governmental revenues per year respectively and reduce GHG emissions annually by 17.1 resp. 17.4 CO_2-eq. over the value chain.

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A LCA modelling assumptions

A.1 Data handling and country-specific changes per product

This Annex describes data and assumptions used in the models for the different products. Textual explanations specify the data handling for the version of this report for Germany, France and the EU. Country (EU) specific data is given in the different tables.

Average emissions for 1 kg of animal product were calculated using total production amount in the respective country and the total emissions related to the production system of these products as provided by i4ce and Ecologic for the analysis for Germany and France. For the EU, publicly available emission data was used. Production amounts for meat were provided in carcass weight (cwe). To use the provided data for LCA models for animal production at farm, amounts in cwe were converted to live weight. For more detail, see Section A.1.8.

Note that the final results of this study are expressed in external costs per 1 kg of animal product ready for consumption, excluding packaging. For meat, this means 1 kg of meat, ready to leave the slaughter house, for milk, cheese this means 1 kg of product after processing, ready to leave the factory, and for eggs it means 1 kg of eggs ready to leave the egg farm.

A.1.1 Feed

General feed composition

In some cases, it was possible to adjust the feed composition based on country-specific data. However, feed conversion ratios (FCRs) could not be determined consistently because of discrepancies between reporting methods. Therefore, we assumed the same FCRs between countries, but with different feed composition. We took the following steps:
1. List amounts of each feed in the original Agri-footprint process.
2. Calculate total amount of dry matter with dry matter content stated in Agri-footprint processes.
3. Check if protein content in feed is similar to newly reported feed composition, and if so:
4. Multiply total amount of dry mass with shares of each feed type. To get amount of dry mass for each feed type.
5. Multiply amounts of dry mass for each feed type by 1/dm content to get the new fresh mass to enter in the Agri-footprint process.

The adaptations were made for beef cattle (France) and dairy cattle (France and Germany). In the sections per animal in this Annex, the specific calculations and assumptions are shown.

Compound feed market mixes

The datasets for compound feed were made specific by changing the market mix of the ingredients and other inputs from the country of the original AGRI-FOOTPRINT process to the DE, FR or EU specific process for as many processes as possible. For the processes where no specification to DE or FR was possible, we either changed them to RER (more representative) or left them in the original country if no other sets are available.
For the EU, the RER market mixes were considered the most representative. Table 17 shows which processes were specified for DE, FR or EU, which were made more representative by changing them to RER, and which were only available for the original country.

Table 17 - Changes in compound feed market processes for the EU

Ingredients and inputs in compound feed	Country specific?
Beef cattle	
Barley grain	RER market process
Wheat grain	RER market process
Molasses	RER market process
Rapeseed meal	RER market process
Oat grains	RER market process
Soybeans, market mix, at regional storage/FR Economic	FR/DE market
Maize	RER market process
Electricity	EU27 market process
Heat	EU27 market process
Dairy cattle	
Barley Grain	RER market process
Citrus pulp	NL market process, RER not available
Maize gluten	NL market process, RER not available
Maize	RER market process
Palm kernel expeller	RER market process
Rapeseed meal	RER market process
Soybean meal (solvent)	RER market process
Soybean hulls	
Molasses	RER market process
Sugar beet pulp dried	
Triticale grain	RER market process
Wheat gluten feed	NL market process, RER not available
Wheat bran	NL market process, RER not available
Wheat grain	RER market process
Electricity	EU27 market process
Chicken (all components that occur in feed for broilers, broiler parents and laying hens.	
Maize	RER market process
Wheat grain	RER market process
Wheat bran	NL market process, RER not available
Soybean meal (solvent)	RER market process
Sunflower seed meal (solvent)	RER market process
Rapeseed meal (solvent)	RER market process
Oat grain	RER market process
Crude palm oil	RER market process
Fat from animals,	NL market process, RER not available
Meat bone meal	NL market process, RER not available

Ingredients and inputs in compound feed	Country specific?
Electricity	EU27 market process
Heat	EU27 market process
Peas dry	RER market process
Citrus Pulp dried	NL market process, RER not available
Cassava root	NL market process, RER not available
Molasses	RER market process
Fat	NL market process, RER not available
Peas	RER market process
Soybean heat treated	NL market process, RER not available
Crushed stone	RER market process
Pigs (all components that occur in feed for pig fattening, sows and piglets)	
Wheat grain	RER market process
Barley grain	RER market process
Rye grain	RER market process
Maize	RER market process
Triticale grain	RER market process
Wheat middlings and feed	NL market process, RER not available
Wheat gluten feed	NL market process, RER not available
Maize middlings	NL market process, RER not available
Molasses	RER market process
Sugar beet pulp	NL market process, RER not available
Crude palm oi	RER market process
Soybean meal	RER market process
Soybean hulls	NL market process, RER not available
Rapeseed meal	RER market process
Sunflower seed meal	RER market process
Palm kernel expeller	RER market process
Fat from animals	NL market process, RER not available
Electricity mix AC	EU27 market process

Table 18 - Changes in compound feed market processes for France and Germany

Ingredients and inputs in compound feed	Country specific?
Beef cattle	
Barley grain	RER, no country-specific market mix
Wheat grain	FR/DE market
Molasses	RER, no country-specific market mix
Rapeseed meal	RER, no country-specific market mix
Oat grains	RER, no country-specific market mix
Soybeans, market mix, at regional storage/FR Economic	FR/DE market
Maize	FR/DE market
Electricity	FR/DE
Heat	EU, no country-specific process
Dairy cattle	
Entered in Beef at farm process?	
Barley Grain	RER, no country-specific market mix
Citrus pulp	NL, no other country available
Maize gluten	NL, no other country available
Maize	FR/DE market

Ingredients and inputs in compound feed	Country specific?
Palm kernel expeller	RER, no country-specific market mix
Rapeseed meal	RER, no country-specific market mix
Soybean meal (solvent)	FR/DE market
Soybean hulls	NL, no other country available
Molasses	RER, no country-specific market mix
Sugar beet pulp dried	NL, no FR or DE available.
Triticale grain	RER, no country-specific market mix
Wheat gluten feed	NL, no other country available
Wheat bran	NL, no other country available. Should we adapt wheat bran NL in the market process?
Wheat grain	FR/DE market
Electricity	FR/DE
Chicken (all components that occur in feed for broilers, broiler parents and laying hens	
Maize	FR/DE market
Wheat grain	FR/DE market
Wheat bran	NL, no other country available.
Soybean meal (solvent)	FR/DE market
Sunflower seed meal (solvent)	RER
Rapeseed meal (solvent)	RER
Oat grain	RER
Crude palm oil	RER
Fat from animals,	NL, no other country available.
Meat bone meal	NL, no other country available.
Electricity	FR/DE market
Heat	EU
Peas dry	RER
Citrus Pulp dried	NL, no other country available
Cassava root	NL, no other country available
Molasses	RER
Fat	NL, no other country available
Peas	RER for FR, DE for DE
Soybean heat treated	NL, no other country available
Crushed stone	RER
Pigs (all components that occur in feed for pig fattening, sows and piglets)	
Wheat grain	FR/DE
Barley grain	RER
Rye grain	RER for FR, DE for DE
Maize	FR/DE
Triticale grain	RER
Wheat middlings and feed	FR/DE
Wheat gluten feed	NL, no other country available for consumption mix
Maize middlings	NL, no other country available for consumption mix
Molasses	RER
Sugar beet pulp	NL, no other country available for consumption mix
Crude palm oi	RER
Soybean meal	FR/DE
Soybean hulls	NL, no other country available for consumption mix
Rapeseed meal	RER
Sunflower seed meal	RER
Palm kernel expeller	RER

Ingredients and inputs in compound feed	Country specific?
Fat from animals	NL, no other country available for consumption mix
Electricity mix AC	FR/DE

Land use change in soy production

Part of the carbon footprint of soy production is caused by direct land use change (dLUC). Different ecosystems have different carbon stocks. The most well-known example is a land that was previously (rain)forest and is now used for soybean production. A field of soybeans (and its soil) holds much less carbon than a forest, and therefore the difference in carbon stocks is included in the carbon footprint of crops associated with deforestation.
The European Soy Monitor (IDH and IUCN NL, 2021) classifies certain certification schemes as ‘deforestation-free’. This is soy that is certified under a selection of strict schemes.[24] France and Germany have a market share of ‘deforestation-free soy’ of 16 and 25% respectively. The EU28+ average share is 25%.[25]

An important aspect of a certification scheme is the ‘cut-off date’. This is the date after which no land conversion is allowed to occur in order to comply with the standard. Of the ‘deforestation-free’ schemes, RTRS has the latest cut-off date: 3rd of June 2016.[26] Therefore this is the date for which it can be guaranteed that there was no deforestation. Looking at PAS-2050 methodology, direct land use change (dLUC) or deforestation is calculated using a term of 20 years. As June 2016 is only 6 years in the past instead of 20 years, in this study we calculate the dLUC-emissions proportionally to this.[27] This means that corrections to the dLUC emissions of soy have been made as follows:

- France: 16% * 30% = -4.8% dLUC emissions of soy;
- Germany: 25% * 30% = -7.5% dLUC emissions of soy;
- EU28+: 25% * 30% = -7.5% dLUC emissions of soy.

