# Assessing potential pesticide-related ecotoxicity impacts of food products across different functional units

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**ABSTRACT**

The study aims to 1) demonstrate and apply a method for assessing the potential freshwater ecotoxicity impacts due to pesticide use in the primary production associated with six food products (chicken fillet, minced pork, minced beef, drinking milk, pea soup and wheat bread), and 2) evaluate how five different functional units (FUs) influence the results. Pesticide emissions were inventoried using an extended, updated and site-specific version of the PestLCI v. 2.0.5 model. In the impact assessment, USEtox v. 2.01 was used. The results show that the choice of FU has little influence on the outcome: four out of five FUs yield the same ranking of the animal-based food products: impact potentials decrease in the order minced pork > chicken fillet > minced beef > milk. The plant-based food products score considerably lower than the animal-based food products, regardless of FU. Notably, impact potentials of beef are lower than of chicken and pork, regardless of FU, contrary to typical carbon footprint and land use results for meat products. We conclude that the choice of FU did not influence the ranking of animal vs. plant-based food products. Also, we conclude that carbon footprints are inadequate proxy indicators of ecotoxicity impacts of food products and that ecotoxicity impacts need to be considered specifically, alongside other important impact categories.

Keywords: functional units, freshwater ecotoxicity, pesticides, USEtox, PestLCI.

## 1. Introduction

Estimates suggest that the planetary boundaries proposed to define the safe operating space for humanity have been transgressed for chemical pollution (Diamond et al., 2015), as well as for biodiversity loss (Rockström et al., 2009). Agricultural chemicals, such as pesticides, provide many benefits, but also contribute to chemical pollution, in e.g., surface waters (Stehle and Schulz, 2015), and to loss of biodiversity (Hallmann et al., 2014, Beketov et al., 2013, Whitehorn et al., 2012, Henry et al., 2012, Geiger et al., 2011). Despite being a highly relevant impact category in environmental assessments of food products, the ecotoxicity impacts from pesticide use are often excluded (Henriksson et al., 2012, de Vries and de Boer, 2010, Nemecek et al., 2016).

The choice of functional unit (FU) can have a large influence on results and conclusions in life cycle assessment (LCA) studies. The FUs should capture the primary function of the assessed product – such as nutrition in the case of food – but food LCAs usually only assess impacts in relation to kg food (Roy et al., 2009, de Vries and de Boer, 2010, Nijdam et al., 2012). Sonesson et al. (2016) developed new FUs based on the quality and/or quantity of protein, as well as the dietary context, with the intention to contribute to more relevant and useful information about the environmental impacts of food products. FUs based on protein quantity and/or quality are relevant since proteins are essential nutrients and associated with widely different environmental impacts depending on origin, and production methods.

The aim of this study is to 1) demonstrate and apply a method for assessing the potential freshwater ecotoxicity impacts due to pesticide use in the primary production associated with six food products and 2) evaluate the influence of different FUs on the results.

## 2. Methods

Six food products are considered: chicken fillet, minced pork, minced beef, drinking milk, pea soup and wheat bread. These food products are based on eight crops: rapeseed, feed wheat, bread wheat, barley, oats, grass/clover, peas and soybean. Food products are produced in the county of Västra Götaland, South West of Sweden. Seven of the crops are locally produced, and one (soybean) is produced in Mato Grosso, Brazil.

The pesticide application data represent current, typical and realistic use of pesticides in the studied crops and region, and were primarily obtained from Sonesson et al. (2014) which compiled information about current agronomic practices in the studied crops and regions (SLU, 2015). Pesticide application data for soybean were obtained from Nordborg et al. (2014) and represent cultivation of conventional soybean (not genetically engineered).

