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Feeding livestock food residue and the consequences for the environmental impact of meat

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Abstract

The environmental impact of meat is high mainly due to the feed required by livestock in combination with the impacts of cultivating, transporting and processing of feed crops such as tapioca and grains. Like regular feed crops, livestock also feed on residue from the food industry, such as pulp, scrap and peels. Both types of raw material have different environmental impacts. Feeding food residue to livestock is an efficient way to upgrade a low quality material into high quality foods. In the Netherlands, food residue represents the majority of the feedstock for feed. Distinguishing crops from food residue has consequences for the ascribed environmental impact of meat. This paper separates these two streams using volume, environmental impact and their relevance in meat production. An assessment is made of three food industries (sugar beet industry, vegetable oil industry and potato product industry) that produce the largest stream of food residue, and of the pork industry, as an example of meat production. The environmental impact of food residue-based feed is allocated in three different ways: mass ratio, economic basis, and no assigned burden. We found that the amount of pork produced from food residue is substantial. The environmental impact of food residue-based feed is also significantly lower than grain-based feed. We discuss changes in vegetable and in animal product consumption that influence the environmental impact of pork. It is concluded that the use of current food residue keeps the environmental impact of livestock foods relatively low. However, a further increase in meat consumption would require more feed grains with a correspondingly larger environmental impact because food residues are used up.

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Keywords: Meat; Livestock; Food residue; Consumption

1. Introduction

The production and consumption of food requires large amounts of resources such as land, water, materials and energy and causes emissions such as greenhouse gases, pesticides, heavy metals and domestic wastes to the biosphere. This environmental impact of food is expected to increase due to population growth and a more luxurious consumption. Research has been done on lowering resource use and emissions per kilogram produced food [1–7]. In order to reduce the environmental impact and to provide current and future population with sufficient food supplies, it is often suggested to transform or substitute animal food products [8,9]. These conclusions are largely based on the fact that 32% of the world yielded grains [10] and up to 68% of the grains used by developed countries [11] are being fed to livestock. A diet of meat, therefore, uses more resources than a vegetarian diet [12]. Feeding crops such as grains and tapioca to livestock may be unsustainable because natural resources, e.g. land, water and energy, used by feed crops could also be used for cultivating food crops [13] or for preserving nature [14].

Livestock is, however, not only fed crops. In industrialized countries livestock is fed with concentrates purchased from the feed industry. To produce concentrates the feed industry purchases feedstock from international markets. The feedstock used is selected on a least cost basis [15]. The feedstock purchased includes not only crops (wheat, maize, soybeans,
tapioca, etc.) but also food residue from, for instance, the food processing industry (oilseed scrap, molasses, potato peels, etc.). Currently, 70% of the feedstock used in the Dutch feed industry originates from the food processing industry [16]. These food residues are generated due to consumption of vegetable or vegetable-based foodstuffs. For instance, a sugar beet processing plant yields beside sugar and also beet pulp and molasses for feed purposes. The total amount of food residue is significant. According to Elzenga et al. [17] more than half of the industrial waste, $10.4 \times 10^9$ kg of the total $19.1 \times 10^9$ kg, produced in the Netherlands originate from the food industry of which $7.6 \times 10^9$ kg is used as a feed source. Feeding food residue to livestock can be seen as an effective option for handling waste, because it transforms an inedible stream into high quality food products, such as meat, milk, and eggs.

The goal of this paper is to determine the effect of feeding food residue on the environmental impact of meat produced in the Netherlands. Therefore, a distinction is made between meat produced from food residue and that from grain-based feed.

2. Method

2.1. Boundary setting

The focus of this paper is on the present Dutch food system. The Netherlands produces large amounts of food products which yield a large amount of food residue. This study takes into account the largest streams of food residue from the Dutch food industries, namely the sugar beet industry, the vegetable oil industry and the potato product industry. These three industries produce 66% [18] of the available food residue in the Netherlands and 45% of the total amount of feedstock used in the feed industry for concentrate production. Residues of the other food industries are considerably smaller or are too diverse in composition and, therefore, not taken into account.

