Feed sources for livestock: Recycling towards a green planet

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Production of food has re-emerged at the top of the global political agenda, driven by two contemporary challenges: the challenge to produce enough nutritious food to feed a growing and more prosperous human population, and the challenge to produce this food in an environmentally sustainable way. Current levels of production of especially animal-source food (ASF), pose severe pressure on the environment via their emissions to air, water, and soil; and their use of scarce resources, such as land, water, and fossil energy. The livestock sector, for example, is responsible for about 15% of the global anthropogenic emissions of greenhouse gases and uses about 70% of global agricultural land.

Many proposed mitigation strategies to feed the world sustainably, therefore, focus primarily on reducing the environmental impact of the livestock sector, so-called production-side strategies. Other strategies focus on changing consumption patterns by reducing consumption of ASF, or on shifting from ASF with a higher environmental impact (e.g. beef) to ASF with a lower environmental impact (e.g. pork or chicken), so called consumption-side strategies.

Most of the environmental impact of production of ASF is related to production of feed. One production-side strategy to reduce the environmental impact is the use of products that humans cannot or do not want to eat, such as co-products, food-waste, and biomass from marginal lands for livestock feed (referred to as 'leftover streams' in this thesis). This strategy is effective, because feeding leftover streams to livestock transforms an inedible food stream into high-quality food products, such as meat, milk, and eggs.

Two production-side strategies that use leftover streams as livestock feed were explored in this thesis: replacing soybean meal (SBM) in diets of growing pigs with either rapeseed meal (RSM) or with waste-fed larvae meal. Replacing SBM with RSM in growing-pig diets was assessed because RSM became increasingly available following an increase in bio-energy production in the EU. In this strategy, therefore, the RSM content in pig diets increased at the expense of SBM. SBM is an ingredient associated with a high environmental impact. It was expected, therefore, that replacing SBM with RSM in pig diets would lead to a decrease in the environmental impact of pork production. Replacing SBM with waste-fed larvae meal was assessed because recent developments show the environmental benefits of rearing insects as livestock feed. Insects have a low feed conversion ratio (kg feed/kg product) and can be consumed completely, without residual materials, such as bones or feathers. The nutritional value of insects is high, especially as a protein source for livestock. Insect-based feed products, therefore, can replace conventional feed ingredients, such as SBM. Altogether this strategy suggests that waste-fed larvae meal might become an important alternative feed source in the future.

To gain insight into the status quo of the environmental impact of both mitigation strategies, replacing SBM with RSM or with waste-fed insects, we first used the attributional life cycle assessment (ALCA) method. Based on the ALCA method, results showed that each mitigation strategy was promising. Replacing SBM with RSM in growing pig diets hardly changed either global warming potential (GWP) or energy use (EU), but decreased land use (LU) up to 16% per kg body weight gain. As expected, feed production had the largest environmental impact, responsible for about 50% of the GWP, 60% of the EU, and 77% of the total LU. Feed production in combination with feed intake, were the most sensitive parameters; a small change in both these two parameters changed the results. Replacing SBM with waste-fed larvae meal in growing-pig diets showed that EU hardly changed, but GWP (29%) and LU (54%) decreased per kg body weight gain. Based on ALCA results, each mitigation strategy, therefore, seems to offer potential to reduce the environmental impact of pork production. An ALCA, however, has two disadvantages: it does not account for product-packages and it does not consider feed-food competition.

The first disadvantage of ALCA was that the complexity of dealing with product-packages is not fully considered. 'Product-package' refers to a multiple-output situation. During the processing of sugar beet, for example, beet-pulp and molasses are produced in addition to sugar. Sugar, beet-pulp, and molasses together form a 'package of products' because they cannot be produced independently from each other. An ALCA does not account for the fact that the production volume of the co-product(s) depends on the demand for the determining product (e.g. sugar), which results in the limited availability of co-products. Increasing the use of co-products in animal feed, consequently, results in reducing use of a co-product in another sector, requiring them to be replaced with a different product. The environmental impact of increasing the use of a co-product or food-waste, therefore, depends on the net environmental impact. The net environmental impact refers to the environmental benefits of using the product in its new application minus the environmental cost of replacing the product in its old application.

A consequential theoretical framework was developed to account for product-packages. The results, based on the consequential framework, contradicted standard ALCA results. The consequential LCA (CLCA) method we used for replacing SBM with RSM showed an increased GWP (up to 15%), EU (up to 12%), and LU (up to 10%) per kg body weight gain. Moreover, this

CLCA method showed that replacing SBM with waste-fed larvae meal increased GWP (60%) and EU (90%), but decreased LU (73%) per kg body weight gain.