Pesticide emissions were calculated using an extended, updated and site-specific version of the pesticide emission model PestLCI v. 2.0.5 (Dijkman et al., 2012). This model has been described as the most advanced pesticide emission inventory model currently available for use in agricultural LCAs (van Zelm et al., 2014). PestLCI takes into account the physico-chemical properties of pesticides (e.g., degradation rates), local field conditions (e.g., slope), pedoclimatic conditions at the time and place of application (e.g., air temperature and soil clay content), and agronomic practices (e.g., tillage type). These parameters were adjusted to local conditions for the assessed crops and regions.

In the impact assessment, USEtox version 2.01 (www.usetox.org, Fantke et al., 2015a, Rosenbaum et al., 2008), released in February 2016, was used. USEtox is an emission route-specific impact assessment model developed in a "scientific concensus" process that "merged" several toxicity impact assessment models (Hauschild et al., 2008). It is generally recognized as the most advanced model currently available for comparative assessment of chemicals and their toxic effects on humans and freshwater ecosystems (see e.g., Hauschild et al. 2013) and recommended by several influential organizations and authorities (Fantke et al., 2015a). We used site-generic characterization factors at midpoint level. Characterization factors represent an estimate of the Potentially Affected Fraction (PAF) of species in (freshwater) space and time per unit emission, measured in the unit Comparative Toxic Unit ecotoxicity (CTUe) per kg emitted substance, where 1 CTUe = $PAF \cdot m^3 \cdot day$. New characterization factors were calculated for nine pesticide active substances, which were not available in the USEtox 2.01 database. In total, 26 pesticide active substances are included in the study.

Potential freshwater ecotoxicity impacts per kg harvested crop were first calculated as described above. Impact scores per kg food product consumed in the household were then derived by calculating the amount of crop(s) needed to produce each food product, taking into account representative conversion efficiencies in the assessed production systems, and downstream food processing (milling, slaughter, and cooking in the household). The production chains are described in Sonesson et al. (2014).

Impacts were assessed in relation to five FUs: food mass (kg), food energy content (Mcal), and three FUs that take protein quantity and/or quality into account: "kg protein", and the newly developed FUs "kg digestible protein" and "kg PQI-adjusted food (AD)" where PQI stands for protein quality index and AD stands for average Swedish diet (Sonesson et al., 2016). The PQIs are dimensionless coefficients based on the composition of nine essential amino acids in the food product, the true ileal digestibility of each amino acid, the composition of the amino acids in the total dietary intake, and the nutritional requirements for the amino acids. The PQIs are thus dependent on the dietary context: the higher the PQI, the more valuable the product in a given diet. The idea is that products with a higher nutritional value (in relation to the dietary supply) will get more favorable LCA results (i.e. lower environmental impacts), and vice versa. Sonesson et al. (2016) developed PQIs for three Swedish diets with different supply of protein, but found that the dietary context was of little importance when ranking food products with regard to environmental performance. Therefore, only PQIs for one of the diets, AD, was included here.

## 3. Results

The potential freshwater ecotoxicity impacts for the six food products are presented in Figure 1. Beef scores lower than chicken and pork; pea soup and wheat bread have much lower impact potentials than the animal-based food products, and milk scores in-between the meat products and the plant-based food products. These results are stable across all five FUs.

The four mass-based FUs yield the same ranking of the animal-based food products: impact potentials decrease in the order minced pork > chicken fillet > minced beef > milk (Figure 1). In relation to food energy content, chicken fillet scores higher than pork, since the energy density (Mcal $kg^{-1}$) of chicken fillet is 25% lower than of minced pork, hence less valuable from an energy perspective.

