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LCA FOR AGRICULTURE

Applying the nutrient footprint method to the beef production and consumption chain

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Abstract

Purpose An indicator of nutrient use efficiency through the entire food chain has been lacking. This article proposes a nutrient footprint method to estimate the efficiency of using both nitrogen (N) and phosphorus (P) in animal production chains following Life Cycle Assessment (LCA).

Methods Following the nutrient footprint method of Grönman et al. (2016), we applied the nutrient footprint method to the Finnish beef production and consumption chain. We defined N and P flows associated with the beef chain from a product-specific point of view. The nutrient footprint is a resource efficiency indicator which combines the amount of nutrients captured for use in the production and consumption chain and their nutrient use efficiency (NutUE) either in the primary product or in both the primary + secondary products.

Results and discussion Each 1000 kg of Finnish beef consumed requires 1700 kg N and 189 kg P during its life cycle. The percentage of virgin nutrient is more than 50% for N, but only 25% for P. NutUE in the primary product and in both primary + secondary products for N is 1% and 47% and for P is 0.2% and 74%, respectively.

Conclusions The nutrient footprint offers information about NutUE in a simple and comparable form. In transition towards systems with sustainable nutrient use, it is essential to identify hot spots of nutrient leakage to be able to close them and improve food chains.

Keywords Food chain · Life cycle thinking · Nitrogen · Nutrient use efficiency · Phosphorus

1 Introduction

Demand for apatite mining for phosphorus (P) and for conversion of nitrogen (N) into its reactive form for use in fertilisers has increased the use of P and N. Even though nutrient balances and emissions of N and P have been monitored extensively, particularly in farming, an indication of nutrient use efficiency (NutUE) through the entire food chain has been lacking.

In this study, our aim was to develop further the basic nutrient footprint method introduced recently by Grönman et al. (2016) by applying it to an animal food product—beef. The nutrient footprint describes the efficiency of nutrient use in a specific production chain and distinguishes virgin from recycled nutrients. The method was originally tested on oat flakes and oat porridge. Beef was chosen because previous Life Cycle Assessment (LCA) studies show it to have larger environmental impacts than those of plant and other animal products (Reijnders and Soret 2003; Williams et al. 2006; Carlsson-Kanyama and González 2009; Audsley and Wilkinson 2012; Leip et al. 2014). Most LCA studies compare different kinds of production systems and, therefore, stop at the farm gate. Some exceptions for beef exist (Carlsson-Kanyama and González 2009; Mieleitner et al. 2012; Opio et al. 2013; Rivera et al. 2014; Uwizeye et al. (2016)), but to our knowledge, no studies exist on nutrient issues of animal products "from cradle-to-grave", i.e. until waste management.

The nutrient footprint method developed by Grönman et al. (2016) combines the amounts of nutrients captured [kg of N

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and P] for use in the production chain with the percentage of nutrients used [%], either in the primary product or in both the primary + secondary products. The captured nutrients are further divided into virgin and recycled nutrients. Virgin nutrients are extracted from nature and converted into a reactive form for the production chain studied (e.g. inorganic fertilisers), while recycled nutrients (e.g. manure, sewage sludge, secondary products of food processing industry), already captured in a previous production process, are recycled to the production chain studied. All phases of the production and consumption chain are included: from fertiliser production to human food product to wastewater treatment. The method offers information about nutrient use efficiency in a simple and comparable form. Thus, the nutrient footprint complements typical LCA studies on global warming, eutrophication and acidification potential.

Uwizeye et al. (2016) developed a method similar to that of Grönman et al. (2016) for NutUE which takes into account both N and P but stops at the end of the processing stage. In addition, it does not distinguish virgin from recycled nutrients or whether nutrients are captured for the primary product or for primary + secondary products. Erisman et al. (2018) also developed a method for NutUE, but it considers only N. It also has a broader system boundary, not specifying different chains. A different concept of the nutrient footprint was presented by Leach et al. (2012), who developed an N footprint tool which calculates annual per capita N losses to the environment caused by food consumption. For each food category, they defined a Virtual N factor which equals total N loss in the production chain divided by the N that remains in the consumed product. Similarly, Leip et al. (2014) calculated N footprints of food products as direct N losses to the environment per unit of product; however, they excluded production chain phases beyond livestock slaughtering. Leip et al. (2014) also developed an N investment factor, representing the total external N required to produce the N in one unit of product. These approaches, however, include only N and do not consider the recycling of nutrients from the latter life cycle phases of food consumption and wastewater treatment. Our approach, in contrast, gives a more holistic view of nutrient circulation in the food chain by combining nutrient use and emission data in all phases of the production chain until the treatment of human wastewater.

Annual beef production in Finland was 81 million kg in 2013, representing ca. 26% of total meat production (Luke statistics 2015a). Beef production has decreased 15% since 2003, while at the same time, total meat production has increased 4%. Annual beef consumption in 2013 was 18 kg per capita, corresponding to 100 million kg for the total population (Eurostat 2015; Luke Statistics 2015b). The share of beef in total meat consumption was 24% in 2013. From 2003 to 2013, beef consumption increased less than total meat consumption (4 and 11%, respectively). There are no statistics on the share of meat production originating from beef cattle, but the share of suckler cows in all cows (including suckler cows and dairy cows) was 17% in 2014 (Luke Statistics 2015c). Beef cattle production is relatively evenly distributed across Finland, although animal numbers are highest in Ostrobothnia and northern Savo, where dairy production is also concentrated. The case study was quantified using average data for a male calf originating from the Finnish suckler cow-calf system.

