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Estimating greenhouse gas emissions from food consumption: methods and results

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There is currently a clear consensus neither on the contribution of food to global anthropogenic greenhouse gas (GHG) emissions nor on the share of animal products in global food emissions. Based on a literature review, **we estimate that food consumption is responsible for 13.8 $GtCO_2e$ (±3.6 $GtCO_2e$) in 2010**, *i.e.* 28% of global emissions across all sectors. **The consumption of animal products represents 62% of this amount**, with about 8.5 $GtCO_2eq$ (±2.4 $GtCO_2eq$). Various methods that are not harmonized at the international level can be used to estimate the GHG footprint of food. We describe these methods, their limitations and the different databases available.

SOMMAIRE

According to the Intergovernmental Panel on Climate Change (IPCC)**, the land sector is responsible for just under a quarter of global anthropogenic emissions (10 to 11 GtCO_2eq).** This value covers agricultural production and other lands, but does not cover the transportation, processing or sale of food products. In addition, this figure includes emissions associated with non-food production such as biofuels, paper or cotton. Several estimates of the global footprint of food consumption have been attempted, but their results do not always converge. These discrepancies are due to a lack of harmonization of consumption-based accounting methods.

Greenhouse gas (GHG) emissions are generally estimated via **two main families of approaches**:

The ***top-down* approaches** – or **by the atmosphere** – estimate concentrations of different GHGs directly in the atmosphere. Using top-down approaches alone, it is not possible to attribute quantities of GHGs to specific sources or sinks. For example, one cannot accurately allocate quantities of carbon dioxide (CO_2) to a set of industrial installations or vehicles in a given territory. For this reason, top-down approach will not be treated in this study.

- ***Bottom-up* approaches** – or **inventories** – consist in multiplying activity data with corresponding emissions or sink factors. For example, we can estimate the GHG emissions of the French road sector by multiplying the number of kilometers traveled by the average amount of CO_2 emitted by a road vehicle. The reliability of this approach depends on the extent of knowledge on emission processes – in our example the CO_2 emission process by road vehicles – or GHG sinks. The results of this method are therefore characterized by an uncertainty that is not always easy to estimate (Montzka, Dlugokencky, and Butler 2011).

Bottom-up methods can be divided into two broad approaches of GHG emissions accounting, the choice of which depends on the goal pursued:

- **Production-based** accounting methods allow an inventory of the different sources and sinks of emissions in a given territory: factories, forests, livestock, etc. Most national climate change mitigation policies are based on results of this approach. This method is also employed in international climate negotiations to determine countries' Nationally determined Contributions (NDCs). Countries borders are therefore chosen to allocate responsibility into global GHG emissions.
- **Consumption-based** accounting methods measure the GHG emissions generated a population through the goods and services it consumes. By focusing on the end-use of consumers, these approaches internalize the trade in GHG emissions embedded in the trade of goods and services. The responsibility is therefore allocated to consumers rather than to territories.

Unlike production-based approaches, consumption-based accounting methods are not harmonized. This often results in different orders of magnitude of varying reliability for the same source of emission. The objective of this study is to identify the challenges of food consumption emission accounting, to detail the methods used in the literature, and to clarify their results.

BOX 1. GHG EMISSIONS OF THE LAND SECTOR ARE HIGHLY UNCERTAIN

Whether for production or consumption approaches, estimates of GHG emissions from the agricultural sector and LULUCF are particularly uncertain. Estimates of emissions generated by agricultural crop or livestock production have an uncertainty of about ±30%, and the LULUCF sector of ±50%. In comparison, CO_2 emissions from burning fossil fuels have an uncertainty of about 10% (Francesco N. Tubiello *et al.* 2015).

1. Production-based inventory

The purpose of production-based inventories is to **record the emissions generated in a given territory, wherever the products and services of that territory are consumed**. The results of this approach are mainly those used in climate negotiations and the most frequently cited. They are however by construction insufficient to estimate the GHG footprint of food.

Unlike other bottom-up **approaches**, **the production-based approach is internationally harmonized.** The most trusted database is the United Nations Framework Convention on Climate Change (UNFCCC), which compiles national GHG inventories. The methodology used for these inventories was defined by the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UNFCCC [1]. UNFCCC countries must follow the IPCC Guidelines (IPCC 2006) for reporting anthropogenic emissions and removals (**Box 2**).

BOX 2. THE THREE LEVELS OF PRECISION OF THE IPCC METHOD

To account for emissions, the IPCC defines three **"Tiers",** *i.e.* **three levels of methodological complexity**. Tier 1 is the simplest estimation method, based on the multiplication of a national activity data and a default emission factor provided by the IPCC. Tier 2 involves looking for an emission factor specific to the territory concerned while Tier 3 often uses complex models and/or data sources.

1. Limited consideration of the full cycle of food products

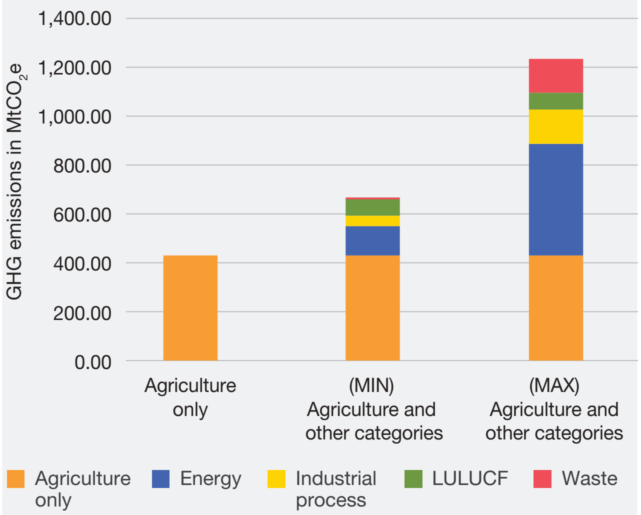
The IPCC inventory method distinguished five major categories of sources or sinks: Energy, Industrial Processes and Product Use, Agriculture, Land Use, Land-Use Change and Forestry (LULUCF), and Waste.