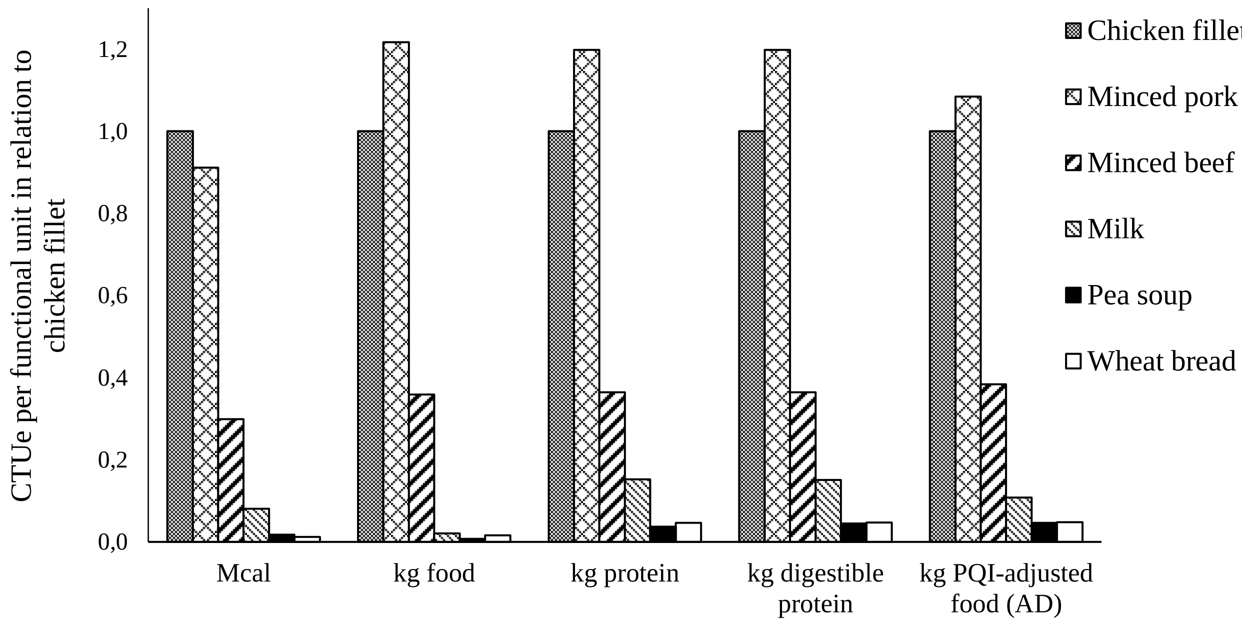


**Figure 1:** Potential freshwater ecotoxicity impacts of food products in CTUe (Comparative Toxic Units ecotoxicity) per functional unit (FU), in relation to chicken fillet. PQI = protein quality index, AD = average Swedish diet. Results are presented in relation to chicken fillet since we are primarily interested in how the different FUs rank the food products, and since the FU "kg PQI-adjusted food (AD)" represents a fictitious mass flow, rendering the absolute values difficult to interpret in terms of actual impacts and non-comparable to impact potentials expressed in relation to FUs that represent physical mass flows.

## 4. Discussion

The plant-based food products have considerably lower potential freshwater ecotoxicity impacts than the animal-based food products. This is primarily due to animal-based food production systems being less efficient at converting inputs (feed crops) to outputs (meat, milk or eggs), than plant-based food production systems, due to losses of energy and nutrients associated with an additional trophic level in the food chain. Therefore, the total use of pesticides per unit product becomes higher for animal-based food products, compared to plant-based food products, unless animal-based food production systems rely on grazing with very little feed crop supplement.

The four mass-based FUs yield the same ranking of the animal-based food products: impact potentials decrease in the order minced pork > chicken fillet > minced beef > milk. In particular, chicken and pork score higher than beef, for all five FU, despite poultry and pigs having higher feed conversion ratios and shorter cycle lengths than cattle. These results are primarily explained by the food products being based on different crops (Table 1) that are subject to different pesticides in the primary production, and consequently (widely) different potential freshwater ecotoxicity impacts. In relation to kg harvested crop, the impact potential of grass/clover is $1.7 \cdot 10^{-5}$ CTUe, while the impact potentials of feed wheat, bread wheat, peas, rapeseed, oats, barley and soybean are 10, 11, 14, 24, 42, 51 and 642 times greater, respectively. In Västra Götaland, 36% of the beef comes from specialized beef cattle and 64% comes from the dairy production system. Grass/clover is an important feed in both production systems, but contribute only 4% to the impact potentials of beef and milk (Table 1), due to very low pesticide use in cultivation. In contrast, the high impact potentials of chicken and pork are explained by the feed rations of poultry and pigs containing large amounts of soymeal produced from soybeans, with much higher pesticide inputs in cultivation.