2 Materials and methods

2.1 Nutrient footprint method

The nutrient footprint method was presented in detail by Grönman et al. (2016). In short, it describes the efficiency of nutrient use by a specific production chain by (1) the amounts of nutrients [kg of N and P] used, (2) whether nutrients are virgin or recycled and (3) the efficiency with which these nutrients [%] are used in the particular production chain (Fig. 1) (i.e. NutUE). Nutrient losses at each life cycle phase are estimated. Nutrients in primary and secondary products are calculated separately.

2.2 System boundary and functional unit

The system boundary of the beef production case study included multiple stages of production and consumption (Fig. 2). The primary product of the beef production chain is beef, but the case study also included several secondary products. The results of the nutrient footprint are described in two ways: (1) considering only the NutUE of the primary product and (2) also considering the NutUE of secondary products in addition to the primary product. We included the NutUE and nutrients in the main production chain of the primary product, beef. The main production chain included production of agricultural inputs, feed crop cultivation, animal production, food processing, supply and trade, consumption and wastewater treatment. The NutUE of further processing of secondary products and waste was not considered, but the nutrients in secondary products themselves, such as internal organs and skin, were considered potentially usable. Note that waste, including food waste recycled as bio-waste, was considered to be a secondary product and not waste when the nutrients were considered potentially usable. Although nutrients in leather can remain isolated from nutrient circulation for a long time, they can be returned to use later, so we considered them potentially usable.

The functional unit for the case study was 1000 kg of beef from a beef bull eaten by the consumer. This differs slightly from the previous study by Grönman et al. (2016), in which the functional unit was 1000 kg of oat flakes reaching the

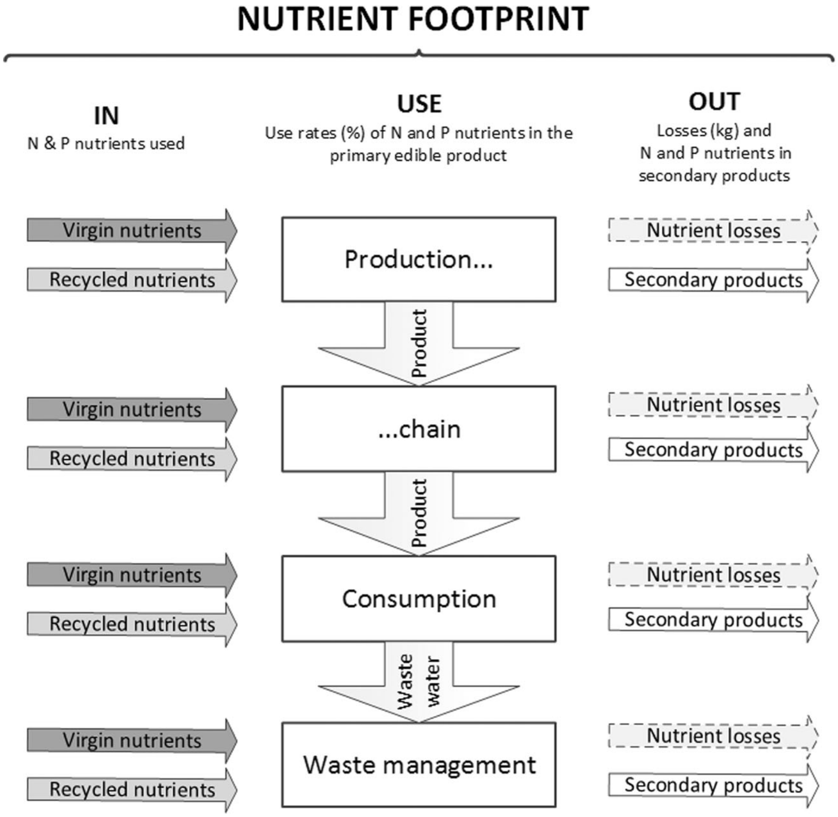


Fig. 1 The nutrient footprint principle. Adapted from Grönman et al. (2016)