The **agriculture category** of the IPCC contains mainly emissions related to enteric fermentation and manure management, as well as N_2O emissions from fertilizer application. On a worldwide scale, this category is responsible for about 5 $GtCO_2eq$ (Francesco N. Tubiello *et al.* 2015), *i.e.* 10.2% of global anthropogenic emissions (FN Tubiello *et al.* 2014).

The IPCC agriculture category, is however only a subset of the emissions generated by global food consumption. On the one hand, it excludes both the upstream (production of machinery, fertilizers and pesticides, change of land use, etc.) and downstream (transport, processing, waste treatment, etc.) stages of food consumption. On the other hand, it includes the production of non-food agricultural products (textiles, fuels, etc.).

For Annex I countries [2] **only, it is possible to distinguish agriculture-related emissions in the remaining four main categories:** emissions from deforestation due to agricultural activity, industrial processes (including fertilizer production and food processing) and part of the energy consumption of agriculture are accounted for in other categories of the UNFCCC inventory. For example, the IPCC agriculture sector of the European Union (EU) represents 430 $MtCO_2eq$, *i.e.* 11% of total EU emissions with LULUCF. If other agricultural-related sources from other main categories are added, emissions lay between 670 $MtCO_2eq$ and 1,230 $MtCO_2eq$ – 16% to 31% of total EU emissions (**Figure 1**, see **Table 2** for the full methodology).

FIGURE 1. EU GHG EMISSIONS FROM AGRICULTURAL AND FOOD SECTOR IN 2016 DEPENDING ON THE PERIMETER



Source: I4CE from UNFCCC inventories

Methodology : MIN is the sum of other posts related exclusively or almost exclusively to agriculture. MAX is the sum of positions that are partly related to agriculture. See Appendix **Table 2**.

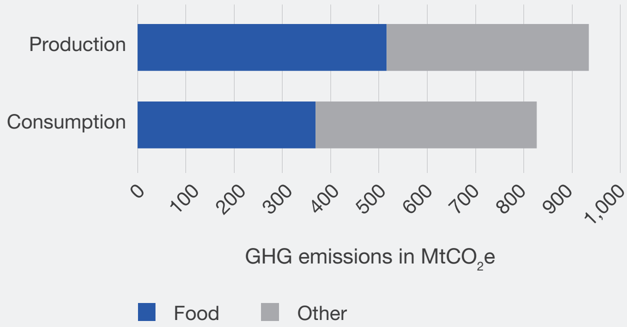
1 Decision FCCC/SBSTA/2006/9.

2 The most developed countries that have more stringent carbon accounting obligations.

2. A method that does not cover international exchanges

Production-based accounting methods **leave out the exchanges of emissions embedded into international trade**. Yet, trade flows have increased by 7% annually between 1980 and 2011 (World Trade Organization 2013). Hence, one can observe large differences between emissions from production and consumption. For example, Brazil's emissions from agricultural production were larger than Brazil's food GHG footprint in 2005 (**Figure 2**). This difference can be explained in particular by a largely positive trade balance of raw foodstuffs with 165 Mt of net exports in 2005 (FAO 2018).

FIGURE 2. GHG EMISSIONS OF BRAZIL'S CONSUMPTION AND PRODUCTION WITHOUT LULUCF IN 2005



Source: (Environmental Footprint Explorers 2018)

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Current data from production-based accounting are therefore subject to two limitations that prevent a reliable estimation of food consumption emissions: **the impossibility of covering the total footprint** of food products on the one hand, and **the impossibility of attributing these emissions to a given population** on the other hand. While life cycle analysis answers the first pitfall, other strategies have been adopted to respond to the second.

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2. Life Cicyle Analyses cover the total footprint of diets

The principle of Life cycle analysis (LCA) is to **account for the emissions generated during the entire cycle of the product**: from input production to waste management.

1. Product-level LCA

1. An international framework, and European and French initiatives of harmonization

LCA is a tool for **assessing the overall environmental impact of a product, from its production to final consumption,** or "from cradle to grave". The LCA method was harmonized by the ISO 14040 standard in 1997 (revised in 2006). This standard defines the main principles but does not describe the technical details of each step of an LCA. In 2013, ISO 14064 defines more specifically the methodology for calculating the climate impact – or "carbon footprint" – of a product. An LCA is characterized by four major stages:

1. **The definition of the scope and objectives**: the purpose of the study, the limits of the system considered, the functional unit used (kg, ha, protein, etc.), and the hypotheses;
2. **Life Cycle Inventory** (LCI): this involves collecting the required data from Phase 1;
3. **The impact estimate**: the results of the inventory are distributed in different categories in a harmonized way in order to compare different sources of emissions;
4. **The interpretation results** to draw useful and accessible conclusions for decision-makers.

The comparability of LCA results is however made difficult by the multitude of methodological options left by ISO standards. In Europe, the ILCD Handbook (JRC 2010) of the European Commission is a reference, but it does not limit much more these methodological choices.

In 2013, the European Union launched the Single Market for green products initiative, whose first pilot phase was completed in 2016. One of the objectives of this initiative was to create a global and harmonized approach to measure the environmental footprint of products. This approach has been tested on eleven food products, and a second pilot phase is underway (PRé sustianability 2015).

In France, ADEME launched in 2009 the Agribalyse program, aimed at developing a publicly accessible and harmonized LCA database for agricultural products. The LCAs exclude land use change emissions and cover steps from cradle to farm gate for crop production and from cradle to retail for animal productions. In 2015, 116 agricultural product LCAs were publicly available, with 44 animal-based and 72 plant-based products (Colomb *et al.* 2015).

2. The main challenges of LCAs

A comparison of several ACVs for the same food product revealed **significant and frequent differences between results** (Röös, Sundberg, and Hansson 2014).