Fresh grass, grass silage and maize silage production

Grass and maize (both fresh and silage) are important feedstuffs for cattle. Grass and maize production processes in Agri-footprint where therefore made country-specific as far as data allowed. Additionally, the ammonia emissions of crop residue decomposition were recalculated using the most recent NEMA (RIVM, 2021) method and therefore these are lower than in the Agri-footprint standard processes.

Manure application on agricultural soils are limited by the European nitrates directive (European Commission, 2021). Germany and France are therefore limited to 170 kg N from manure/ha. In contrast: the Netherlands currently avails of a derogation due to which more nitrogen from animal manure can be applied: up to 250 kg N/ha instead of 170 kg N/ha (RVO, 2019). In practice, even more is applied in the Netherlands: 277 kg N/ha on average (WUR, 2005).

24 Included certification schemes are RTRS (cut-off date June 3rd 2016 (RTRS, 2021)) p.24-25, ISCC + (cut-off date January 1st 2008 (ISCC, 2020)), Proterra (cut-off date 2008 (Proterra Foundation, 2021)), Danube/Europe Soy (cut-off date annuary 1st, 2008 (Donausoja, sd)), CRS/BFA and SFAP-Non Conversion (cut-off date May 2009 (CRS, 2020)).

25 We use this as a proxy for EU27 by lack of better data.

26 This is the absolute cut-off date for all land types, some lands are not allowed to be converted since May 2009.

27 6/20 = 30%, and therefore 70% of the dLUC emissions of soy are still included in ‘deforestation-free soy’.

In France, in addition to the European nitrates directive, the following rules apply:
- minimal vegetation cover during rainy periods and a management of crop residues in order to avoid nitrogen leaks;
- the introduction and maintenance of permanent vegetation cover along certain watercourses, sections of watercourses and water bodies larger than 10 hectares (grass strips).

The management of crop residues will have an effect on N_2O and ammonia emissions. However, without knowing more about specifically which measures are implemented, this cannot be quantified.
A number of countries in the EU currently avail of a derogation. These countries and their market shares in EU milk and beef production are listed in Table 19.[28] These market shares indicate to what extend fodder produced on animal farms is likely to have been produced with additional manure application. The sum of these country shares is used to model average manure application rates in the EU for grass and maize (and their silages) produced for animal feed.

Table 19 - Countries availing of derogation and their market shares for milk and beef production

Country	Milk market share	Beef market share
Ireland	5%	8%
The Netherlands	8%	6%
Belgium[29]	3%	3%
Denmark	3%	2%
Total EU derogation countries	**20%**	**19%**

Source: EUROSTAT.

In summary, adaptations to the grass and maize production processes in Agri-footprint are as follows:
- animal manure application on maize- and grassland: 170 kg N/ha for FR and DE, the levels for EU27 are based on a weighted average of countries with and without derogation;
- reduced ammonia emissions from crop residues on intensively managed grassland: 2.31 kg NH_3/ha/y instead of 44.91 kg NH_3/ha/y and no ammonia emissions from crop residues in maize silage production, because the N-content in fodder maize is lower than the threshold value in (RIVM, 2021) kg NH_3/ha/y instead of 5.67 kg NH_3/ha/y (RIVM, 2021).

A few aspects would preferably be updated here as well, but this was not possible at the moment:
- reduced N application from manure due to additional regulation (in this case in Germany);
- reduced emissions from improved crop residue management (in this case in France).

28 For countries availing of derogation: www.icos.ie/2021/11/30/derogation-from-the-nitrates-directive-process-explained/.

29 Derogation only applies to Flanders. As no specific market share data for Flanders could be found, the total values for Belgium are used.

A.1.2 Land use

Land use was not modelled country-specific in the LCA models. The main reason for this is potential double counting, as in the reported land use metrics per country it is unclear which area of this is used for cultivation of fodder and which part is permanent grazing area. Land use for fodder (and other feed crops) and sables is included in the LCA.

A.1.3 Beef from beef cattle for meat production (incl. veal)

Changes to original Agri-footprint processes for beef production were made to make these country-specific as far as data allowed. The processes in Agri-footprint are:
- beef meat, at slaughterhouse/IE Economic;
- beef cattle, at farm/IE Economic.

In addition to the emission data reported in Table 20, the following processes were made country-specific:
- water, unspecified natural origin;
- electricity mix;
- process steam from natural gas.

For emissions where no country specific data was modelled, Agri-footprint emissions were not adjusted. Economic allocation between meat and by-products is kept the same as original Agri-footprint process.

Table 20 - EU data for 6707.99 kton cwe yearly production of beef incl. veal

Parameter	Parameter specification	Region	In kton/year	Modelled country-specific data
Methane (CH_4)	Enteric fermentation	EU	3,356.8	Yes
Methane (CH_4)	Manure management	EU	343	Yes
Nitrous oxide (N_2O)	Manure management	EU	18.4	Yes
Ammonia (NH_3)	Manure management	EU	398.36	Yes
PM				No
Feed composition	Average feed composition (% on dm basis)	EU	Fresh grass: 52% Grass silage: 30% Compound feed: 12% Maize silage: 6%	Yes (weighted average of IE and FR)
Feed conversion				Yes (as a result of feed composition and quantity)

Table 21 - German data provided by Ecologic for 936 kton cwe yearly production of beef from beef cattle

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific
Methane (CH_4)	Enteric fermentation	DE	128.1	Yes
Methane (CH_4)	Manure management	DE	23.9	Yes
Nitrous oxide (N_2O)	Manure management	DE	9.1	Yes
Ammonia (NH_3)	Manure management	DE	7.9	Yes
Fine PM				No
Feed composition				No
Feed conversion				No
Land use	At farm	DE	Added land use: 0.78 ha/cow	Yes

For France, emission data showed large deviation from the emission data reported in Germany and Agri-footprint. This could be because France exports a large amount of calves abroad, and these are therefore not reported as meat produced in France. In that case, calculating the emissions intensity of meat using national statistics is unreliable.
We followed a conservative approach, in which the highest values from either Germany or Agri-footprint were used for the model.

Table 22 - French data provided by I4CE for 1,270 kton cwe production of beef from beef cattle

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific data
Methane (CH_4)	Enteric fermentation	FR	785.8	No (DE value used)
Methane (CH_4)	Manure management	FR	47.1	No (AGRI-FOOTPRINT value used)
Nitrous oxide (N_2O)	Manure management	FR	2.7	No (DE value used)
Ammonia (NH_3)	Manure management	FR	87.1	No (DE value used)
Fine PM				No
Feed composition	Average feed composition	FR	Fresh grass: 52% Grass silage: 30% Compound feed: 10% Maize silage: 8%	Yes
Feed conversion				No
Land use	At farm	FR	Added land use: 0.02 ha/cow	Yes

Note: Country-specific emissions are not used due to discrepancies, see explanation above.

Feed composition: Fresh grass, grass silage, maize silage, compound feed

Assumptions Beef cattle:
- Since i4ce listed aggregated values for fresh grass and grass silage, we assume that the ratio between fresh grass and grass silage is the same as in the original Agri-footprint process.
- Since the model of compound feed is made up of diverse other processes, there is no average dry matter content listed. We use the dry matter content of barley grain as a proxy for compound feed (87%, Agri-footprint process: 'Barley grain, market mix, at regional storage/RER Economic').
- I4ce lists 2% of 'other fodder'. We model these as grass.

- For German beef cattle, no data on average feed composition were accessible. Therefore, the same feed consumption as in the original Agri-footprint process was used.

The feed composition for the EU was based on a weighted average of the country-specific data available: Ireland and France. The EU market shares for these countries and the weighting factors used for the EU LCA model are shown in Table 23.

Table 23 - Beef market shares of the countries for which specific feed data was available and weighting factors used for determining the average EU feed composition

Country	Market share	Weighting factor EU
France	19%	71%
Ireland	8%	29%

Correction to include veal

Veal is meat from calves. This meat has a lower environmental footprint because the animals are slaughtered at a younger age. The calves mostly come from the dairy sector and are raised to be up to 8 or 12 months old. Definitions of veal differ per country.
For example, in the Netherlands, meat from calves up to 8 months old can be called 'veal', and up to 12 months old can be called 'old veal'. In France, the category 'old veal' is called 'young cattle'. There are different types of veal: white and rose. White veal is from calves slaughtered at an age <8 months who have had a diet low in fibre and iron and therefore the meat is very light-coloured. There are serious animal welfare issues with white veal, but in some countries this meat is very popular. Rose veal comes from calves that had a diet with higher levels of fibre and iron and therefore the meat is darker coloured.

There is quite some import and export of live calves between EU countries and therefore numbers of production (slaughter) or consumption within a country is not directly related to the amount of calves living in a country. Good statistics about the veal sector per country are lacking, because of the im- and export, and because veal is often grouped within a larger category of 'beef including veal', or if reported as a separate category, definitions differ per country (as discussed above). Statistics for production in the EU as a whole are more reliable because of this (but still wanting of improvement).