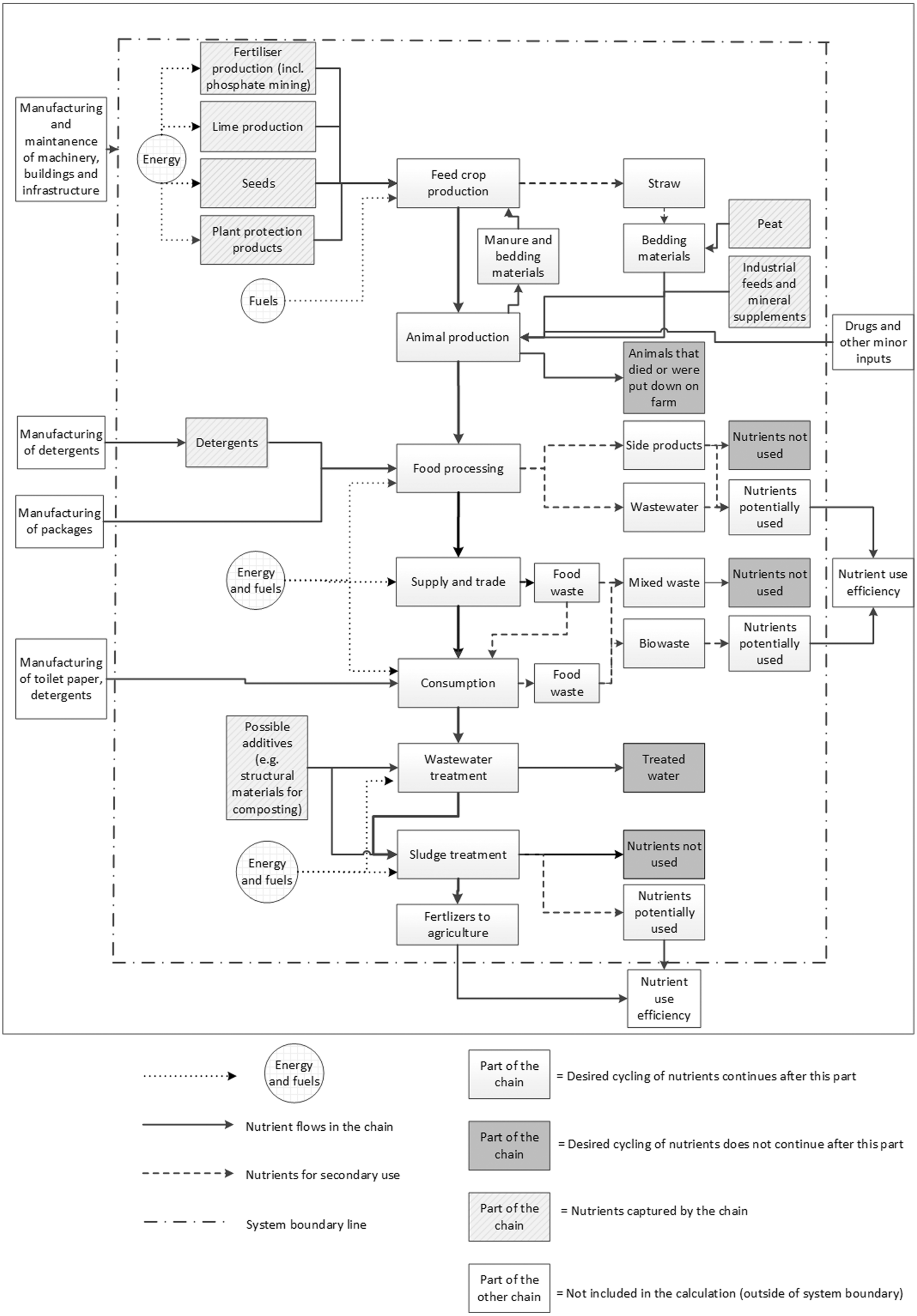
consumer. Furthermore, Grönman et al. (2016) included NutUE of food-waste treatment in the system boundary but excluded energy consumption during food preparation. In the present study, we excluded NutUE of food-waste treatment because we considered it not to belong to the main product chain. In addition, due to the difference in the definition of the functional units used by Grönman et al. (2016) and in the present study, we included energy consumption during food preparation.

2.3 Data acquisition

Data on the production of inorganic fertilisers were obtained from their manufacturers: Yara (2017) for N and Prud'Homme (2010) for P. Data on feed crops and animal production were based on a Finnish national LCA project on beef (FootprintBeef). In that project, a model integrating biological plant and animal models as well as the environmental LCA approach was developed. Nutrient flows through the beef production system, including inputs used, are modelled using dynamic biological functions. The model connects animal growth, feeding intensity and composition, feed production and manure and fertiliser use on different soil types and describes them for the lifetimes of a bull and a suckler cow. The inputs and outputs were adjusted accordingly to reflect the functional unit of this study. The model assumes that all feed crops are cultivated on farms and that all manure from cattle is spread on their own feed crops.

Nutrient losses during the animal production stage were calculated by subtracting the nutrients retained in the cattle from nutrients in inorganic fertilisers bought to produce the feed crops that fulfil energy requirements of the bull and suckler cow. Besides these inorganic fertilisers and manure excreted by the animals under study, no other N and P inputs (such as manure or other organic fertilisers from other farms) were assumed. Nutrients in manure were considered recycled nutrients, and losses during manure storage and field application were taken into account (Grönroos et al. 2009).

Mean data of nutrient inputs and emissions for a male calf originating from the Finnish suckler cow-calf system was used in the present study. In addition, part of nutrient inputs and emissions during the lifetime of a suckler cow was allocated to the latter's calves based on physical causality, following energy requirements in Finnish feeding recommendations for different activities of the suckler cow: maintenance, lactation, pregnancy and growth (Luke Statistics 2018). The energy requirement for maintenance of the suckler cow was allocated to the suckler cow's lactation, pregnancy and growth according to the relative shares of lactation, pregnancy and growth in their summed energy requirement (Table 1). Thus, each calf was assigned the energy requirement of one pregnancy, one lactation, and the share of one pregnancy and one lactation of the maintenance of a suckler cow. All energy required for