Variability, uncertainty and insufficient data

Part of the variability of results can be explained by the diversity of production or consumption practices for one single product. This however can be fairly well controlled by defining typologies of practices for the same product. For example, we can define different features for the same product "apple": use of fertilizer or no use, transport mode (air, road, etc.), cooking or not, etc. Moreover, like any method of GHG emissions estimation, the LCA results are characterized by an uncertainty, partly stemming from the uncertainty on emission factors.

Finally, many LCAs make extensive use of the EcoInvent database, which contains previously performed LCA results. The use of this database greatly facilitates the task, but rarely allows a fine choice: **for a given product, there are often only one or two references**, whose production situations may be very different from the one being studied.

Methodological discrepancies

Differences in methods often emerge regarding the **modeling of direct land use change** (LUC)[3] and indirect LUC (iLUC)[4]. In order to limit these uncertainties, standards for carbon footprint measures of food products are developed: PAS 2050 of the *British Standards Institution* (BSI 2011), the *Greenhouse Gas Protocol Reporting Standard* from the *World Resource Institute* and the *World Business Council for Sustainable Development* (WRI and WBCSD 2011), and ISO 14067 of the *International Standards Organization* (Röös, Sundberg, and Hansson 2014).

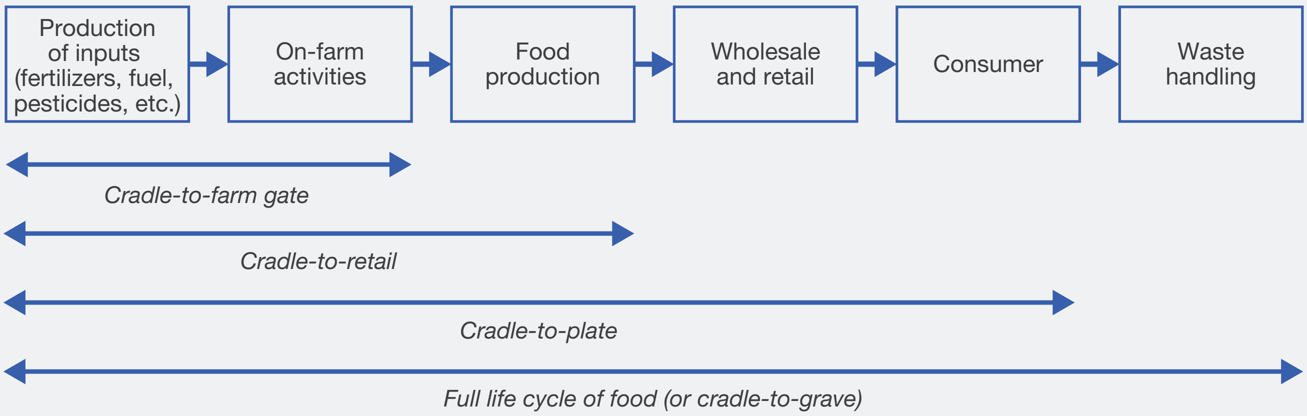
Different specifications of the scope of analysis can also explain some of the differences in results. Most of the estimates stop at the farm gate, while studies from cradle to plate and a fortiori from cradle to grave are considerably less frequent (**Figure 3**). This is explained by the great variability of post-farm emissions (in particular depending on the type of transport used), and by the importance of the types of consumer behavior for emissions from the post-sale stage (Röös, Sundberg, and Hansson 2014).

The attribution of emissions is problematic when the same production system generates several types of products. This is particularly the case for the milk industry, which also produces meat and manure. It is generally

3 Direct LUC are conversions of a any land type into croplands or grasslands.
4 Indirect LUC (or iLUC) are land conversions induced by the strong growth of croplands or grasslands.

2. THE LIFE CYCLE ANALYSIS: COVER THE TOTAL FOOTPRINT OF DIETS

FIGURE 3. DIFFERENT DEFINITIONS OF THE SCOPE OF A LCA FOR THE CARBON FOOTPRINT OF A FOOD PRODUCT



Source: (Röös, Sundberg, and Hansson 2014)

recommended to avoid as much as possible the allocation of the total footprint of the system to the different products. However, this is rarely possible and satisfying. The majority of LCAs allocate emissions in proportion to the economic value of the various co-products, which is a good proxy for their responsibility in the motivation to produce and therefore to emit. Physico-chemical allocation matrices specific to the milk industry have also been developed (Feitz *et al.* 2007). For manure, it is generally agreed to attribute emissions related to their storage on farms and those related to their application to crops. When the economic value of manure is low, or even negative, this choice is debatable.

3. Global territorial LCA

The purpose of territorial LCA is to estimate the total footprint of a given population's consumption. **When done on a global scale, the methodology used for a territorial LCA is generally the same as a classical production-based approach**. The only difference is in the perimeter of the selected sources of emissions, which is larger than the simple emissions of the agricultural production phase. In other words, the quantities produced (and thus consumed) are multiplied by the emission factors specific to the place of production for each phase of the product cycle. The emission factor data used may be national or regional averages from the literature (Gerber *et al.* 2013) or derived from existing LCAs (Poore and Nemecek 2018). Results presented in **Figure 4** and **Figure 5** are obtained from global territorial LCAs.

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In many cases, however, the goal is to estimate the GHG footprint of food consumption in a region, a country or a municipality. Taking into account the footprint of products is thus no longer sufficient as one must be able to identify which products are consumed by the population studied: it's the consumption approach.

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3. Consumption approaches allocate emissions to a population

In order to attribute GHG emissions to the consumption of a population, two major methodologies have been developed, but neither has been formally harmonized worldwide. The local territorial LCAs on the one hand are rather solid but require a large amount of data; and the input-output tables on the other hand use already existing data but are subject to significant uncertainties.