**Table 1:** The contribution from crops to the potential freshwater ecotoxicity impacts in CTUe (Comparative Toxic Units ecotoxicity) per kg food product. The "-" indicate that the crop is not used in the production of the food product. The percentages all sum up to 100%.

| | **Bread** | **Chicken fillet** | **Minced pork** | **Minced beef** | **Milk** | **Pea soup** |
|---|---|---|---|---|---|---|
| Wheat | 100% | 4% | 4% | - | - | - |
| Rapeseed | - | 1% | 2% | - | - | - |
| Soybean | - | 95% | 66% | 23% | 26% | - |
| Barley | - | - | 21% | 40% | 38% | - |
| Oats | - | - | 7% | 32% | 31% | - |
| Peas | - | - | - | - | - | 100% |
| Grass/clover | - | - | - | 4% | 4% | - |

The finding that beef scores better than chicken and pork, for all five FUs, is noteworthy since it contradicts findings in studies quantifying carbon footprints and land use of meat products. Such studies typically attribute larger impacts to beef, than to chicken and pork, due to lower feed conversion ratios and reproduction rates in beef production system, as well as methane emissions from enteric fermentation contributing to climate impacts (Nijdam et al., 2012, Westhoek et al., 2011).

Despite a detailed and site-specific inventory of pesticide usage and emissions in the studied crops and regions, the results are subject to uncertainties and limitations. Some data display large spatial and/or temporal variability, such as type and amount of pesticides applied and soil and climate conditions (influencing emissions). In addition, feed rations vary within production systems, in particular in beef production systems (Westhoek et al., 2011). Intensive feedlot systems with little or no grass and more soybeans or other protein-rich feed crops would likely score higher. More research is needed to assess how different beef production systems perform. Less variation can be expected for chicken and pork production in the industrialized world, since these production systems are more standardized.

More comprehensive assessments are needed where ecotoxicity impacts are considered specifically, alongside other important impact categories in environmental assessments of food products. For example, besides the amount of land needed to support production, the quality of land is also an important factor to account for. van Zanten et al. (2016) showed that from a land use efficiency perspective, some ruminant production systems outperform both monogastric and food crop production systems.

While plant-based food products have lower impact potentials than the animal-based food products, caution should be applied before generalizing this finding, since only six food products were assessed. Some fruits and vegetables may score higher than meat products due to the use of high-toxicity pesticides in the cultivation.

## 5. Conclusions

Despite being a highly relevant impact category, ecotoxicity impacts from pesticide use are often excluded in environmental assessments of food products. Here, we assessed the potential freshwater ecotoxicity impacts due to pesticide use in the primary production of six food products produced in Sweden. We also assessed how the results vary across five different FUs.

The plant-based food products have much lower impact potentials than the animal-based food products, for all five FUs. The choice of FU was thus not critical to the degree that it influenced the ranking of animal vs. plant-based food products (but it partly influenced ranking within these categories). However, only six food products were assessed here. Ecotoxicity impacts of a wider range of food products, e.g., tropical fruits, need to be assessed in order to establish whether plant-based food products always score better than animal-based food products.

We also found that beef has lower freshwater ecotoxicity impacts than chicken and pork. This result, which is stable across the FUs, stands in sharp contrast to typical carbon footprint and land use results. Carbon footprints are sometimes used as proxy indicators of environmental impacts. We conclude that carbon footprints are inadequate proxies of the ecotoxicity impacts of food products.

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