Environmental data of veal is also difficult to come by. A recent study by (Kool, et al., 2020) assessed the environmental impact of different types of veal in the Netherlands through the years, of which results can be used as a reference. In this study, we have not made specific LCA models for veal due to the large data uncertainties, both environmentally and economically. Instead, we have made a correction the 'beef, from beef cattle' numbers using production statistics for veal in the EU as a whole (Euroveal, 2021). In terms of environmental data, we use beef from dairy cows as a proxy for veal. This seems acceptable because:
- our LCA models for dairy cattle are much more robust than the LCA models that we could make for veal (given the lack of data);
- the veal sector and its environmental impact is strongly linked to the dairy sector;

— both climate change and acidification impacts of veal from (Kool, et al., 2020) and this study are comparable[30], and these are the most important indicators for the external costs.

The EU statistics show that around 10-15% of total beef and veal comes from calves and young cattle (Euroveal, 2021). Around 25-30% of beef comes from dairy cattle. That makes that a total of ~40% of meat in the EU comes from, or is strongly linked to the dairy sector (including veal), and ~60% of the meat comes from the beef cattle sector (from bulls, bullocks and heifers). In emission inventories, veal and young cattle are included in statistics for the beef cattle sector. Using that classification, the beef cattle sector produces ~72.5%[31] of the beef, and the dairy sector ~27.5%. The share of veal meat in the total beef sector is therefore 17%[32]. Subsequently, we use the following weighting factors in the average footprint calculations: 83% beef from beef cattle and 17% beef from dairy cattle in the EU. For Germany and France, we use country specific market data on the origin of meat. Table 24 summarizes the results.

Table 24 – Weighting factors for beef incl. veal origin

Origin	EU average	France	Germany
Beef cattle	83%	77%	84%
Dairy cattle	17%	23%	16%

A.1.4 Pork

Changes to original Agri-footprint processes for pork production were made to make these country-specific as far as data allowed. The processes in Agri-footprint are:
— pig meat, at slaughterhouse/NL Economic;
— pig fattening, at farm/NL Economic;
— piglet, at farm/NL Economic.

In addition to the emission data reported in Table 25 and Table 26, the following processes were made country-specific:
— water, unspecified natural origin;
— electricity mix;
— process steam from natural gas.

30 Terrestrial acidification is strongly linked to ammonia, and ammonia is the most dominant emission in the external costs of cattle products. Terrestrial acidification impacts are 95–98 g SO_2-eq./kg veal meat in (Kool, et al., 2020), and in this study 86-124 g SO_2-eq./kg beef from dairy cattle. Climate change impacts are 10.8-13.5 kg CO_2-eq./kg veal meat in (Kool, et al., 2020), and in this study 7.4–8.3 kg CO_2-eq./kg beef from dairy cattle. Climate change numbers are in the same order of magnitude, but may be slightly underestimated by using beef from dairy cattle as a proxy, which is therefore a conservative approach.

31 60% (bulls, bullocks and heifers) + 12.5% (veal and young cattle).

32 12.5% (veal and young cattle)/72.5% (bulls, bullocks, heifers, veal and young cattle).

Table 25 - EU data for the production of 22,768.3 kton pork produced yearly in the EU

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific data
Methane (CH_4)	Enteric fermentation	EU	168.3	Yes
Methane (CH_4)	Manure management	EU	697.3	Yes
Nitrous oxide (N_2O)	Manure management	EU	7.55	Yes
Ammonia (NH_3)	Manure management	EU	384.6	Yes
PM				No
Feed composition				No
Feed conversion				No

Table 26 - German data provided by Ecologic for 4,726 kton cwe pork produced yearly in Germany

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific
Methane (CH_4)	Enteric fermentation	DE	17.7	Yes
Methane (CH_4)	Manure management	DE	70.6	Yes
Nitrous oxide (N_2O)	Manure management	DE	14.1	Yes
Ammonia (NH_3)	Manure management	DE	65.9	Yes
FPM				No
Feed composition				No
Feed conversion				No

Table 27 shows the results for France:

Table 27 - French data provided by I4CE for 2,274 kton cwe pork produced yearly in France

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific data
Methane (CH_4)	Enteric fermentation	FR	9.8	Yes
Methane (CH_4)	Manure management	FR	55.2	Yes
Nitrous oxide (N_2O)	Manure management	FR	0.1	Yes
Ammonia (NH_3)	Manure management	FR	51.9	Yes/No[a]
FPM				No
Feed composition				No
Feed conversion				No

[a] Ammonia emissions are modelled country specific, but using emission data from the Informative Inventory Report 2021 for the year 2019 downloaded from www.citepa.org/fr/ceenu/. This data is more in line with data used for Germany and EU.

For emissions where no country specific data was modelled, Agri-footprint emissions were not adjusted. Economic allocation between meat and by-products is kept the same as original Agri-footprint process

A.1.5 Chicken

Changes to original Agri-footprint processes for chicken production were made to make these country-specific as far as data allowed. The processes in Agri-footprint are:
- chicken meat, at slaughterhouse/IE Economic;
- broiler fattening, at farm/NL Economic;
- one-day-chicken, at farm/NL Economic;
- hatching egg, at farm/NL Economic;
- broiler parents <20 weeks, at farm/NL Economic;
- broiler parents >20 weeks, at farm/NL Economic.

In addition to the emission data reported in Table 28-Table 30, the following processes were made country-specific:
- water, unspecified natural origin;
- electricity mix;
- process steam from natural gas.

EU data on methane and nitrous oxide could not be separated between broilers and laying hens. In order to fill this data gap, we used the most conservative numbers in our dataset as proxy, which in this case are the numbers from France.

Table 28 - EU data for the production of 13,542 kton chicken meat produced yearly in the EU

Parameter	Parameter specification	Region	In kton/year	Modelled country-specific data
Methane (CH_4)	Manure management	EU		No, FR used
Methane (CH_4)	Enteric fermentation	EU		
Nitrous oxide (N_2O)	Manure management	EU		No, FR used
Ammonia (NH_3)	Manure management	EU	153.14	Yes
PM				No
Feed composition				No
Feed conversion				No

Table 29 - German data provided by Ecologic for 1,379 kton cwe chicken produced yearly in Germany

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific
Methane (CH_4)	Manure management	DE	2.0	Yes
Methane (CH_4)	Enteric fermentation	DE	No data	No
Nitrous oxide (N_2O)	Manure management	DE	1.0	Yes/No[a]
Ammonia (NH_3)	Manure management	DE	12.3	Yes
PM				No
Feed composition				No
Feed conversion				No

[a] Used this value, but added the standard indirect emission factor of N_2O as reported in Agri-footprint to this, because otherwise the N_2O emissions would be 20 times lower than in FR, which seems unrealistic.

Table 30 - French data provided by I4CE for 1,180 kton cwe chicken produced yearly in France

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific data
Methane (CH_4)	Manure management	FR	8.0	Yes
Methane (CH_4)	Enteric fermentation	FR	No data	No
Nitrous oxide (N_2O)	Manure management	FR	0.21	Yes
Ammonia (NH_3)	Manure management	FR	35.1	Yes/no[a]
PM				No
Feed composition				No
Feed conversion				No

[a] Ammonia emissions are modelled country specific, but using emission data from the Informative Inventory Report 2021 for the year 2019 downloaded from https://www.citepa.org/fr/ceenu/. This data is more in line with data used for Germany and EU.

For emissions where no country specific data was modelled, Agri-footprint emissions were not adjusted. Economic allocation between meat and by-products is kept the same as original Agri-footprint process

A.1.6 Beef and milk from dairy cattle

Changes to original Agri-footprint processes for milk and beef from dairy cattle production were made to make these country-specific as far as data allowed. The processes in Agri-footprint are:
- milk standardised (full fat), at farm/NL Economic;
- dairy cow, at farm/NL Economic;
- beef meat, fresh, from dairy cattle at slaughterhouse/NL Economic.

In addition to the emission data reported in Table 31, the following processes were made country-specific:
- water, unspecified natural origin;
- electricity mix;
- process steam from natural gas.

Table 31 - EU data for the production of 142,194 kton milk produced yearly in the EU

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific data
Methane (CH_4)	Enteric fermentation	EU	2,954.0	Yes
Methane (CH_4)	Manure management	EU	471.2	Yes
Nitrous oxide (N_2O)	Manure management	EU	12.4	Yes
Ammonia (NH_3)	Manure management	EU	358.0	Yes
PM				No
Feed composition	Average feed composition	EU	Fresh grass: 21% Grass silage: 45% Maize silage: 14% Compound feed: 17% Dairy cow wet by-product feed: 3%	Yes
Feed conversion				Yes

Table 32 - German data provided by Ecologic for 33,165 kton milk from dairy cattle produced yearly in Germany

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific
Methane (CH_4)	Enteric fermentation	DE	556.1	Yes
Methane (CH_4)	Manure management	DE	82.6	Yes
Nitrous oxide (N_2O)	Manure management	DE	27.9	Yes
Ammonia (NH_3)	Manure management	DE	50.4	Yes
PM				No
Feed composition	Average feed composition	DE	Fresh grass: 6% Grass silage: 35% Maize silage: 23% Hay: 5% Straw: 3% Compound feed: 24% Dairy cow wet by-product feed: 5%	Yes

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific
Feed conversion				No
Land use			Added land use: 3.05 ha/cow	Yes

Table 33 - French data provided by I4CE for 24,512 kton milk from dairy cattle produced yearly in France

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific data
Methane (CH_4)	Enteric fermentation	FR	434.3	Yes
Methane (CH_4)	Manure management	FR	36.8	Yes
Methane (CH_4)	Manure management	FR	1.4	Yes
Nitrous oxide (N_2O)	Manure management	FR	117.4	Yes/no[a]
Ammonia (NH_3)				No
PM	Average feed composition	FR	Fresh grass: 21% Grass silage: 45% Maize silage: 14% Compound feed: 17% Dairy cow wet by-product feed: 3%	Yes
Feed composition				No

[a] Ammonia emissions are modelled country specific, but using emission data from the Informative Inventory Report 2021 for the year 2019 downloaded from https://www.citepa.org/fr/ceenu/. This data is more in line with data used for Germany and EU.