1. Local territorial LCAs

The territorial LCA method is not only used on a global scale but also at the level of local communities, notably to carry out GHG emissions assessments for these communities (**Box 3**). **The method breaks down in two stages**:

1. Estimating the emissions generated in the territory by food production at all stages of the products cycle.
2. Adding emissions contained into imports remove emissions contained into exports.

Such an approach – which can also be used at the level of a country or region – **thus requires a considerable amount of data**, especially on the emission factors of the trading partners of the territory in question. As pointed out in Part 2, these data are still too scarce and too poorly harmonized to allow for consistently robust estimates.

2. Input-output tables

Unlike local territorial LCAs, the input-output table method uses data already available. The counterpart is that the results of this method are highly aggregated and still present significant uncertainties (**Box 4**).

This method consists in **overlaying three layers of data**: (1) national GHG emission data (most often the UNFCCC production inventory, or IPCC emission factors); (2) national final consumption data; and (3) international trade flows data.

In other words, it consists in adding an environmental module (GHG emissions) to the already existing input-output tables (combining trade and consumption data). **No international harmonization has yet been achieved**, and considerable differences remain between the different estimates. In addition, most databases do not consider land use change emissions. Finally, unlike a global LCA, the input-output table methods allow to estimate the contribution of products only at a very high aggregation level (raw agricultural products, agri-food products). This is due to the fact that this method uses existing trade data that are often not very detailed.

BOX 3. SOME EXAMPLES AT EUROPEAN AND FRENCH LEVELS

At European level, some estimates have been proposed for the consumption of animal products (Leip *et al.* 2010, 2015). As for total food consumption, Sandström *et al.* (2018) estimated both the average footprint of an EU citizen and the average footprint per EU member states.

At the French scale, Barbier *et al.* (2019) have proposed an estimate of French diets footprint, without LULUCF emissions. The selected perimeter covers all the stages from the cradle to the plate (transport after purchase included) at home and out of home. Only packaging and waste treatment were not taken into account.

BOX 4. DATABASES WITH RELATIVELY UNCERTAIN RESULTS

Globally, there are three big Environmentally Extended Multi-Regional Input-Output Tables (EE MRIOT): Eora, EXIOBASE and WIOD (Moran and Wood 2014). These databases cover the main GHG sources outside LULUCF. The results of these three databases display large discrepancies that remain difficult to explain (Kanemoto, Moran, and Hertwich 2016).

At the European Union level, Eurostat produces consumption and production inventories using the input-output table method. These data have been collected in a standard way in all EU member states since 2008. The end uses are distinguished by products of the *Classification of Products by Activity* (CPA) (European Union and Eurostat 2008). Yet, the results of this database seem rather unexploitable. On the one hand, the level of detail of CPA categories is very limited: "Products from agriculture, hunting and other related services", "Fish and other fishery products", etc. On the other hand, the results are based on the strong assumption that non-EU production systems have the same emission factors as in the EU, which would tend to underestimate imported emissions. Finally, the database excludes emissions and removals from the LULUCF sector as well as indirect emissions (EUROSTAT 2017).

In France, the Data and Statistical Studies Service (SDES) of the General Commission for Sustainable Development (CGDD) has produced its own estimates based partly on Eurostat data. These were calculated for CO_2, CH_4 and N_2O excluding LULUCF using trade flows, final consumption and GHG emissions data from NAMEA air, Eurostat, IEA, FAO, INSEE and Customs (CGDD 2012). Only part of the data, already processed, is publicly available at a high level of aggregation.

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Various methods and databases therefore exist for estimating GHG emissions from food demand (Table 1). Some even try to find a method combining production approach and consumption approach (Kander *et al.* 2015). In addition to the uncertainty inherent in estimating emissions from the land sector (see Box 1), this multitude of sources complicates the emergence of relatively consensual orders of magnitude.

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TABLE 1. SUMMARY OF THE CHARACTERISTICS OF THE THREE BOTTOM-UP METHODS

	Production	Consumption	Footprint	
		Input-output tables	Territorial LCA	Product-level LCA
Perimeter	A production system	A set of consumers	A set of consumers	The entire cycle of a product
Required data	Activity data x Emission factors	Activity data x Emission factors + International Trade Flow* + Final consumption*	Activity data x Emission factors If local territorial LCA: + International Trade Flow* + Emission factors of imports	Activity data x Emission factors
Harmonized method	Yes (IPCC / UNFCCC)	No	No	In the course of harmonization
Covers international exchanges	No	Yes	Yes	Yes

Source: I4CE

** Existing and internationally harmonized data.*

4. GHG emissions from food consumption: key figures

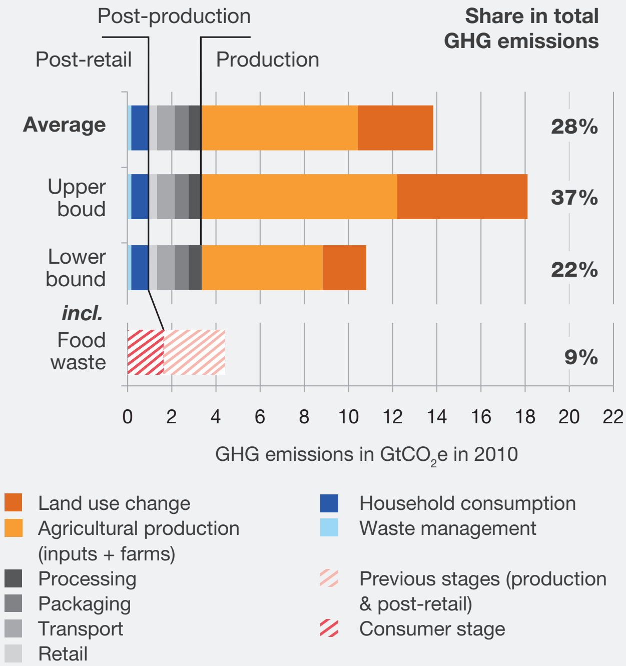
The lack of harmonization of accounting methods for the food GHG footprint leads to divergent results that are often difficult to compare. This section presents the results of an analysis of the existing literature both on the footprint of global food consumption and on emissions related to the consumption of animal-based products.