Fertiliser production (incl. phosphate mining)
Lime production
Seeds
Plant protection products
Energy
Fuels
Manufacturing and maintanence of machinery, buildings and infrastructure
Feed crop production
Straw
Manure and bedding materials
Bedding materials
Peat
Industrial feeds and mineral supplements
Animal production
Drugs and other minor inputs
Animals that died or were put down on farm
Manufacturing of detergents
Detergents
Manufacturing of packages
Food processing
Side products
Nutrients not used
Wastewater
Nutrients potentially used
Nutrient use efficiency
Energy and fuels
Supply and trade
Food waste
Mixed waste
Nutrients not used
Biowaste
Nutrients potentially used
Manufacturing of toilet paper, detergents
Consumption
Food waste
Possible additives (e.g. structural materials for composting)
Wastewater treatment
Treated water
Energy and fuels
Sludge treatment
Nutrients not used
Nutrients potentially used
Fertlizers to agriculture
Nutrient use efficiency
Energy and fuels
Nutrient flows in the chain
Nutrients for secondary use
System boundary line
Part of the chain = Desired cycling of nutrients continues after this part
Part of the chain = Desired cycling of nutrients does not continue after this part
Part of the chain = Nutrients captured by the chain
Part of the other chain = Not included in the calculation (outside of system boundary)

◀ **Fig. 2** Simplified life cycle phases and system boundary of the beef production and consumption chain. In the production and use of fuel and energy, the following are taken into account: nitrogen (N) and phosphorus (P) in the fuel and in fertilisers and seeds used to produce biofuels; emissions from energy production (N_2O, NH_3) and fuel combustion NO_x, NH_3 and N_2O; and P in ashes left from fuel combustion, if used

suckler cow growth was assigned to the meat coming from the suckler cow itself, as was the energy required for one pregnancy and lactation (as a proxy for the emissions of a suckler cow's dam during its pregnancy and lactation). This resulted in allocating 43% of emissions to the meat of a suckler cow and 57% to its calves.

An estimate of the number of cattle that died or were put down on Finnish farms was obtained from Hartikainen et al. (2014). According to European Commission (EC) Regulation 999/2001 (EC (European Commission) 2001), they are defined as class 1 risk materials for transmissible spongiform encephalopathies (TSEs) and must therefore be destroyed by incineration.

After slaughter, meat and other organs are separated and either processed into different food, feed and fertiliser products or disposed of as waste. We obtained data from a meat processing company and a company recycling animal-based secondary products and waste materials. Supplementary data from the literature and nutritional databases were used to calculate the percentages of different body parts and organs in live weight as well as where they end up during processing (EC (European Commission) 2001; Aalto 2010; Kauffman 2012; Huuskonen 2012). Data on the specific nutrient contents of bovine meat and organs were obtained from the USDA (2014) nutritional database, bone N content from Kauffman (2012), bone P content from Beighle et al. (1994) and blood and hoof N and P contents from the Fineli (2013) food composition database. All of these data were used to estimate the percentages of N and P that flow from an adult beef bull to primary and secondary products and waste materials at the gate of the meat processing company (Fig. 3).

Estimates of the energy used to store food in the retail chain were obtained from Taipale (2011). An estimate of the percentage of food wasted in retail chains was obtained from Eriksson et al. (2014). Estimates of the energy used by consumers to store and prepare food were obtained from Taipale (2011). The percentage of beef mass lost during food preparation was estimated as 26% (Sääksjärvi and Reinivuo 2004). In addition, 3.4% of the purchased beef was estimated to end up as food waste after food preparation (Hartikainen et al. 2013).

It was assumed that for a normal adult population, in which bodyweight remains stable, nutrient flow is balanced between intake and excretion. Little information is available about treatment of food waste from households; however, it can be estimated that 21% (23–29 million kg annually) of household food waste in Finland is collected separately as bio-waste (HSY 2011; Silvennoinen et al. 2012; Statistics Finland 2012; Silvennoinen 2013). The remaining 79% (98–100 million kg) ends up in municipal mixed waste. Therefore, it was assumed that 21% of the food waste nutrients of beef remain in usable form and 79% is lost. Nutrient flows during wastewater treatment were calculated as described by Grönman et al. (2016).

2.4 Sensitivity analysis

Sensitivity analysis was conducted for the factors that presumably influence the NutUE of the beef chain strongly. We selected the factors that affected the results the most in the previous study on oat flakes (Grönman et al. 2016): yield (kg/ha) and N fertilisation intensity (kg N/ha). In addition, we selected two factors that are specific to animal production: the percentage of nutrient inputs and emissions of the suckler cow allocated to calves and the killing-out percentage (i.e. carcass weight divided by live weight). Factors such as product losses during supply and trade, the magnitude of household waste and rates of N and P reduction during wastewater treatment were excluded because the previous study (Grönman et al. 2016) showed that they had little influence. Each factor was varied by ± 10% separately and independently.

3 Results

3.1 N and P footprints

One thousand kg of consumed beef require 1700 kg N and 189 kg P during its life cycle. The percentage of virgin nutrient is more than 50% for N but only 25% for P (Figs. 4 and 5).