For emissions where no country specific data was modelled, Agri-footprint emissions were not adjusted. Economic allocation between meat and milk and by-products is kept the same as original Agri-footprint process.

Feed composition: Fresh grass, grass silage, maize silage, compound feed

Assumptions general:

- The same assumptions as for beef cattle were used, plus additional assumptions below.
- Weighted average feed composition (and quantities per unit of milk produced, therefore implicitly also including feed conversion) of the countries from which data was available is used (the Netherlands from Agri-footprint, France and Germany from this study). The weighted average is determined using the EU market shares of these countries.
- The Agri-footprint process lists dairy cow wet by-product feed as a component in the feed mix. I4ce does not list this type of feed. Therefore we model this as compound feed.

Assumptions France:

- I4ce lists a share of straw in the feed mix. The Agri-footprint process for beef cattle does not contain straw. Since straw is not further specified in terms of crop, we model straw as oat straw. We calculated the environmental costs of 1 kg straw from different crops to see if the values differ a lot. If rounded to one decimal, 3 out of 4 round to 0,1 €/kg. Since this shows that the differences are small, this supports the choice to pick one of these crops to model straw. The choice fell on oat straw because its environmental costs are closest to the average of 0,076 €/kg (see Table 34).

Table 34 - Environmental costs of different types of straw

Unit	Barley straw, consumption mix, at feed compound plant/NL Economic	Oat straw, at farm/NL Economic	Rye straw, at farm/NL Economic	Wheat straw, at farm/NL Economic	Average
Euro	0.046	0.084	0.114	0.061	0.076

Assumptions Germany:

- Data for feed composition are mostly given in a higher level of detail than needed in the available resources, such as (Thünen, 2021). Feed requirements are split in sub-categories of nutrients instead of feed type. For dairy cattle, (Thünen, 2021) does provide feed mixes for four different dairy cattle farm systems. These farming systems are distinguished by source of feed, amongst which grazing and no grazing. The share in which every of these farming systems is present in Germany is not mentioned. Therefore we use (Bundesinformationszentrum Landwirtschaft, 2022), stating that 31% of Germany's dairy cows grazes for at least 6 months a year. Therefore, we assume that the two farming systems with grazing make op 31% together, and that the two farming systems without grazing make up 69% together. Those shares we divide equally among the faming systems within this share 31% / 2 = 15,5% and 69% / 2 = 34.5%. With these shares we calculate a weighted average feed mix for dairy cattle in Germany (see Table 36).

- Ecologic lists a share of hay in the feed mix. The Agri-footprint process does not contain hay. We add an Ecoinvent process: Hay, Swiss integrated production, intensive {CH}| market for hay, Swiss integrated production, intensive | Cut-off, U. (Agri-footprint has no hay process).

Table 35 - German dairy farming systems and assumptions for shares in total number of dairy farms

Abbreviation for farming system	Farming system	Assumption for share in total dairy farms		Explanation
GW14, dc	Grassland farm with grazing	15.50%	31.00%	31% of all German dairy cows on average graze 6 months/year (Bundesinformationszentrum Landwirtschaft, 2022).
FW14, dc	Forage production farm with grazing	15.50%		
GN14, dc	Grassland farm , no grazing	34.50%	69.00%	We assume that the rest (100-31%) do not graze.
FN14, dc	Forage production farm no grazing	34.50%		Assumption because no data: half the dairy cows live on grassland farms, the other half on forage producing farms.

Table 36 – German assumptions for feed composition of dairy cattle

	Component in feed mix	GW14, dc (%)	GN14, dc (%)	FW14, dc (%)	FN14, dc (%)	Sum=share in feed composition (%)	
Roughage	Pasture grass	3.30	0.00	2.39	0.00	5.69	6%
	Grass silage	5.43	16.22	3.35	9.97	34.96	35%
	Maize silage	1.89	4.17	5.02	11.52	22.61	23%
	Hay	0.00	2.62	0.00	2.35	4.97	5%
	Straw	0.59	1.04	0.48	1.04	3.14	3%
Compound feed	Soy/ rapeseed expeller	0.31	0.93	0.74	2.35	4.33	4%
	Wheat/barley	0.62	1.14	0.31	0.69	2.76	3%
	MLF[1]	3.32	6.45	3.15	6.45	19.37	19%
	MLF[1]	0.00	1.83	0.00	0.00	1.83	2%
	Minerals	0.03	0.07	0.06	0.14	0.30	0%
	Total compound feed	4.28	10.42	4.26	9.63	28.59	29%

1 MLF = Milchleistungsfutter: dairy concentrate feed.

Assumptions EU:
The feed composition for the EU was based on a weighted average of the country-specific data available: Germany, France and the Netherlands. The EU market shares for these countries and the weighting factors used for the EU LCA model are shown in Table 34.

Table 37 – Milk market shares of the countries for which specific feed data was available and weighting factors used for determining the average EU feed composition

Country	Market share	Weighting factor EU
Germany	19%	46%
France	15%	35%
the Netherlands	8%	20%

Feed conversion

German and French dairy cows have different average diets with different compositions. This has a relation with productivity. German dairy cows have a higher share of compound feed and lower share of fodder. This has an influence on the productivity and the amount of feed eaten by the cows. The average productivity of German dairy cows is higher than that of French dairy cows.

French dairy cattle is reported to eat 70 kg feed per day, and have an average productivity of 6,800 litres/year.[33] The average milk production of cows in Germany is slightly above 8,000 litres/year.[34] In the LCA model we therefore included the recommended daily feed ration for German cows with a productivity of 8,000 litres/year (Thünen, 2021, p. 134). The recommended crude protein consumption was used to calculate the daily ration for German cows (Meyer, 2005, p. 122). This showed that German cows eat on average around

33 www.filiere-laitiere.fr/en/key-figures/50-facts-about-french-dairy-industry

34 See www.statista.com/statistics/1251626/milk-yield-per-cow-germany/ and www.dairyindustries.com/news/30833/germanys-dairy-market-report/

22.5 kg dm feed per day, as opposed to 24 kg dm per day in France. The feeding regimes were adapted accordingly.
EU average feed conversion is related to the feed composition in the LCA model and therefore the average EU production is also based on the market shares of these countries.

A.1.7 Eggs

Changes to original Agri-footprint processes egg production were made to make these country-specific as far as data allowed. The processes in Agri-footprint are:
- consumption egg, at farm/NL Economic;
- laying hen <17 weeks, at farm/NL Economic.

In addition to the emission data reported in Table 38 and Table 28 – EU data for the production of 13,542 kton chicken meat, the following processes were made country-specific:
- water, unspecified natural origin;
- electricity mix;
- process steam from natural gas.

Table 38 - EU data for 6,306 kton eggs produced yearly in the EU

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific data
Methane (CH_4)	Manure management	EU		No, DE taken as Proxy
Nitrous oxide (N_2O)	Manure management	EU		No, FR taken
Ammonia (NH_3)	Manure management	EU	69	Yes
PM				No
Feed composition				No
Feed conversion				No

EU data on methane and nitrous oxide could not be separated between broilers and laying hens. In order to fill this data gap, we used the most conservative numbers in our dataset as proxy, which in this case was France for N_2O and Germany for CH_4.

Table 39 - German data provided by Ecologic for 977 kton eggs produced yearly in Germany

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific
Methane (CH_4)	Manure management	DE	2.4	Yes
Nitrous oxide (N_2O)	Manure management	DE	1	Yes/No[a]
Ammonia (NH_3)	Manure management	DE	7.9	Yes
PM				No
Feed composition				No
Feed conversion				No

[a] Used this value, but added the standard indirect emission factor of N_2O as reported in Agri-footprint to this, because otherwise the N_2O emissions would be 10x lower than in FR, which seems unrealistic.

For France the following data were used for eggs production:

Table 40 – French data provided by I4CE for 892 kton eggs produced yearly in France

Parameter	Parameter specification	Country	In kton/year	Modelled country-specific data
Methane (CH_4)	Manure management	FR	2.3	Yes
Nitrous oxide (N_2O)	Manure management	FR	0.9	Yes
Ammonia (NH_3)	Manure management	FR	20.6	Yes/no[a]
PM				No
Feed composition				No
Feed conversion				No

[a] Ammonia emissions are modelled country specific, but using emission data from the Informative Inventory Report 2021 for the year 2019 downloaded from https://www.citepa.org/fr/ceenu/. This data is more in line with data used for Germany and EU.

For emissions where no country specific data was modelled, Agri-footprint emissions were not adjusted. Economic allocation between meat and by-products is kept the same as original Agri-footprint process

A.1.8 General assumptions

Conversion factors

- Milk density: 1.03 kg/l (FAO, 2012).
- Weight of an egg: we use 61.5 g (Agri-footprint V.5). We checked if this weight for eggs used by AgriFootprint applies to the French situation. 61.5 g falls into the middle of the range that the French authorities list as weight for a medium French egg: 53-63 g (Ministère de léconomie des finances et de la France, 2022).