1. Worldwide

1. The share of food in global anthropogenic emissions

Global food consumption would emit between 10.8 $GtCO_2eq$ and 18.1 Gt CO_2eq, *i.e.* 22% to 37% of global anthropogenic emissions (**Figure** 4) (see Appendix **Table** 4 and **Table** 5 for more details on the data retained). Most of the emissions come from the production phase (land use change and agricultural production), while the emissions generated by the post-production and post-sale stages are relatively limited with 2.4 $GtCO_2eq$ and 1 $GtCO_2eq$ respectively. Furthermore, if waste management is the smallest emission source, emissions embedded in food wasted at the consumption phase are not negligible with 1.6 $GtCO_2e$. Note that the estimation of emissions integrated into food waste is itself subject to the uncertainty that characterizes each previous stage of the cycle.

FIGURE 4. WORLD FOOD GREENHOUSE GASES EMISSIONS



Sources: I4CE using (Vermeulen, Campbell, and Ingram 2012a; Poore and Nemecek 2018; FAO, n.d., 2014)

Note: there is no uncertainty estimate for post-production, post-sale and food waste figures, because there is only one reliable estimate for each emission source.

METHODOLOGY

These findings come from two studies of the four recent estimates of GHG emissions in global food consumption. Vermeulen, Campbell, and Ingram (2012) on the one hand made the first estimate with a territorial LCA based partly on FAO data and partly on the existing literature. Poore and Nemecek (2018) on the other hand have computed the most recent estimate with a territorial LCA based on a large number of product-level LCA (over 2,000) (see Annex **Table** 4 for more details). Once the differences in perimeters (one covered seafood and the other not) and reference date corrected, the results of the two studies appear relatively close.

The significant uncertainty on land use change emissions is noteworthy. It is linked (i) to the uncertainty inherent to LULUCF emission estimates and (ii) to the difficulty of attributing land use changes (deforestation in particular) to agriculture and. Vermeulen, Campbell, and Ingram (2012) obtain a range of plus or minus 4 $GtCO_2eq$ based on a measure of IPCC (2007) on the one hand, and on the assumption that 75% of forest degradation are related to agriculture on the other hand (Blaser and Robledo 2007). Poore and Nemecek (2018) uses a model* consistent with the IPCC recommendations and estimates that agriculture was responsible for 61% of forest losses between 1990 and 2010. The authors acknowledge however that their approach probably underestimates the contribution of agriculture to land use change. According to another study, 80% of deforestation is related to agriculture (Hosonuma *et al.* 2012). An average of the high and low value of Vermeulen, Campbell, and Ingram (2012) and the result of Poore and Nemecek (2018) thus appear to give an acceptable range for land use change emissions (see Appendix **Table** 5 for the methodology).

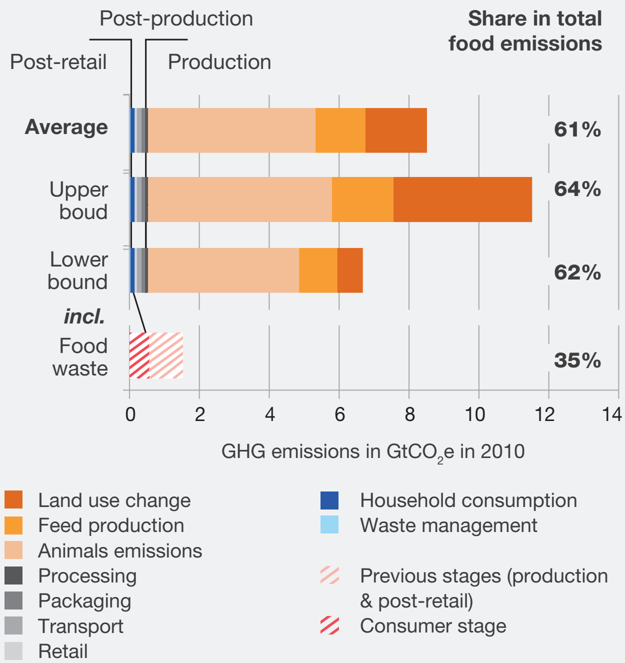
** Direct Land Use Change Assessment Tool, version 2013.1*

2. The contribution of animal products to food demand emissions

About 63% of food-related emissions are due to animal products[5] consumption with 8.5 Gt CO_2eq and 11.5 GtCO_2eq in 2010 (Figure 5). Again, most GHGs are emitted during the land use change and agricultural production phase. As mentioned, the agricultural production here covers not only the emissions generated on farm, but also the emissions related to the production of inputs such as fertilizers, pesticides, machinery, energy, etc. Gerber *et al.* (2013) estimate that ruminant (cattle, sheep and goat) farming represent 75% of total emissions from land use change and agricultural production phases.

5 All animal-based products except fish and fisheries.

FIGURE 5. WORLD GREENHOUSE GASES EMISSIONS FROM ANIMAL FOOD PRODUCTS



Source: I4CE according to (Gerber et al. 2013, Dhoubhadel, Taheripour, and Stockton 2016, Cassidy et al. 2013, Poore and Nemecek 2018, FAOSTAT 2018)

METHODOLOGY

Gerber *et al.* (2013) **is a reference for livestock sector emission accounting** but the perimeter of the estimates stops at the gates of the farm. Estimates covering global feed emissions presented previously can thus complete these shortcomings.