Table 1 Share, %, of the total life time energy requirement of a suckler cow allocated to different activities and to each of its five calves, as percentages of the total

Share	Maintenance	Lactations (5)	Pregnancies (5)	Growth
Share of total energy requirement	70	17	5	9
Share of maintenance requirement divided among the other three activities		38	11	20
Share of the total energy requirement allocated to one calf out of 5		11	3	

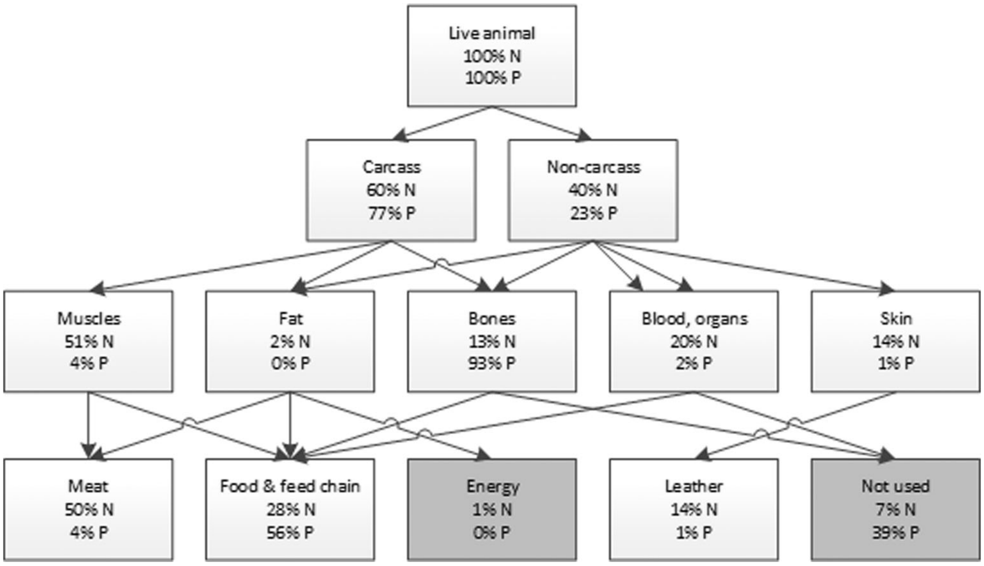


Fig. 3 Flow of beef bull nitrogen (N) and phosphorus (P) from slaughter to retail. Grey boxes indicate that nutrients are not used during or after this step

Virgin nutrients come mostly from inorganic fertilisers, while recycled nutrients come mostly from manure fertiliser and cereal straw bedding material.

For primary + secondary products, NutUE (N) is lowest in the life cycle phases of feed crop cultivation (57%) and wastewater treatment (14%) (Fig. 4), while NutUE (P) is lowest in the phases of food processing (57%), consumption (44%) and wastewater treatment (27%) (Fig. 5). In the food consumption phase, P losses originate from the fuels used in Finnish electricity production (Alakangas 2000; GaBi 6 2012). In the food processing phase, P is lost in the body parts (skull, brain, spinal cord and vertebrae) which are destroyed by incineration as class 1 risk materials for TSEs. In wastewater treatment, most of the N is released into the waterways or lost as gaseous N into the air (Säylä and Vilpas 2012), and only 30% of N ends up in the sludge and could be recycled. In contrast, 96% of wastewater P is sequestered in the sludge. Currently, only about half of the sludge nutrients are used as fertilisers either in agriculture (3%) or elsewhere (e.g. landscaping) (Lindsberg and Vilpas 2009).

The NutUEs of the primary product are remarkably lower than those of the primary + secondary products in the life cycle phases of animal production (for N and P) and food processing (for P). The lower values in the animal production phase show that most of the nutrients are returned back to the feed crop production phase as manure and bedding. In the food processing phase, 28% of animal N and 56% of animal P ends up in the secondary products, especially animal skin (14% of animal N and 1% of animal P).

3.2 Sensitivity analysis

Yield and N fertilisation intensity of feed production affected model results most strongly (Table 2). A 10% increase in the yield increased NutUE (N) and NutUE (P) of the primary + secondary products by more than 1 and almost 2 percentage points, respectively. A corresponding decrease in the yield reduced the NutUE of the whole chain almost equally. Variation in N fertilisation intensity affected NutUE (N) of the primary + secondary products as much as the variation in yield. Variation in the other factors selected—the percentage of nutrient inputs and emissions of the suckler cow allocated to calves and the killing-out percentage of the beef bull—had little influence on NutUE (N) and NutUE (P).

4 Discussion

The results show hotspots in the NutUEs of the beef production and consumption chain. For both N and P, NutUEs are lowest in the wastewater treatment phase. However, improvement in this phase is difficult to reach because the use of nutrients originating from wastewater sludge as fertilisers for crop production creates fears of contaminants ending up in food products. NutUE (N) was also relatively low during feed crop cultivation, indicating that N fertilisation was non-optimum. Precision farming and other measures to optimise N fertilisation to the level of plant requirements could improve NutUE (N).