Live weight, carcass weight (ccw), retail weight equivalent (rwe)

Data on yearly meat production were given in carcass weight (ccw). Direct emissions during animal production happen while animals are alive. To enter the emissions correctly into the models for animal production, we calculate the live weight based on carcass weight and carcass yield.

Definitions carcass weight per animal follows the definition of Eurostat and depends on the animal species under consideration (Eurostat, 2019).

- For pigs it is the weight of the slaughtered pig's cold body, either whole or divided in half along the mid-line, after being bled and eviscerated and after removal of the tongue, bristles, hooves, genitalia, flare fat, kidneys and diaphragm.
- For cattle it is the weight of the slaughtered animal's cold body after being skinned, bled and eviscerated, and after removal of the external genitalia, the limbs, the head, the tail, the kidneys and kidney fats, and the udder.
- For poultry it is the weight of the cold body of the slaughtered farmyard poultry after being bled, plucked and eviscerated. The weight includes poultry offal, with the exception of foie gras.

The calculated emissions per kg product are highly sensitive to carcass yield/ dressing percentage. There is uncertainty in the value to be used as carcass yield because different literature resources contain different values. No reference was found that states typical, widely used values. See the yellow rows in Table 41 for values for carcass yield and references that were used in this study. We preferably selected values from references that are representative for the EU and that are produced by public authorities. In the references we used, no definitions for carcass yield are given, but we are confident to assume that the definitions from (Eurostat, 2019) apply because all references are either published by the European Commission or in the context of a study where the geographical scope is the EU (for chicken). For beef we used the carcass yield of fattened young store cattle, published by the European Commission's Meat Market Observatory (85%) (see Table 41).US-American studies use USDA Economic Research Service data (62%) (see Table 41).

Table 41 – Carcass yields

Animal	Carcass yield	Reference	Remarks
Beef, beef cattle not used	60%	1	Canadian source
Beef, beef cattle not used	53%	2	Beef calves intensive fattening
Beef, beef cattle	58%	3	Fattening of young store cattle
Beef, beef cattle not used	62%	4	USDA-ERS, US source
Beef, dairy cattle	58%	5	Fattening of young store cattle
Pork	78%	6	
Chicken not used	65.70%	7	Lowest value found (Control group of the study)
Chicken not used	73%	8	Medium value
Chicken not used	76.60%	9	Highest value found, in two sources
Chicken	70%	10	Used by WUR

Note: Yellow rows: values that are used in this study.

	References Table 41
1	(Dyer, et al., 2010)
2	(European Commission, 2022)
3	(European Commission, 2022)
4	(Asem-Hiablie, et al., 2019) (USDA, 2012)
5	(European Commission, 2022) https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/methodology-beef-remainders_en.pdf
6	(European Commission, 2022)
7	(de Jong, et al., 2014),P.12
8	(Fanatico, et al., 2008)
9	(Fanatico, et al., 2008)
10	(van Horne & Bondt, 2013) https://edepot.wur.nl/292607

Allocation meat from dairy cattle

This assumption states how much of the impact of a dairy cow we allocate to meat and how much we allocate to milk. We assume that only cows that are not suitable for milk production due to age or illness are used for meat (= spent dairy cattle). These are breeds that are optimised for milk production.

Economic allocation in Agri-footprint (Dutch data):
- raw milk: 92.2%;
- cows for slaughter: 5.2%;
- calves: 2.6%.

Model for system of milk and dairy cows for slaughter

We use the Dutch Agri-footprint-dataset as a base for the milk system. The ratios between the amounts of milk outputs and beef (from dairy cattle) outputs differ per country. For example: in Germany there is less dairy cattle beef output per kg milk output than in the Netherlands. We model this as follows. The model is set up for milk, therefore we enter total emissions of the dairy cattle system into the model as emissions for the total amount of milk. Dairy cows for slaughter (in kg live weight) are included in the model as a co-product of the milk system. For now we use the same ratio beef to milk as the Agri-footprint processes.

Dairy cattle: emissions of peat land

We use the Dutch Agri-footprint-dataset as a base for the milk system. In the Dutch dairy system, emissions from peatland are included. The average Dutch system may include more peatland than the French and German system. We checked the sensitivity of the result to this assumption: emissions from peatland contribute to the total emissions to a negligible extent.

Pork: emissions include piglet breeding and fattening

In the Agri-footprint models, the upbringing of piglets and fattening of pigs are modelled as separate processes. Since the emission data that i4ce and Ecologic provided comprise direct emissions related to the total animal production system, we model these emissions as if they were all emitted during pig fattening. Therefore, these emissions are set to zero in the model for piglet upbringing. The other supply chain inputs and emissions for piglet upbringing are still included in the model at the piglet stage.

A.2 Modelling of organic agriculture systems

This Annex includes the scope and method for including organic agriculture in the LCA models and therewith in the environmental prices.

A.2.1 Feed: rules and consequences in organic agriculture that were included in the models

In this section we describe which rules apply to feed and its production in organic animal farming systems, and which changes we applied in the LCA models to represent these organic agriculture practices.

The most important differences identified are:
- sourcing/location;
- pesticide use;
- manure and artificial fertilizer use;
- yields.

We applied a 80/20 rule in adapting the LCA models, as adapting the full LCA models would costs enormous amounts of time. We took the following steps:
- Identify the five most important compound feed components of all animals, which were:
  - soybeans (and soybean-derived products such as meal);
  - wheat;
  - barley;
  - maize;
  - rapeseed.
- Additionally, we identified the three most important fodder feed crops (for beef and dairy cattle), which were:
  - fresh grass;
  - grass silage;
  - maize silage.

For these eight components, we created country-specific organic processes for both France and Germany using the rules and assumptions that are listed hereafter.

Sourcing of feed

60% of all feed in organic systems must be sourced from the same farm, or if not possible from the region. We assume that the country of production is the region. Max. 40% of the feed can come from outside the region. If a crop is grown in substantial amounts in the country itself, we assume this to be grown and sourced locally. We assume that the 40% of the feed that can come from outside of Europe are soybeans, since these are mostly from China in organic animal agriculture (bionext, 2022).

Organic crop production – no pesticides

No pesticides may be applied in organic agriculture systems. We therefore removed all pesticides and pesticide-related emissions from the LCA models.

Organic crop production – no artificial fertilizer and restricted manure application

No artificial fertilizer may be applied in organic agriculture. We removed all inputs of artificial fertilizers and their associated on-field emissions in the Agri-footprint models so they reflect this rule.

To compensate for removing the artificial fertilizers from the LCA models, we increased the amount of animal manure and its associated on-field emissions. The rules for organic agriculture allow a maximum nitrogen application of 170 kg N/ha/year from animal manure. This is the same as conventional EU rules for application of N from manure. Practical advised application rates in organic agriculture are around 160 kg N/ha/year for fodder crops like maize and rapeseed (Vermeij, et al., 2012) (Commissie Bemesting Grasland en Voedergewassen, 2021). In the LCA models for feed crops, we have increased manure application levels and associated field emissions in European cultivation to 160 kg

N/ha/year if total N-application (both synthetic and from animal manure) in the original (conventional agriculture) LCA process was 160 kg N/ha/year or higher, which is often the case in conventional EU agriculture.[35] If total N applied in the conventional process was lower than 160 kg N/ha/y, the total N-application reported was delivered in the form of animal manure. This is for example the case in China (important for soybean cultivation), where N-application levels are lower than 160 kg N/ha/year (and yields subsequently are lower, too). The N-limit in organic farming is additionally important in countries that avail of derogation, allowing N-application from animal manure up to 250 kg N/ha/year, such as the Netherlands.

Another adaptation to the models related to following from fertilization relates to heavy metals emissions. Heavy metals emissions originate from both artificial fertilizer and manure. Total fertilization rates in organic agriculture are lower, so in Agri-footprint we set all heavy metal emissions at 50% to reflect this.

Organic crop production – yield gap

Yields are lower on average for organic agriculture. This gap is larger in highly industrialised countries where conventional yields are optimised with the help of artificial fertilizers and pesticides. Once the use of those substances is omitted, yields drop further than in systems that were less optimized in the first place. Land use and land cultivation-related impacts such as agricultural machines are higher per kg crop yield accordingly for organic agriculture. Yield gaps are mainly determined using (de Ponti, et al., 2012). For wheat, corn, barley and soybeans, yield gaps are determined based on the current yields in the Agri-footprint database and Figure 2 from de Ponti et al. (2012). Monoculture grass and maize silage are not reported in de Ponti et al. (2012). Therefore, for maize silage, average yield gaps from 'other fodder crops' are taken as a proxy.

For grass (and grass silage) we modelled specific yield gap for different fertilization rates based on (Commissie Bemesting Grasland en Voedergewassen, 2021). This reports a yield gap of 20% when applying 160 kg N/ha/y instead of 400 kg N/ha/y.[36]
A summary of yield gaps used in this study is shown in Table 42.