Regarding emissions from land use change, the result presented on **Figure 5** is an average of the estimations of Dhoubhadel, Taheripour, and Stockton (2016), Poore and Nemecek (2018) and Vermeulen, Campbell, and Ingram (2012). The estimation of land use change emissions from Gerber *et al.* (2013) was not selected because they only take into account the conversion from forests to grasslands in Latin America, and the conversion from forests to croplands for soybean and palm in five countries (Brazil, Argentina, Paraguay, Indonesia and Malaysia). The estimation of Vermeulen, Campbell, and Ingram (2012) is included to ensure consistency between the estimation of land use change emissions from global food consumption on the one hand and from animal products consumption on the other hand. Indeed, Poore and Nemecek (2018) admit being likely to underestimate land use change emissions from food consumption, and the estimate of Dhoubhadel, Taheripour, and Stockton (2016) is similar to their estimate. Including the estimates of Vermeulen, Campbell, and Ingram (2012) thus makes it possible to counterbalance this probable underestimation. As these estimates cover all agricultural production, we applied the rate of 0.67, corresponding to the share of agricultural land use change attributable to livestock deducted from Poore and Nemecek (2018).

Emissions generated at the agricultural production step are an average of Gerber *et al.* (2013) and Poore and Nemecek (2018) results. Although Gerber *et al.* (2013) is the reference on the subject, it is difficult to justify why the results of this study would be necessarily more reliable than those of Poore and Nemecek (2018), the two methodologies being valid and their results similar. In addition, Gerber *et al.* (2013) covers only the main livestock production: cattle, cows and buffaloes, small ruminants (sheep and goats), pork, chicken and chicken.

No livestock-specific estimate of post-farm GHG emissions was found. Thus, we induced these emissions from the results presented in Figure 4. World food greenhouse gases emissions by assuming that the post-farm emission factors are the same for all types of products. We therefore multiply the post-production and post-sale emissions of global food by the percentage of animal products in the total quantities of agricultural products (13%) (FAO 2018). It is therefore the small share of animal products in total agricultural production that explains the low contribution of these products in post-production and post-sale emissions (see Appendix **Table 6** for the methodology).

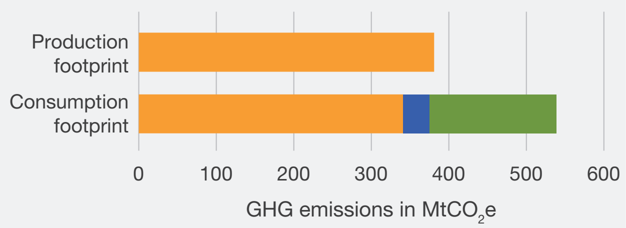
However, **these estimates do not cover GHG emissions avoided by livestock activities**. We can indeed consider the spreading of livestock manure as a substitute for synthetic nitrogen fertilizers that emit GHGs during their production and spreading. These avoided emissions are nonetheless included in the footprint of vegetal products.

2. In the European Union

As mentioned above, **the Eurostat results on the GHG footprint of EU food consumption are to be taken with caution**. According to the Eurostat methodology, the GHG footprint of Europeans would have been 720 $MtCO_2eq$ in 2010. Compared with EU production emissions data for the same year, member states would have imported around 137 $MtCO_2eq$ via their net imports of agricultural and agri-food products. This result seems surprising considering (i) the net exporter position of the EU, especially in animal products; (ii) the absence of emissions from land-use changes in the estimate; and (iii) Eurostat's assumption that non-EU emission factors are the same as in the EU.

Sandström *et al.* (2018) confirms this intuition: according to this local territorial LCA, food consumption of EU-28 citizens would have generated 540 $MtCO_2eq$ in 2010, including land-use changes. According to the authors, the European Union would have been net importer of about 160 $MtCO_2eq$ through its food consumption, mainly because of land use changes in the importing countries (**Figure 6**).

FIGURE 6. GHG EMISSIONS FROM PRODUCTION AND CONSUMPTION IN THE EU-28 IN 2010



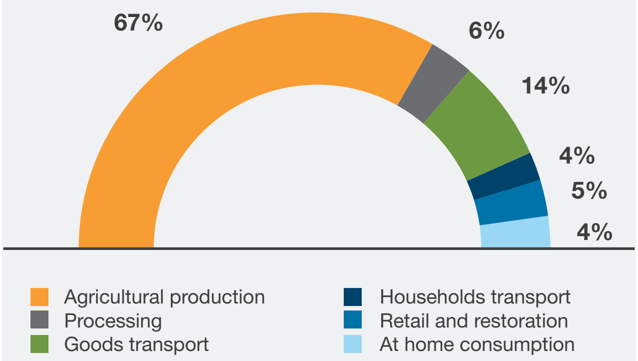
Source: Sandström et al. (2018)

Moreover, according to the same study, **82% of GHG emissions from European food consumption come from animal products** (excluding seafood products, diesel use in agriculture and all post-farm emissions except international transport).

3. In France

According to Barbier *et al.* (2019), **food consumption in France represents 163 $MtCO_2eq$ or 24% of the country's total GHG footprint**. Two-thirds of these emissions would come from the agricultural production stage, while transport represents 20%, and the consumption phase 10% **(Figure 7)**.

FIGURE 7. GHG EMISSIONS FROM FOOD CONSUMPTION IN FRANCE



Source : Barbier et al. (2019)

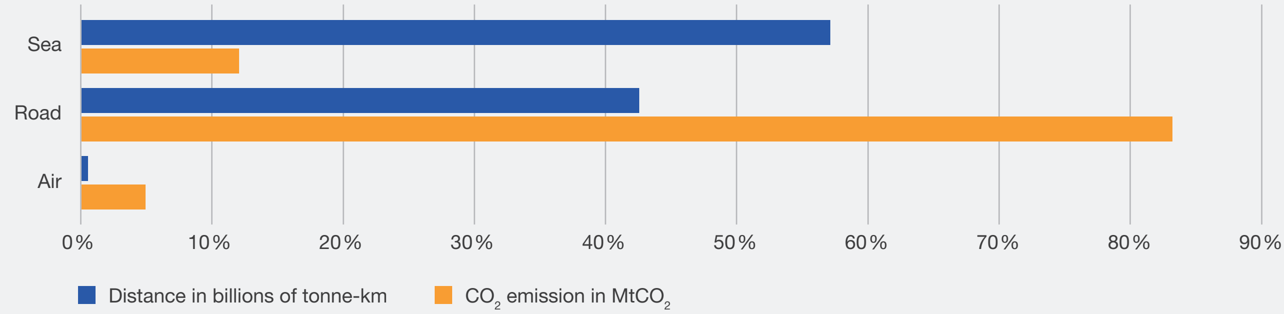
Reducing the share of animal products in the diet remains an essential option: animal products represent 70%[6] of the emissions from the total. However, **the authors also highlight the importance of the residential-tertiary sector and transport in the food consumption emissions**: almost half of the emissions from food are CO_2.