The Netherlands imports large quantities of agricultural products (e.g. wheat, beans) which are processed domestically into agricultural commodities (e.g. bread, chocolate). These commodities are largely exported. Attributing all food residues produced in the Netherlands to the Dutch population would, therefore, result in an unrealistically large amount per person. Consequently, the amount of meat per person produced from food residue would be largely overestimated as well. Therefore, we determine the food residue production for the average Dutch person on the basis of his/her food consumption pattern. The residues are, subsequently, used as feed for pigs to determine the potential amount of livestock food (pork) that can be produced per person. Pigs are selected, instead of cattle or poultry, for reasons of their intermediate feed conversion ratio, for producing only a single food product and for consuming only feed from the feed industry. By this approach we limit the number of multifunctional processes and therefore the number of allocations required. To compensate for this simplification the amount of pork produced from food residue is compared with the recommended animal protein consumption in the Netherlands.

2.2. Indicators

The production of feedstock and meat results in many different environmental impacts. Gerbens-Leenes et al. [19] give an overview of indicators for environmental sustainability in food production, from a local level to regional level to global level. To understand environmental effects and interactions within the food production system they propose using the global environmental performance indicators: land use, energy use and water use. Therefore, this study selected global environmental performance indicators that are affected by feed: land use and energy use. Water use is not selected in this study because water requirements per unit of nutritional energy provided by the crop are all in the same order of magnitude [20]. Therefore, no differences in water use will be found in this study. Crop production is by far the largest land user in the pork production chain and land used to produce feed crops competes directly with land used for food crops. Furthermore, land requirements differ considerably per crop due to the different yields. The energy use for crop production and transportation of crops varies also considerably per crop because of different energy inputs per kilogram of product for ploughing, harvesting, manure pesticides, etc. Moreover, different crops are produced in different regions of the world resulting in diverging energy use for transportation. In previous studies the energy and the land requirements of various feed ingredients are quantified [21,22]. These values are used to quantify the flows in this system analysis of the food production system.

2.3. Allocation

Intentionally food residues from the food industry were regarded as waste and had, therefore, no environmental impact. However, these food residues have become useful products and the food industry derives nowadays a profitable income from selling their food residues. Furthermore, food residues can be used for multiple purposes. Besides as a feed ingredient food residues can, for instance, also be used for providing renewable energy. Due to the economical value and the multiple uses of food residues Zhu and van Ierland [23] argue that food residues should be ascribed an environmental impact. To attribute an environmental impact to food residues various allocation methods can be applied [24]. In this study, three allocation methods were perceived as most relevant and used for allocating the environmental impact of food residues:

1. On a by-product basis, meaning that no environmental impact was attributed to the food residue product but only to the main product.
2. On the present economical value as feedstock for feed.
3. On mass ratio.
3. Qualifying animal protein production

3.1. Food consumption pattern

Opinions differ on the daily recommended amount of protein (vegetable and animal) required for a healthy diet. For example, in the Netherlands 60 g of proteins per day is recommended for an adult while the World Health Organization and the Food and Agricultural Organization recommends 51 g/day [25]. The daily amount of protein required differs between gender and age. The Health Council of the Netherlands advises individuals to consume vegetable and animal proteins in a ratio of 1:1, meaning that a daily animal protein consumption of approximately 30 g/day is recommended [26]. According to the last food consumption survey in the Netherlands the average consumption of animal proteins is 52 g/cap/day half of which was meat-based and the other half consists of fish, milk and egg products [27]. Since pork has a protein content of approximately 20%, 150 g of pork meat has to be consumed to comply with the recommended 30 g of animal protein per day.