Compared to oat flakes (Grönman et al. 2016), beef has lower NutUEs in the phases of crop production, food processing, supply and trade and consumption, as well as in the entire chain (Table 3). Beef's lower NutUEs during crop cultivation are likely to be caused at least in part by the larger percentage of manure used as fertiliser. When manure is used, the farmers may not consider that some of the nutrients will be released after the current growing season (in subsequent years), and

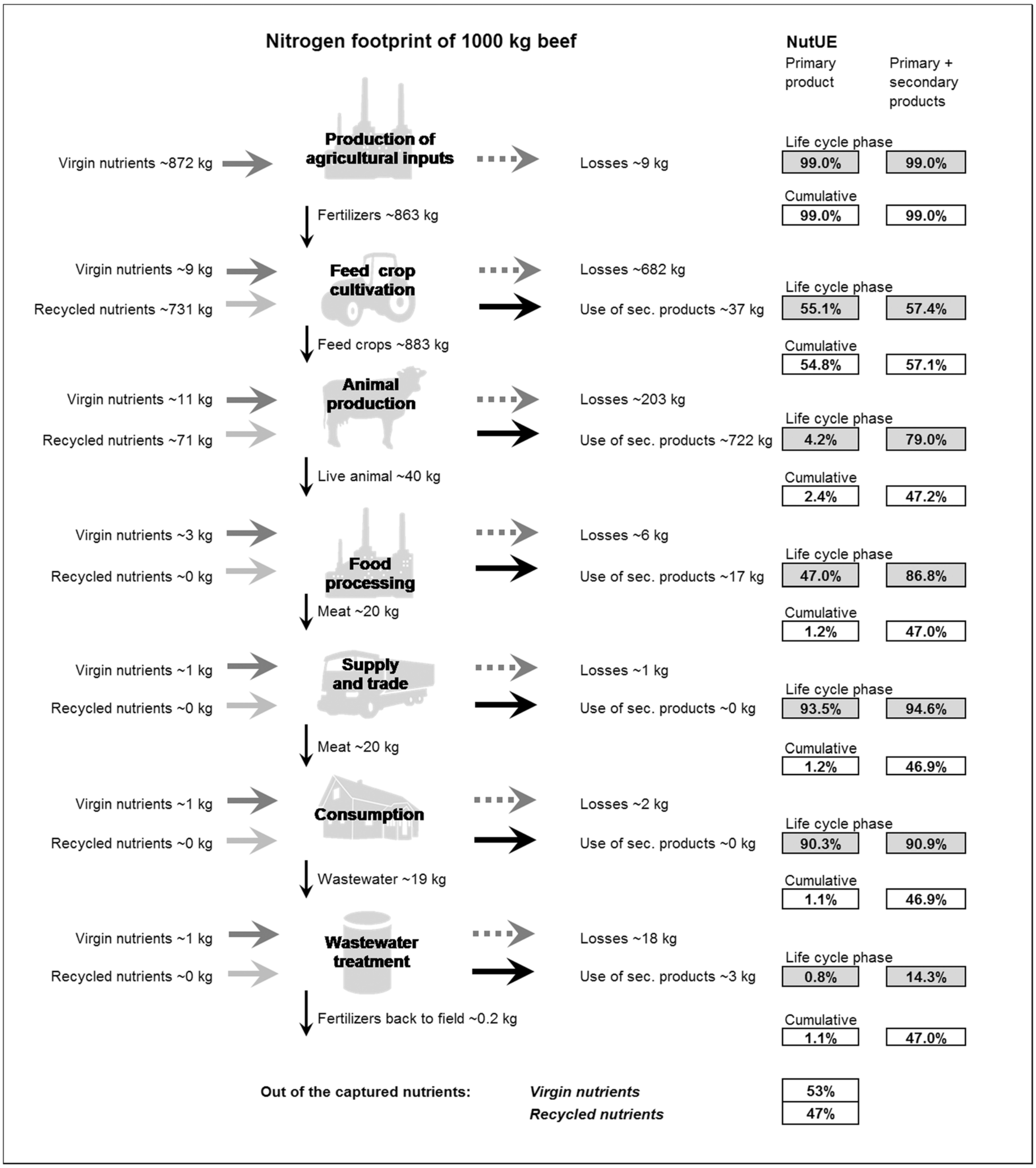


Fig. 4 Nitrogen (N) footprint of beef, including nutrient use efficiency (NutUE) of each phase of the production and consumption chain. Arrows represent N flows. Dark grey arrows represent virgin N and light grey arrows recycled N entering the chain. Dashed arrows represent N losses and black arrows N that can be used when recycled. Black vertical arrows represent N flows that transfer through the chain phases studied

therefore, more nutrients are applied than what the crops need. Also, farmers normally estimate fertilisation rates based on optimal growing conditions and optimised yield potential, but these often do not occur, increasing the risk that excessive nutrients will be released to the air or water. Beef has lower NutUE than oat flakes in the consumption phase because energy consumption (and related nutrient losses during energy production) during oat flake preparation was excluded (Grönman et al. 2016). Likewise, beef has lower NutUE in the supply and trade phase because it is refrigerated, while oat flakes can be stored at room temperature, requiring no additional energy.