On the one hand, **energy consumption represents more than 20% of the emissions generated at the agricultural production stage**: half comes from the direct use of energy (fuel and heating), the other half from indirect consumption (fertilizers, phytosanitary products, equipment manufacturing, building construction).

On the other hand, emissions from goods transport (from production to sales) and households (from retail to home) are significant. **Although most food is transported by sea, road transport accounts for more than 80% of freight transport emissions (**Figure 8**)**. Moreover, about 80% of household food-related trips are for purchases (the rest for eating out), and these trips are almost exclusively made by car.

6 Calculated by the authors by attributing emissions at retail and consumer stage proportionally to the weight of animal products in total consumption. Barbier *et al.* (2019) only mention that animal products represent 85% of emissions at agricultural level.

FIGURE 8. DISTANCES AND EMISSIONS FROM THE TRANSPORT OF FOOD GOODS IN FRANCE



Source: Barbier et al. (2019)

Finally, the quantities of CO_2 emitted by retail and restoration on the one hand and by home consumption on the other hand are almost equal. Despite similar energy consumption, **small food-related establishments (restaurants, small shops, cafés, etc.) would emit more CO_2 than mass retailers** because of their gas consumption. In addition, an out-of-home meal would be twice as intense in CO_2 as a home-cooked meal, because of energy uses that are not specific to food production (heating, lighting, etc.).

GHG emissions from French food consumption (109 $MtCO_2eq$) are also slightly lower than emissions from French agricultural production (118 $MtCO_2eq$). As the authors point out, this is a low estimate of the food consumption footprint, particularly since the LULUCF sector could not be covered. The emissions contained in imported food products would have been higher had LULUCF been taken into account. The study confirms that the agricultural production phase accounts for most of the GHG footprint of French food, and focuses on reducing energy demand.

Conclusion

To date, there exists no harmonized method to estimate the GHG footprint of food consumption. **The GHG footprint of global food consumption can be roughly estimated at 13.8 GtCO$_2$eq (±3.6 GtCO$_2$eq), *i.e.* around 30% of global emissions**. This initial estimate nevertheless suffers from a high degree of uncertainty at each stage of the product cycle. Nearly 62% of this footprint is attributable to animal products, with still high uncertainties. This high uncertainty could be reduced, notably via:

- better information on the causes of land use changes;
- improved knowledge about the emission factors of the LULUCF and Agriculture sectors;
- more data on emission factors in emerging and developing countries, and on energy consumption in the food processing and packaging industries.

Accounting is even more complicated at the regional, country or community level as the GHG footprint must be corrected for trade flows. The two most used methods to date result from a tradeoff between reliability of results and availability of data. The input-output tables are based on available and harmonized data but their results are still relatively unreliable. With the development of new data (including the multiplication of LCAs produced), more local territorial LCAs are being conducted. The average footprint of a European was then estimated at 1.1 tCO$_2$eq (with LULUCF), and that of a French at least 1.7 tCO$_2$eq (without LULUCF).

This is again a first approximation: in addition to the sources of uncertainty already mentioned, the results are also strongly dependent on the level of information on imported goods. In particular, emissions from land-use changes are particularly difficult to attribute. Take the case of a soybean-producing country, part of whose area has been cultivated for a long time for soybeans, and another one which has required deforestation. Accurate consideration of LULUCF emissions from the country of import would require knowing the share of deforestation soybeans in total imports. The same applies to transport emissions if the country imports the same product by sea and air.

Production-based inventories have probably been chosen as the basis for climate negotiations because countries have direct control over and have data about the emissions occurring on their soil. Accounting for the food consumption footprint requires (i) being able to trace the entire cycle of food consumption, and (ii) having relatively precise data on international trade and final consumption of food. Yet, reliable estimation of national GHG footprints would provide an alternative definition of countries' responsibility into climate change.

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Annexes

TABLE 2. DETAILED METHODOLOGY FOR THE STRICT AND BROAD ESTIMATION OF GHG EMISSIONS FROM AGRICULTURE BASED ON UNFCCC DATA

Categories and sub-categories					MIN	MAX
Energy	**Fuel Combustion**					
		Manufacturing Industries and Construction	1.A.2.e Food Processing, Beverages and Tobacco		X	X
		Transport	Road Transportation	1.A.3.b.ii Light duty trucks		X
				1.A.3.b.iii Heavy duty trucks and buses		X
		Other Sectors	Agriculture/Forestry/Fishing	1.A.4.ci Stationary	X	X
				1.A.4.c.ii Off-road vehicles and other machinery	X	X
				1.A.4.c.iii Fishing	X	X
Industrial Processes and Product Use						
	Mineral Industry	2.A.2 Lime Production			X	X
	Chemical Industry	2.B.1 Ammonia Production			X	X
	Product Uses as Substitutes for ODS	2.F.1 Refrigeration and Air conditioning				X
	Other	2.H.2 Food and beverages industry			X	X
Agriculture					X	X
Land Use, Land-Use Change and Forestry						
	Cropland	4.B.1 Cropland Remaining Cropland			X	X
		4.B.2 Land Converted to Cropland			X	X
	Grassland	4.C.1 Grassland Remaining Grassland			X	X
		4.C.2 Land Converted to Grassland			X	X
Waste						
	5.A Solid Waste Disposal					X
	Biological Treatment of Solid Waste	5.B.1 Composting			X	X
		5.B.2 Anaerobic Digestion at Biogas Facilities				X
	5.C Incineration and Open Burning of Waste					X
	5.D Wastewater Treatment and Discharge					X