Table 42 - Yield gaps in organic agriculture (compared to conventional agriculture) used in this study

Feed crop	Yield gap
Soybeans	0% (due to low yields of conventional soybeans in Agri-footprint model for China)
Wheat	35% (DE); 25% (FR)
Barley	31%
Maize	11%
Rapeseed	18%
Fresh grass	20%
Grass silage	20%
Maize silage	15%

35 N-content of various animal manures were taken from www.rvo.nl/sites/default/files/2018/01/Tabel-5-Forfaitaire-stikstof-en-fosfaatgehalten-in-dierlijke-mest-2018.pdf

36 This yield gap is higher than the 11% reported in (de Ponti, et al., 2012).

Organic soy production – land use change

There are some land use change rules for organic produce under the international certification body IFOAM.[37] However, most organic soy in the EU comes from China and deforestation is currently not an issue in soy production there.[38]

A.2.2 Animal farming: differences at animal farms that were included in the models

Feed conversion to model higher land use per animal, more movement and longer life time of animals

Animals in organic production systems live longer, and have more space to move around. A longer life and more physical movement leads to more feed input per kg of animal product. More feed means more indirect land use per animal. Direct increased land use through larger space per animal in the stable is excluded as this is marginal compared to the feed land use. The feed-input per kg of animal product is expressed as feed conversion ratio (FCR). Differences in feed conversion efficiency and feed composition are taken from (Gaudaré, et al., 2020) and (van Wagenberg, et al., 2017). In chicken and pig systems, there is not much difference in feed composition. However on average, per unit of product 4.5% more feed is needed for organic pig systems, 46.5% for broilers and 17% for laying hens.[39]

No information could be found on changes in feed composition or feed conversion for organic beef cattle. As the average beef cattle systems considered in this study are relatively extensive, they are considered comparable to organic systems. As there are no additional rules for e.g. slaughtering age of beef cattle, we assume the same life span and same feed conversion efficiency. Comparing the slaughtering age in Ireland (which is also the basis for the Agri-footprint LCA model for beef), shows that there is no significant difference in slaughter age: 22–27 months for organic beef cattle versus an average of 24 months in Agri-footprint (33 months if the adult suckler cows are included in the calculation).[40]

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37 See www.ifoam.bio/sites/default/files/2020-04/ifoam_norms_version_july_2014.pdf

38 As reported in Agri-footprint, which makes use of the Blonk direct land use change assessment tool: www.blonksustainability.nl/news/update-of-the-blonk-direct-land-use-change-assessment-tool

39 Production reduction of egg farming systems can also be expressed in loss in egg production instead of an increase in feed demand. According to (van Wagenberg, et al., 2017) decrease in egg production is on average 7%. This refers to all input for egg farming, such as feed, new laying hens, energy and heat. However, it is not clear how egg production is expressed (per laying hen, per m^2, or per year). Since the interpretation of egg productivity is unclear, and feed is the input that largely determines the environmental impacts of animal products, we stick to using feed conversion to model the lower productivity. This is in line with the approach for all other animal products). This results in a conservative approach, since an increase of 17% in feed demand for the same amount of outputs causes a bigger change than a 7% decrease in outputs for the same amount of inputs.

40 See www.farmersjournal.ie/organic-beef-how-do-cattle-perform-702869, www.agriland.ie/farming-news/beef-focus-i-just-find-the-organic-system-to-be-a-more-natural-way-of-farming/ and www.independent.ie/business/farming/beef/fury-at-plan-to-reduce-age-of-cattle-slaughter-41054902.html

Feed composition

Feed composition is assumed to be the same as in conventional systems for beef cattle, pigs, and chickens.

For dairy cattle, the average feed in the EU, Australia and New Zealand is composed of a higher percentage forage (grass, grass silage and maize silage 76 instead of 60%) and lower percentage compound feed (24 instead of 40%) (Gaudaré, et al., 2020). According to the data received in this study, the fodder percentage in France is already higher than 76%, which indicates more extensive farming methods. Therefore, no changes are made regarding feed composition and quantity, and direct emissions following from a different diet (increased methane emissions due to higher fodder percentage) and more extensive farming (reduced ammonia from increased time in pasture). In Germany, the fodder percentage is lower than 76% and therefore this is raised to 76% in the LCA model for organic production in Germany. Due to the lower compound feed use in Germany, the productivity of the cows is lower and on average, 10% more feed is needed to produce the same amount of milk (Gaudaré, et al., 2020). Increased forage percentage also leads to estimated increased methane emissions from enteric fermentation of 9.6% (based on the trials using dry matter intake as shown in Table 4 in (Aguerre, et al., 2011), diets composition 61:39 and 68:32).

Direct emissions

Lower ammonia emissions occur in organic animal farming systems due to increased outdoor grazing. Dairy cattle has increased outdoor grazing time. According to (Smolders & Plomp, 2012) the average outdoor grazing of Dutch dairy cattle is 3,300 hours. Conventional dairy cattle outdoor grazing is 1,780 hours on average (Hoving, et al., 2014). Every hour of additional outdoor grazing reduces ammonia emissions by 3.3 grams (Hoving, et al., 2014) and therefore ammonia emissions are reduced by 5.02 kg NH_3/animal/year. As no data has been found regarding differences in outdoor grazing between conventional and organic beef cattle, and the modelled beef cattle process already includes >200 days of outdoor grazing, no ammonia reductions are assumed for organic beef cattle.

Increased life span

We assumed differences in feed conversion efficiency to be representative of increased life span of meat animals. I.e. if 1.5 times more feed is needed, we assume the animals lives 1.5 times longer, as we assume a linear relation. Therefore direct emissions (ammonia, etc.) are also increased by the same percentage. This is an imperfect approach, but best available by lack of better data about life span.

A.2.3 Limitations of the LCA method with respect to organic agriculture

Some of the benefits of organic agriculture compared to conventional agriculture are reduced pesticides (residues and run-off to the environment), support for local biodiversity (among which pollinators), improved soil health, more ecosystem functions (e.g. water retention) and improved animal welfare (Milieucentraal, 2022; Van der Werf, et al., 2020; Consumentenbond, 2018).

Some of these beneficial effects cannot yet be captured by current LCA methodology and databases. The LCA methodology was originally designed for industrial products, rather than food. As such, LCA studies focus on the impacts per unit of a product (such as the impact per kg of food). In current LCA studies with a focus on impacts per unit of product, three main factors are underrepresented or not taken into account at all (Van der Werf, et al., 2020):

- a lack of operational indicators for three key environmental issues: land degradation (e.g. soil quality), biodiversity losses, pesticide effects;
- a narrow perspective on functions of agricultural systems (e.g. support of pollinators);
- inconsistent modelling of indirect effects, such as (importantly) land use effects and land use changes.

Because the yields of intensive agriculture systems are higher than the yields of organic agriculture, this means the impact per kg of agriculture product can be higher for organic food. However, if broader system impacts and previously discussed local impacts are left out of the equation, this does not yield the full picture of sustainability. Organic agriculture often has a beneficial effect on local soil, local climate and local ecosystem characteristics, compared to intensive agriculture. As a result, the impacts per unit of land occupied and the impacts on the entire local system (for example on the biodiversity of neighbouring natural areas) is often lower for organic agriculture (Van der Werf, et al., 2020; Milieucentraal, 2022; Pré Sustainability, 2016).
Currently, biodiversity impacts are predominantly being measured based on direct land use, which is not suitable for the comparison of different production systems (Van der Werf, et al., 2020).

These points should be remembered when interpreting LCA results. One form of agriculture is not by definition better than the other, as there are different trade-offs between the two systems.

B LCA results

Environmental impact results (ReCiPe Midpoint 1.13)

Table 43-Table 45 show the midpoint environmental impact results from the LCA models for EU, France and Germany for conventional animal products.

Table 43 - Environmental impacts (midpoints) per kg of animal product in EU27

Impact category	Unit	Beef Beef cattle incl. veal	Beef Dairy cattle	Pork	Chicken	Egg	Milk (standardised full fat)	Cheese (Gouda)
Climate change	kg CO_2-eq.	31.42	8.31	6.17	5.87	3.00	1.25	10.06
Ozone depletion	kg CFC-11 eq.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial acidification and eutrofication	kg SO_2-eq.	0.87	0.17	0.13	0.07	0.06	0.03	0.21
Freshwater eutrophication	kg P-eq.	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Marine eutrophication	kg N-eq.	0.45	0.08	0.04	0.02	0.02	0.01	0.09
Human toxicity	kg 1,4-DB-eq.	1.16	0.25	0.26	0.15	0.10	0.04	0.30
Photochemical oxidant formation	kg NMVOC	0.03	0.01	0.01	0.01	0.00	0.00	0.01
Particulate matter formation	kg PM_{10}-eq.	0.09	0.02	0.01	0.01	0.01	0.00	0.02
Terrestrial ecotoxicity	kg 1,4-DB-eq.	0.05	0.02	0.04	0.03	0.02	0.00	0.02
Freshwater ecotoxicity	kg 1,4-DB-eq.	0.01	0.01	0.01	0.01	0.01	0.00	0.01
Marine ecotoxicity	kg 1,4-DB-eq.	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Ionising radiation	kBq U235-eq.	0.24	0.15	0.14	0.10	0.07	0.02	0.15
Agricultural land occupation	m^2a	29.57	6.17	7.22	4.51	3.40	0.96	7.36
Urban land occupation	m^2a	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural land transformation	m^2	0.03	0.02	0.03	0.06	0.03	0.00	0.03
Water depletion	m^3	0.16	0.05	0.05	0.07	0.08	0.01	0.05
Metal depletion	kg Fe-eq.	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Fossil depletion	kg oil-eq.	1.74	0.53	0.55	0.43	0.27	0.08	0.65