The NutUEs of dairy cattle of Uwizeye et al. (2016) (27–48% for N and 46–85% for P) lie in the same ranges as those in the present study (47% for N and 74% for P for primary + secondary products), despite the significant differences in the methods. Uwizeye et al. (2016) consider NutUEs until the end of primary processing and include soil nutrient stocks, while the present study considers the entire chain and excludes soil nutrient stocks. Although their method may be more

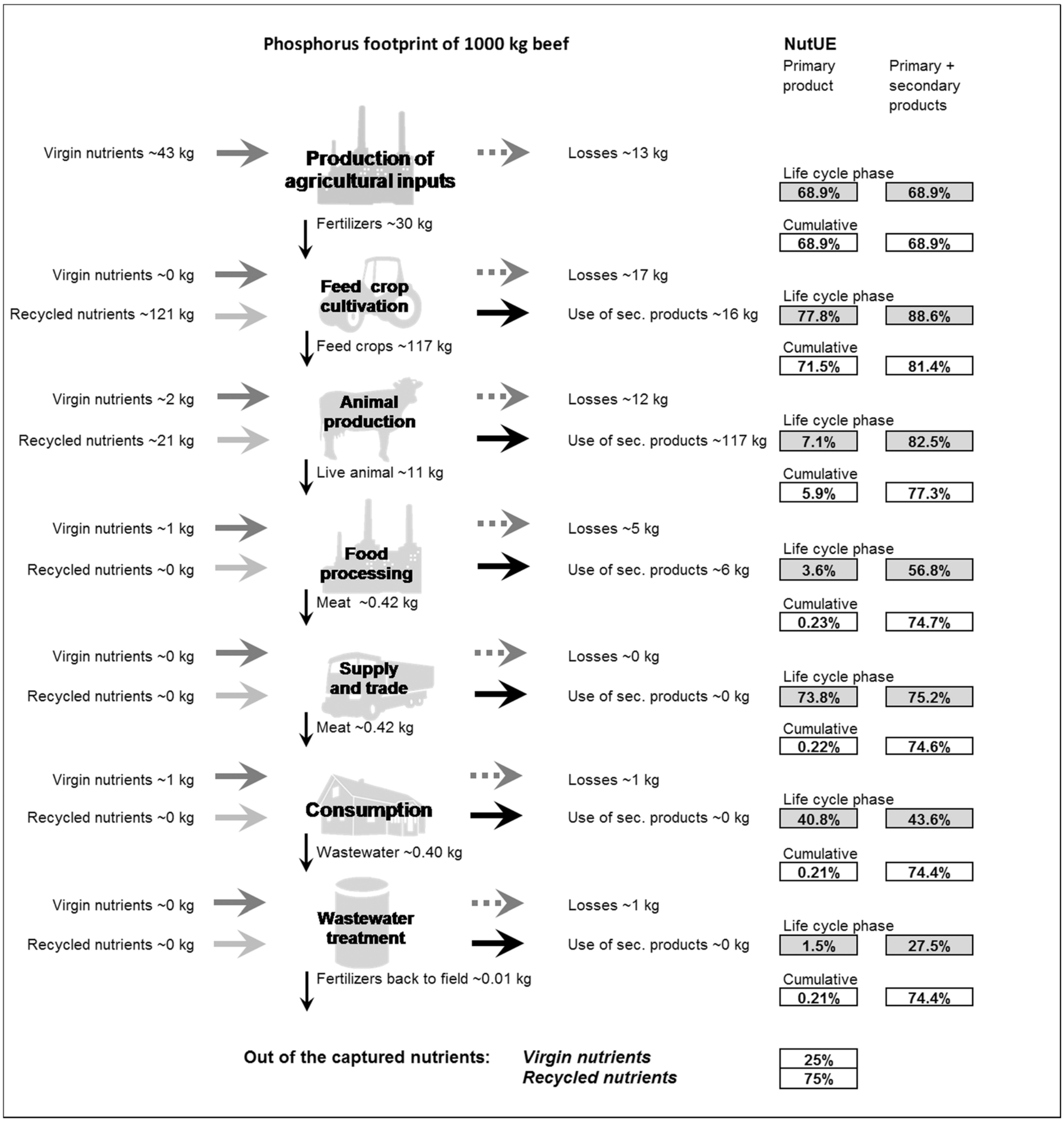


Fig. 5 Phosphorus (P) footprint of beef, including nutrient use efficiency (NutUE) of each phase of the production and consumption chain. Arrows represent P flows. Dark grey arrows represent virgin P and light grey arrows recycled P entering the chain. Dashed arrows represent P losses and black arrows P that can be used when recycled. Black vertical arrows represent P flows that transfer through the chain phases studied

motivating for chain actors up to the end of primary processing, consideration of the entire chain provides a wider perspective for authorities as well as for actors beyond primary processing, such as operators of wastewater treatment plants and processors of recycled nutrients.

In the literature, few authors have estimated N use. Leip et al. (2014) calculated an N footprint (direct N losses to the environment per kg carcass weight) and N investment factor of beef production systems in the European Union (EU) 27, using a farm gate system boundary, including slaughtering. In their study, the N footprint was ca. 500 g N/kg carcass weight, and N investment was 15–20 kg N/kg N in carcass weight. These values are relatively similar to those in the present study: 436 g N/kg carcass weight and 35 kg N/kg N in carcass weight.