Source: I4CE

TABLE 3. COMPARISON OF THE THREE EE MRIOS CHARACTERISTICS

	Eora26v199.82	EXIOBASE3	WIOD
Covered period	1970-2015	1995-2012	1995-2009
Covered countries	183 countries	43 countries (90% of global GDP) & 5 regions "Rest of the world"	EU-27 [(1)] & 13 other countries [(2)] & "Rest of the world"
Covered gas	CO_2, CH_4, N_2O	CO_2 and non-CO_2 (no detail available)	CO_2, CH_4, N_2O
Sectors covered	about 15,000 sectors	163 industries	IPCC sectors
Emission database used	EDGAR	Estimations combining activity data and emissions factors from Eurostat, using IPCC methodology and EMEP/EEA [(3)]	Energy: IEA data Other sectors [(4)]: National data if available Estimation using IPCC methodology if not

Source: (Kanemoto, Moran, and Hertwich 2016) (Genty, Arto, and Neuwahl 2012) and (Wood et al. 2014)

(1) Before Croatia's entry

(2) Australia, Brazil, Canada, China, India, Indonesia, Japan, Korea, Mexico, Russia, Taïwan, Turkey and United States of America

(3) For European Monitoring...

(4) Fugitive fuel emissions, industrial processes, products use (paint, cleaning products, etc.), agriculture, waste management and other anthropogenic sources

TABLE 4. CHARACTERISTICS OF EXISTING GLOBAL GHG EMISSIONS ESTIMATES AND REASONS FOR REJECTING THEM FROM THIS STUDY

	Vermeulen, Campbell, and Ingram (2012)	Tilman and Clark (2014)	Poore and Nemecek (2018)	Schmidt and Merciai (2014)
Method	Territorial LCA			Input Output Table
Data	FAO data and scientific literature	Product-level LCAs and scientific literature		EXIOBASE v2
Reference year	Mid-2000	2009	Around 2010	2004
Products covered	All but marine products	All	All	All
Retained or rejected	Retained	Rejected	Retained	Rejected
Reason behind retained/rejected decision	The data used are those of FAO on world agricultural production. For other items, the authors used the literature estimates.	Poore and Nemecek (2018) use the same method but the results are more recent and the ACV database produced is considerably larger (2,278 vs. 555)	The data used are mainly those of the LCV product retained. Nevertheless, some gaps are supplemented with estimates of the existing literature.	Compared with the results of Gerber *et al.* (2013) specific to animal products, those of Schmidt and Merciai (2014) are still significantly higher, even after the differences in perimeters and reference year have been corrected. However, the results of Gerber *et al.* (2013) refer to: they result from a detailed modeling of biomass flows in the livestock system. On the other hand, the designers of EXIOBASE v2 have themselves recognized a form of failure concerning emissions from agriculture and LULUCF.

Source: I4CE

TABLE 5. SOURCES OF DATA USED TO ESTIMATE GHG EMISSIONS FROM GLOBAL FOOD CONSUMPTION

Stages of the cycle	Data used	Rationale
Land use change (LUC)	Average of lower and upper bound from Vermeulen, Campbell, and Ingram (2012) and Poore and Nemecek (2018)	Poore and Nemecek (2018) admit they may underestimate emissions from LUC
Agricultural production		It is difficult to decide in favor of one or the other of the methodologies.
Processing	(Poore and Nemecek 2018)	For many of these positions, Vermeulen, Campbell, and Ingram (2012) used a single national estimate and extrapolated it globally. In addition, the estimates of Poore and Nemecek (2018) are more recent.
Transport		
Packaging		
Retail		
Consumption	(Vermeulen, Campbell, and Ingram 2012)	The estimates of Poore and Nemecek (2018) stop at the sale.
Waste management		
Out of cycle		
Food waste	(FAO 2013) (FAO, *s. d.*)	Single reliable estimation known

Source: I4CE

TABLE 6. SOURCES OF DATA USED TO ESTIMATE GHG EMISSIONS FROM CONSUMPTION OF ANIMAL PRODUCTS

Stages of the cycle	Data used	Rationale
Land use change (LUC)	Average of Dhoubhadel, Taheripour, and Stockton (2016), Poore and Nemecek (2018) and Vermeulen, Campbell, and Ingram (2012) whose results are multiplied by 0.67 – *i.e.* the share of deforestation due to livestock deforestation due to agriculture after (Poore and Nemecek 2018))	The exclusion of Gerber *et al.* (2013) is due to the incompleteness of the covered LUCs: only the conversion of forests to grasslands in Latin America, and the conversion of forests to cultivated land for soybeans and palm in Brazil, Argentina, Paraguay, Indonesia and Malaysia. The inclusion of the results of Vermeulen, Campbell, and Ingram (2012) allows to maintain coherence between the emission results for the global feed and for the products of the breeding, as well as to represent the high uncertainty which characterizes this post. Without this inclusion, CAT emissions from livestock would likely have been underestimated.
Agricultural production	Average of Gerber *et al.* (2013) and Poore and Nemecek (2018)	It is difficult to decide in favor of one or the other of the methodologies.
Processing	Prorated estimates of Poore and Nemecek (2018) or Vermeulen, Campbell, and Ingram (2012) as appropriate	Absence of estimates of post-farm GHG emissions specific to animal products
Transport		
Packaging		
Retail		
Consumption	(FAO 2013) (FAO, *s. d.*)	Only reliable estimate known, gives the share of animal products in the footprint of food waste.
Waste management		

Source: I4CE

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