Table 44 - Environmental impacts (midpoints) per kg of conventional animal product in Germany

Impact category	Unit	Beef Beef cattle incl. veal	Beef Dairy cattle	Pork	Chicken	Egg	Milk	Cheese
Climate change	kg CO_2-eq.	29.17	7.41	5.47	5.05	2.73	1.11	8.97
Ozone depletion	kg CFC-11 eq.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial acidification and eutrofication	kg SO_2-eq.	0.87	0.13	0.13	0.06	0.05	0.02	0.15
Freshwater eutrophication	kg P-eq.	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Marine eutrophication	kg N-eq.	0.44	0.06	0.04	0.02	0.02	0.01	0.07
Human toxicity	kg 1,4-DB-eq.	1.15	0.22	0.25	0.15	0.10	0.03	0.27
Photochemical oxidant formation	kg NMVOC	0.03	0.01	0.01	0.01	0.00	0.00	0.01
Particulate matter formation	kg PM_{10}-eq.	0.09	0.01	0.01	0.01	0.01	0.00	0.02
Terrestrial ecotoxicity	kg 1,4-DB-eq.	0.07	0.02	0.04	0.04	0.03	0.00	0.03
Freshwater ecotoxicity	kg 1,4-DB-eq.	0.02	0.01	0.01	0.01	0.01	0.00	0.01
Marine ecotoxicity	kg 1,4-DB-eq.	0.01	0.01	0.00	0.00	0.00	0.00	0.01
Ionising radiation	kBq U235-eq.	0.23	0.14	0.12	0.09	0.06	0.02	0.14
Agricultural land occupation	m^2a	30.23	5.52	6.59	3.87	2.85	0.86	6.58
Urban land occupation	m^2a	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural land transformation	m^2	0.03	0.02	0.03	0.05	0.02	0.00	0.02
Water depletion	m^3	0.22	0.06	0.07	0.03	0.03	0.01	0.08
Metal depletion	kg Fe-eq.	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Fossil depletion	kg oil-eq.	1.79	0.53	0.53	0.41	0.25	0.08	0.64

Table 45 - Environmental impacts (midpoints) per kg of conventional animal product in France

Impact category	Unit	Beef Beef cattle incl. veal	Beef Dairy cattle	Pork	Chicken	Egg	Milk	Cheese
Climate change	kg CO_2-eq.	27.08	7.68	5.48	5.51	2.90	1.17	9.39
Ozone depletion	kg CFC-11 eq.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial acidification and eutrofication	kg SO_2-eq.	0.90	0.18	0.12	0.09	0.05	0.03	0.21
Freshwater eutrophication	kg P-eq.	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Marine eutrophication	kg N-eq.	0.44	0.09	0.04	0.02	0.02	0.01	0.11
Human toxicity	kg 1,4-DB-eq.	1.05	0.25	0.24	0.15	0.10	0.04	0.30

Impact category	Unit	Beef Beef cattle incl. veal	Beef Dairy cattle	Pork	Chicken	Egg	Milk	Cheese
Photochemical oxidant formation	kg NMVOC	0.03	0.01	0.01	0.01	0.00	0.00	0.01
Particulate matter formation	kg PM_{10}-eq.	0.09	0.02	0.01	0.01	0.01	0.00	0.02
Terrestrial ecotoxicity	kg 1,4-DB-eq.	0.04	0.02	0.03	0.03	0.02	0.00	0.02
Freshwater ecotoxicity	kg 1,4-DB-eq.	0.01	0.00	0.01	0.01	0.01	0.00	0.01
Marine ecotoxicity	kg 1,4-DB-eq.	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Ionising radiation	kBq U235-eq.	0.49	0.31	0.30	0.22	0.14	0.03	0.30
Agricultural land occupation	m^2a	28.94	6.83	6.95	4.36	3.12	1.06	8.15
Urban land occupation	m^2a	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural land transformation	m^2	0.02	0.02	0.03	0.05	0.02	0.00	0.02
Water depletion	m^3	0.29	0.08	0.07	0.08	0.09	0.01	0.09
Metal depletion	kg Fe-eq.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fossil depletion	kg oil-eq.	1.56	0.46	0.45	0.36	0.21	0.07	0.59

Table 46 shows the EU27 midpoint environmental impact results from the LCA models for organic animal products.

Table 46 - Environmental impacts (midpoints) per kg of organic **animal product in** the EU

Impact category	Unit	Beef Beef cattle incl. veal	Beef Dairy cattle	Pork	Chicken	Eggs	Milk	Cheese
Climate change	kg CO_2-eq.	31.42	8.31	6.17	5.87	3,00	1,25	10,06
Ozone depletion	kg CFC-11 eq.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial acidification and eutrofication	kg SO_2-eq.	0.87	0.17	0.13	0.07	0.06	0.03	0.21
Freshwater eutrophication	kg P-eq.	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Marine eutrophication	kg N-eq.	0.45	0.08	0.04	0.02	0.02	0.01	0.09
Human toxicity	kg 1,4-DB-eq.	1.16	0.25	0.26	0.15	0.10	0.04	0.30
Photochemical oxidant formation	kg NMVOC	0.03	0.01	0.01	0.01	0.00	0.00	0.01
Particulate matter formation	kg PM_{10}-eq.	0.09	0.02	0.01	0.01	0.01	0.00	0.02
Terrestrial ecotoxicity	kg 1,4-DB-eq.	0.05	0.02	0.04	0.03	0.02	0.00	0.02
Freshwater ecotoxicity	kg 1,4-DB-eq.	0.01	0.01	0.01	0.01	0.01	0.00	0.01
Marine ecotoxicity	kg 1,4-DB-eq.	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Impact category	Unit	Beef Beef cattle incl. veal	Beef Dairy cattle	Pork	Chicken	Eggs	Milk	Cheese
Ionising radiation	kBq U235-eq.	0.24	0.15	0.14	0.10	0.07	0.02	0.15
Agricultural land occupation	m^2a	29.57	6.17	7.22	4.51	3.40	0.96	7.36
Urban land occupation	m^2a	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural land transformation	m^2	0.03	0.02	0.03	0.06	0.03	0.00	0.03
Water depletion	m^3	0.16	0.05	0.05	0.07	0.08	0.01	0.05
Metal depletion	kg Fe-eq.	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Fossil depletion	kg oil-eq.	1.74	0.53	0.55	0.43	0.27	0.08	0.65

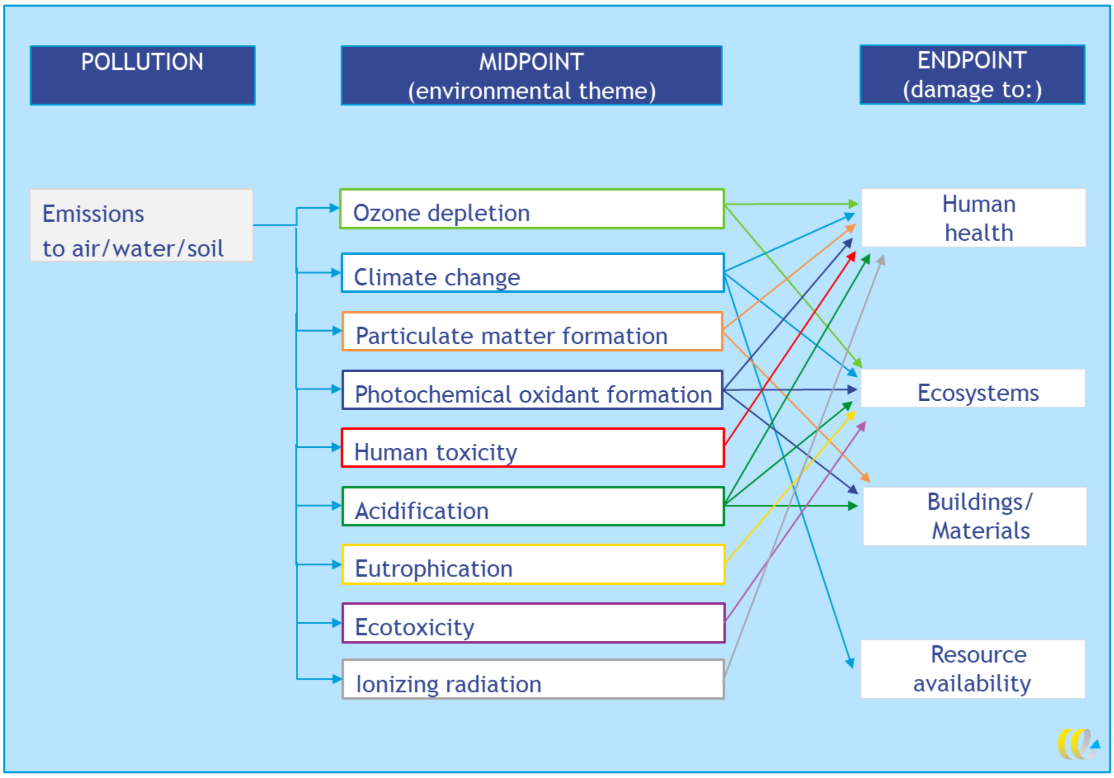
C Economic modelling assumptions

C.1 Environmental prices

Numerous (economic) activities in every-day life cause pollutants as by-products that are emitted to the atmosphere, water and soil. Many of these substances have a negative (direct or indirect) impact on the environment. Environmental scientists distinguish a total of 10 to 20 relevant indicators that together characterise (changes in) the state of the environment. A well-known example is ‘climate change’, to which substances as carbon dioxide (CO_2) and methane (CH_4) contribute. Other indicators are for example ‘human toxicity’, ‘freshwater eutrophication’ and ‘photooxidant formation’. These are referred to as the midpoint impacts of emissions. These changes in the state of the environment are important because they go on to have an ultimate impact, on human health or biodiversity, for example. These latter impacts are known as endpoint impacts.
In environmental science three related levels are thus distinguished: the pollutant level, the midpoint level and the endpoint level.