Accounting for product-packages increased the net environmental impact of each strategy, replacing SBM with RSM or with waste-fed larvae meal. The difference in results between ALCA and CLCA was especially large in the strategy with waste-fed larvae meal. The difference was caused mainly by the use of food-waste. Food-waste fed to larvae was used initially to produce bio-energy via anaerobic digestion. In CLCA, the environmental impact related to replacing the bio-energy function of food-waste with fossil-energy was included. The net environmental impact became negative, because environmental benefits of replacing SBM with waste-fed larvae meal were less than environmental costs related to the marginal energy source, i.e. fossil energy, replacing the bio-energy. Results of the indirect environmental impact, however, are situation specific: if the marginal energy source were wind or solar energy, the net environmental impact of using waste-fed larvae meal might be positive. Waste-fed larvae meal, therefore, appears to be an interesting mitigation strategy only when energy from wind and solar energy are used more dominantly than energy from fossil sources.

If results were based solely on ALCA, then these potentially negative impacts would have been overlooked. Consideration of the environmental consequences of product-packaging, therefore, is essential to determine total environmental costs. If policy makers or the feed industry want to assess the net environmental impact of a potential mitigation strategy, then we recommend to perform a CLCA instead of an ALCA. The framework developed in this thesis can be used to perform such an assessment.

The second disadvantage of an LCA was that it does not take into account feed-food competition, e.g. competition for land between humans and animals. Most LCA studies focus on the total amount of land required to produce one kg ASF. LCA studies do not account for competition for land between humans and animals, or so-called feed-food competition. In other words, they do not include, differences in the consumption of human-edible products by various livestock species or differences in the suitability of land used for feed production as land to cultivate food-crops directly. Given the global constraints on land, it is more efficient to grow food directly for human consumption rather than for livestock. To address the contribution of livestock to a future sustainable food supply, a measure for land use efficiency was developed, called the land use ratio (LUR). The LUR accounts for plant productivity, efficiency of converting human-inedible feed into ASF, and suitability of land for crop cultivation. The LUR also has a life-cycle perspective.

Results of the LUR illustrated that dairy cows on sandy soil, laying hens, and pig production systems in the Netherlands have a LUR >1.0. In terms of protein produced per m^2, therefore, it is more efficient to use these soils for livestock production to produce crops for direct human consumption than to produce feed for livestock. Only dairy cows on peat soil produce human digestible protein (HDP) more efficiently than crops do, because peat is not suitable for crop production. The LUR allows identification of livestock production systems that are able to produce HDP more efficiently than crops do. Livestock systems with a LUR<1.0, such as dairy on peat, have an important role to play in future sustainable nutrition supply.

Results of the LUR showed that livestock production systems using mainly co-products, food-waste, and biomass from marginal land, can produce human digestible protein more efficiently than crop production systems do. The availability of those leftover streams, however, is limited and, therefore, the amount of ASF produced based only on leftover streams is also limited. Because LUR is a ratio, LUR results do not give an indication of how much ASF can be produced based on livestock systems that feed mainly on leftover streams.

The third, and last, mitigation strategy, therefore, focused on the amount of ASF that can be consumed by humans, when livestock are fed only on leftover steams, also referred to as "default livestock". The calculation of the amount of ASF was based on the assumption that a vegan diet was consumed in principle. The resulting co-products and food-waste were fed to pigs and, biomass from grazing land was fed to ruminants. Results showed that in total 21 g animal source protein per person per day could be produced by feeding livestock entirely on leftovers.

Considering feed-food crops and feeding food-waste made an important contribution to the 21 g of protein that could be produced from default livestock. Considering feed-food crops implies that choices have to be made between different crops, based on their contribution to feed and food production. Oil production from soy cultivation, for example, resulted in the co-product SBM. Results showed that considering feed-food crops can affect the final protein production from pork. The practice of feeding food-waste to livestock is currently prohibited due to problems of food safety but the practice shows potential in extensively reducing the environmental impact of livestock production. Considering feed-food crops and feeding food-waste are examples of mitigation strategies that currently can be implemented to reduce further the environmental impact of the livestock sector.

On average, it is recommended to consume about 57 g of protein from ASF or plant-origin per person per day. Only ASF from default livestock does not fulfil the current global protein consumption of 32 g per person per day, but about one third of the protein each person needs can be produced without any competition for land between feed and food production. To feed the world more sustainably, by requiring livestock production systems with a LUR <1.0,

however, a paradigm shift is needed. Global average consumption of ASF should decrease to about 21 g of protein per person per day. Innovations are needed, moreover, to overcome problems of food safety and technical concerns related to collecting the leftover streams. This applies, in particular to food-waste, which is currently unused in livestock production but which presents a valuable strategy in mitigating environmental impacts caused by livestock production. Livestock systems should change their focus, furthermore, from increasing productivity per animal towards increasing protein production for humans per ha. By using leftover streams optimally, the livestock sector is able to produce a crucial amount of protein, while still avoiding competition for land between feed and food crops. Livestock, therefore, can make an important contribution to the future nutrition supply.