According to Chatzimpiros and Barles (2013), the N use efficiency (NUE) of cultivating feed crops on French beef farms was 76%. Their overall NUE of the livestock system (7.2%), calculated as total N in retail products divided by total N inputs, is higher than that in the present study (1.2% when the same phases of the food production chain—from production of agricultural inputs to food supply and trade—are considered). Chatzimpiros and Barles (2013), however, averaged national beef production systems, while the present study considers only the suckler cow-calf system. According to Nguyen et al. (2010),

Table 2 Results of the sensitivity analysis. NutUEprimary product = the nutrient use efficiency of the whole production and consumption chain of the primary product (beef consumed); NutUEtotal = the nutrient use efficiency of the whole production and consumption chain of both the primary + secondary products; pp = percentage points

Variation	Nitrogen (N)		Phosphorus (P)	
	NutUEprimary product	NutUEtotal	NutUEprimary product	NutUE total
Feed crop yield − 10%	+ 0.0 pp	− 1.2 pp	+ 0.0 pp	− 1.7 pp
Feed crop yield + 10%	+ 0.0 pp	+ 1.2 pp	+ 0.0 pp	+ 1.8 pp
N-fertilisation − 10%	+ 0.0 pp	+ 1.2 pp	+ 0.0 pp	+ 0.0 pp
N-fertilisation + 10%	+ 0.0 pp	− 1.1 pp	+ 0.0 pp	+ 0.0 pp
Killing-out percentage − 10%	− 0.1 pp	+ 0.0 pp	+ 0.0 pp	− 0.2 pp
Killing-out percentage + 10%	+ 0.1 pp	+ 0.0 pp	+ 0.0 pp	+ 0.2 pp
Suckler cow allocation − 10%	+ 0.1 pp	+ 0.2 pp	+ 0.0 pp	− 0.4 pp
Suckler cow allocation + 10%	− 0.1 pp	− 0.2 pp	+ 0.0 pp	+ 0.4 pp

NUEs are generally higher in dairy bull-calf systems than in suckler cow-calf systems.

Leach et al. (2012) and Pierer et al. (2014) calculated Virtual N factors for beef. When calculated for only the slaughtered animal, the Virtual N factor for beef in the present study is about twice as high (12.9 vs. 8.5 in Leach et al. (2012) and 5.4 in Pierer et al. (2014)). When including the inputs and emissions allocated from the suckler cow as well, the Virtual N factor of the present study is ca. 5–8 times as high (45.6). The previous studies, however, averaged national beef production systems, while the present study considers only the suckler cow-calf system. Also, they did not include nutrient losses during fertiliser production.

In the literature, even fewer have estimated P use. Nguyen et al. (2010) calculated N and P farm gate balances and efficiencies of typical beef production systems in the EU, including a suckler cow-calf system resembling the system in the present study (Table 4). They report slightly larger N and P balances (calculated as nutrients in imported fertiliser and feed inputs minus nutrients in live animals sold)—437.7 kg N and 12.4 kg P per 1000 kg slaughter weight—than those in the present study (401.9 kg N and 10.6 kg P per 100 kg slaughter weight). However, their NutUEs are higher than those in the present study as well (NutUE (N) 0.09 vs. 0.05, respectively, and NutUE (P) 0.5 vs. 0.34, respectively).

The nutrient footprint offers information about the amount and efficiency of nutrient use in a simple and comparable form. In this sense, it is similar to the water footprint (Hoekstra et al. 2011), even though it does not consider relative access to the resource(s) in the same manner as the water footprint. Unlike water, however, nutrients are directly traded globally, and few regions are self-sufficient in nutrients.

Based on these calculations, the nutrient footprint seems to be a useful method for assessing nutrient use and its efficiency alongside other categories of potential impact, such as climate change and eutrophication potential. Current EC (European Commission) (2013) LCA guidelines already recommend assessing depletion of resources such as water, minerals and fossil fuels alongside categories of potential environmental impact. One can expect to obtain a much clearer overall image of the ecological impacts of products and their flows by combining the nutrient footprint and other resource depletion methods with assessments of potential environmental impacts.

In mainstream LCA, only potential mid-point impacts on the environment are commonly considered, and there is no

Table 3 NutUEs of nitrogen and phosphorus of beef (the present study) compared to that of oat flakes (Grönman et al. 2016), percentage use in the primary + secondary products

Phase	Nitrogen		Phosphorus	
	Beef	Oat flakes	Beef	Oat flakes
Crop production	57	74	89	100
Food processing	87	92	57	94
Supply and trade	95	100	75	100
Consumption	91	95	44	95
Entire chain	47	71	75	99

Table 4 Nitrogen and phosphorus inputs, outputs, balances and efficiencies in the present study and typical suckler cow-calf system in the European Union (Nguyen et al. 2010) presented as kg N and P 1000 kg slaughter weight

	The present study	Nguyen et al. 2010
Slaughter weight, kg	394	348
Age at slaughter, months	19	16
N balance, kg	401.9	437.7
N use efficiency	5%	9%
P balance, kg	10.6	12.4
P use efficiency	34%	50%

link to the overall sustainability and carrying capacity of ecosystems (Bjørn and Hauschild 2015). Recent discussion, however, has focused on whether limits of planetary boundaries should be taken into account (Steffen et al. 2015) to address such impacts (Sandin et al. 2015; Bjørn and Hauschild 2015). Steffen et al. (2015) considered both N and P flows at current levels at high risk of substantially altering the resilience of Earth systems. Therefore, closer attention needs to be paid to nutrient use.

5 Conclusions

The nutrient footprint method assesses nutrient balances of food chains and other bio-based production chains. It offers information about NutUE in a simple and comparable form to policy makers and to actors of the entire production chain. In transition towards systems with sustainable nutrient use, it is essential to identify hot spots of nutrient leakage to be able to close them and improve food chains.

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