Figure 6 illustrates the relationship between them.

Figure 6 - Relationship between emissions (at pollutant level) and impacts (at mid- and endpoint levels)



The environmental prices handbooks of CE Delft (CE Delft, 2017) (CE Delft, 2019b) have been based on this relationship between emissions, midpoints and endpoints. Euro values are obtained by attaching monetary values to the endpoints. Below is information how impacts have been obtained in the environmental prices handbook (EPH)

Human Health

In the EPH, the impact on human health (endpoint) is obtained through the midpoints particulate matter formation, smog formation and human toxicity. Emissions are taken up in the human body by breathing, water consumption or food ingestion.

For air pollution, only impacts that have been included in the (WHO, 2013) framework are included in the EPH.[41] Table 47 shows which health effects have (not) been included.
The related social costs comprise:
- Direct (health care) expenditures: hospital admissions, medical treatment costs, loss of working days/production loss at work due to illness.
- indirect health impacts and accompanied welfare loss: discomfort of diseases such as COPD, and increased mortality risk/reduced life expectancy. Ambient air pollution in both cities and rural areas was estimated to cause 4.2 million premature deaths worldwide in 2016 (WHO, 2021).

Table 47 - Included health effects of exposure to NO_2, $PM_{2.5}$ and ozone in the EPH

Concentration of	Caused by emissions of…	Effects proven and included	Effects proven but not included	Effects probable but not included
PM_{10}/$PM_{2.5}$	$PM_{2.5}$ PM_{10} NO_x SO_2 NH_3	All cause mortality (chronic) Infant mortality Work days loss Restricted activity days (minor and net) Chronic bronchitis (COPD) Respiratory hospital admissions Cardiovascular hospital admissions	Non-lethal cancers	Medication use Lower respiratory symptoms Diabetes
Ozone	NMVOC NO_x SO_2 CO CH_4	Acute mortality Respiratory hospital admissions Cardiac hospital admissions Restricted activity days (minor)	COPD Restricted activity days asthmatic children	Chronic mortality Work days loss Non-lethal cancers
NO_2	NO_x	Increased mortality risk (long-term)* Bronchitis in asthmatic children^ Respiratory hospital admissions^		Cardiovascular effects Acute mortality

Source: CE Delft (2020).
Notes: * Impacts calculated using Relative Risks (WHO, 2013) and country-specific incidence rates.
^ Impacts calculated using Concentration Response Functions (CE Delft et al., 2019) using European incidence rates.

41 With the exception of respiratory problems for asthmatic children aged 6-12.

Ecosystems

In addition, there are impacts on ecosystems taken into account in the EPH: loss of biodiversity and impacts on production crops. Both impacts have been valued: impacts on crops using market prices and impacts on biodiversity through the literature. The valuation of biodiversity rests on an analysis on the amount of species on a particular area of land and impacts are defined in terms of PDF (potentially disappearing fraction). The valuation of this indicator PDF is based on a meta-analysis of willingness to pay studies, what people want to pay to protect biodiversity. One should notice that ultimately this is an anthropocentric approach, the real price of biodiversity loss could be much higher, but is hard to calculate. In the 2023 environmental prices handbook, a comparison will be made between the calculation in the handbook and the studies that have attempted to derive a total value of biodiversity on the planet, as have been summarised in (Dasupta, 2021).

Buildings/materials

Valuation of buildings and materials has been done on a literature review. For more information, see Chapter 5 in (CE Delft, 2018b).

C.2 Price elasticities

General

The price elasticity of demand measures the relative increase in sales of a product, following a relative price change of that product. A price elasticity of -1 indicates that a price increase of 10% leads to 10% decrease in demand. The revenue of the product (price times demand) will then decrease by 1% (110%*90%-100%).

CE Delft has compared generally accepted price elasticities in the Netherlands with generally accepted price elasticities in other countries. For comparison we mainly used meta analyses of price elasticities in the US by Andreyeva, et al. (2010), price elasticities in Europe, Australia and North and South America by Gallet (2010), and cross price elasticities in the EU by Wirsenius et al. (2011).

In addition to own-price elasticity (negative sign), cross-price elasticities also play an important role in demand development. Although price increases have a negative effect on the demand for a product (e.g. pork), consumers alleviate their financial burden by switching to the purchase of another product (e.g. chicken). Substitution between products can be measured using the cross price elasticity of demand. The cross price elasticity measures the relative increase in sales of product X, following a relative price change in product Y. A cross price elasticity of 0.5 indicates that, due to substitution of product X for product Y, demand for product X increases by 5% when the price of product Y increases with 10%. However, if, as assumed here, the prices for *all* (or main) animal products increase, only small shifts between the individual products occur as a result of increase in price of the various animal products. This is also concluded by (CE Delft, 2018a).

For selection of price elasticities, we distinguish between pork meat, beef, chicken, and other meat. Various studies show that the price elasticity of demand for beef is considerably high (Mangen & Burrell, 2003). Price elasticity of beef is generally higher than the price elasticities of pork and chicken (Andreyeva, et al., 2010; Gallet, 2010; Wirsenius, et al., 2011). The price elasticity of minced beef is yet higher. Possibly the relatively low price of chicken and pork, compared to beef, makes the consumer less sensitive to price changes for these products.

It is likely that the price elasticity of meat will be lower in the short term than in the long term. The reason for this is that consumers are not always able — or unwilling — to change their behaviour immediately, due to for instance a lack of acceptable alternatives (meat replacements) or a lack of recipes. Given a strong enough incentive, it is likely that in the future, more alternative products will be introduced, which will facilitate consumers in changing their behaviour. This will lead to an increase in price elasticity.

We use uncertainty intervals to determine the price elasticities on the short and long term. These intervals are based on the meta-analysis by Andreyeva et al. (2010). The average value, for the medium long term, is based on various studies (Gallet, 2010; Wirsenius, et al., 2011; Mangen & Burrell, 2003). By consciously selecting conservative values for price elasticities of demand, we can approximate the effects of substation, without needing cross price elasticities.

Table 48 - Price elasticities (short and long term) for the EU and France

Year	Pork	Beef	Minced beef	Chicken
2021	-0.2	-0.3	-0.5	-0.2
2025	-0.6	-0.8	-1	-0.6
2030	-1	-1.2	-1.5	-1

Germany

Additional literature is available for specific price elasticities in the German market. Empirical analyses show that consumers tend to react inelastically to changes in food prices, so that strong demand side changes to individual product prices are generally not to be expected for food products (Jonas & Roosen, 2006; Thiele, 2008).

In their analysis based on the CAPRI model, (Helming & Kuhlman, 2015) analysed the effect of a 7% tax on meat. The projected decreases in meat demand ranged from 2% for poultry to 3.5% for pork. (Springmann, et al., 2018) also estimated the effects of a specific meat tax on consumption using the IMPACT model and arrive at significantly lower effects. Depending on the level of the tax, they determine a reduction in demand for red meat of 0.2% (for a price increase of 4%) or 4% (for a price increase of 28%). On this basis, it can be assumed that the abolition of the sales tax concession for meat and dairy products would lead to a decrease in consumption of 4% for chicken meat, 5% for pork and dairy products and 6% for beef.

(Deblitz, et al., 2021) assume that the increase of the reduced VAT rate for animal-based products from 7 to 19% would lead to a decrease in consumption of 4% for chicken meat, 5% for pork and dairy products and 6% for beef. (Deblitz, et al., 2021) assume that the retailers pass on the VAT increase to consumers.

(Rahbauer, et al., 2018) investigated to what extent the price elasticity of meat and dairy products differs for different groups of people. They found that low-income and younger groups of people have significantly higher price elasticity. This may translate into a decrease in consumption or a shift towards cheaper products. Consumers who buy higher priced products have lower price elasticities.

As meat-based services (restaurants, caterers, canteens) already pay the standard tax rate of 19%, no decrease in consumption is expected here.

Table 49 – Price elasticity of demand for Germany

Year	Pork	Beef	Minced beef	Chicken	Milk, eggs and cheese
Price elasticity	-0.4	-0.5	-0.5	-0.3	-0.4

Conclusion

In the analysis for the EU and France, we use the price elasticities as given in Table 48. For Germany, we have found sufficient literature to further specify price elasticities to the German market. Therefore, we choose values that are based on German literature (Table 49), but they also fall within range of values used in (CE Delft, 2018a) and as used for the analysis on the EU and France.