The food products that generate the largest food residues are consumed for different purposes. Vegetable oils and sugar are consumed as supplementary food products. Although, sugar has high digestible energy content it is mainly used as a sweetener. Vegetable oils for food consumption are mainly used for baking, frying and food flavouring. In contrast to vegetable oils and sugar, potatoes are consumed for their high starch value. These products have been important foodstuffs in the Netherlands for decades. Fig. 1 shows the consumption of sugar, potato and vegetable oil over the last 40 years.

3.2. Animal feed

Pigs are traditionally scavengers and in early domestication they were raised as a means of utilising human food wastes. If livestock has to function and thrive optimally feed needs to have a certain nutritive quality expressed in the nutritive value of feed. There are different systems to evaluate the nutritive value of feed all relating to the energy content of a common feed ingredient and expressed as feeding units. In the Netherlands the nutritive value for pork is expressed as EW (Energie Waarde; energy value pigs). The nutritive values of the feed ingredients used in this study are extracted from the feed tables of the Dutch Central Bureau for Livestock Feeding [28]. A feed conversion factor of 4.0 EW for 1 kg of slaughtered pork is used [29].

4. Quantifying human inedible residues

4.1. Sugar beet industry

The Dutch sugar beet industry produces sugar and derivatives from domestically grown sugar beets. The average sugar beet yield in the Netherlands is 57.9 t/ha. The energy input for cultivating, processing and transport is 1.27 MJ/kg [30].

A sugar beet contains on average 14% sugar. Therefore, 1000 kg of sugar beet, without the foliage, yields 140 kg of sugar. The remainder, 58 kg of dried pulp, 40 kg of molasses, 15 kg of beet residue, 60 kg of Betacal and 687 kg of water are by-products [31]. The dried pulp and molasses are suitable for feed [28]. Molasses is also used as a feedstock for beverage products and the remainder vinasse is used as feed. The sugar consumption in the Netherlands has been relatively constant for the past several decades amounting to an average consumption of 43 kg/person [32]. This corresponds to 307 kg of sugar beet and results in 18 kg of dried pulp and 12 kg of molasses.

4.2. Vegetable oil industry

Vegetable oils are extracted from oily seeds such as sunflower seeds, rapeseeds and soybeans. The extracted oils are suitable as food oils in households or are utilised for multiple food and non-food purposes in the industry. Oils for food are processed in sauces, margarine, dressings and frying fat. These foods are being used in salads and bread products or used for baking and frying of foodstuffs such as bread, biscuits, meat, fish and chips. Non-food purposes for vegetable oils are among other things: oil chemicals, cleaners, cosmetics, medicines, body-care products, paper, rubber, lubricants and solvents.

Soybean oil represents 84% of the total vegetable oil produced in the Netherlands, making it by far the largest vegetable oil produced there [33]. Soybeans have an oil-content of 20% nearly all of which can be extracted. This means that 10 kg of beans produce 2 kg of oil and 8 kg of soybean scrap. A Dutch person uses yearly approximately 18 kg of vegetable oils for food purposes generating 72 kg of soybean scrap. Soybean yield on average 2.54 t/ha. The energy input for soybeans is 5.26 MJ/kg [30].

4.3. Potato product industry

Total Dutch consumption of potatoes has dropped in the Netherlands from 250 kg/pp/year in 1852 to 97 kg/pp/year in 2002 [32]. However, potato products, chips, fries, precooked potatoes, etc. have increased to 30 kg/pp/year. By producing potato products on average 46% of the potato’s original weight is lost divided in 24% water evaporation and 22% peels and starches which are suitable as a raw material for feed [34]. In

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Fig. 1. The supply of the three foodstuffs that generate the bulk of the food residue in the Netherlands during the period 1960–2000. Source: FAOSTAT [32].
the Netherlands potatoes yield on average 47 t/ha. Energy input for cultivating and transporting potatoes is 1.66 MJ/kg [30].

5. Animal protein production from food residue

Eq. (1) shows how the total amount of pork produced from food residue can be calculated. The consumption of sugar, potatoes and vegetable oil generates food residue with a total nutritive value of 118 EW/cap/year (Table 1). With the feed conversion factor of 4 EW/kg pork this yields an amount of 81 g/pork/person/day.

\[
X = \sum_{i=1}^{n} \frac{a_i \times b_i}{c}
\]

(1)

Where: 
- \(X\) is the amount of pork (g/cap/day); 
- \(a\) the amount of food residue \(i\) (kg/cap/day); 
- \(b\) the nutritive value of food residue \(i\) (EW/kg); and 
- \(c\) the conversion factor for pork (EW/kg).

6. The environmental impact of pork by different allocation methods

Table 2 shows the allocation ratio for each product derived from the different crops as used in this study as well as the energy required for harvesting, processing and transporting the crop. With these data the energy and land input for producing feed for pork consumption is calculated for a grain-based feed and a feed which is based on food residue. The feed based on food residue is allocated according to the different allocation rules. The feed residue with the lowest energy or land input is plotted first followed by the second lowest, etc. until all the food residues are used. In this study the sequence from low to high energy and land use is the following: potato peels, sugar beet pulp, molasses and soybean scrap. When all food residues are used, it is assumed that the feed industry then uses wheat as a feedstock for feed. The results are shown in Figs. 2 and 3. At a consumption of 150 g pork produced from grain-based feed requires 2.7 MJ and 1.8 m². Compared to feed with food residue, grain-based feed always has a higher energy and land use. However, there are large differences between grain-based feed and the various allocation types. Food residue-based feed with an allocation on main product vs. by-product gives no impact until wheat must be fed. A consumption of 150 g pork requires 1.1 MJ and 0.7 m². The price allocation shows an increase in gradient for energy and land input when pork consumption rises above 81 g/day. However, the lowest gradient is when pork consumption is reduced to 29 g/cap/day whereupon only domestic food residue, e.g. from potato and sugar beet, is used as feed source. At a consumption of 150 g pork a price allocation requires 1.9 MJ and 1.2 m². When allocated on a mass basis, the land and energy use is much higher than for the other two allocations. At a consumption of 150 g pork an allocation on mass requires 2.7 MJ for energy and 1.6 m² for land.

7. Discussion

7.1. The total amount of animal food products from food residue

The total amount of food residue in Table 1 represents an underestimate; there are numerous additional food products and non-food products that yield food residue which could also be an excellent feed. The food residues mentioned are, however, less important in terms of tonnage than those listed or are less accurately reported. It is estimated that the listed

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Table 1

<table>
<thead>
<tr>
<th>Food residue</th>
<th>Supply (kg/cap/yr)</th>
<th>NV residue (EW/kg dm)</th>
<th>Available NV (EW/cap/yr)</th>
<th>Available pork (g/pork/cap/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean scrap</td>
<td>72</td>
<td>1.07</td>
<td>77</td>
<td>53</td>
</tr>
<tr>
<td>Dried beet pulp</td>
<td>18</td>
<td>1.15</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td>Molasses</td>
<td>12</td>
<td>0.97</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Potato peels</td>
<td>7</td>
<td>1.22</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>113</td>
<td>118</td>
<td>81</td>
<td></td>
</tr>
</tbody>
</table>

NV: nutritive value. The nutritive value of these food residues as feed and the amount of pork that can be obtained from it.

Source: Dutch Central Bureau for Livestock Feeding (CVB) [28].

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Table 2

<table>
<thead>
<tr>
<th>Crop</th>
<th>Products</th>
<th>Yield (t dm/ha)</th>
<th>Land input (m²/kg)</th>
<th>Energy input (MJ/kg)</th>
<th>Allocation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Grain</td>
<td>3.1</td>
<td>3.78</td>
<td>5.84</td>
<td>100 100 100</td>
</tr>
<tr>
<td>Soybean</td>
<td>Oil</td>
<td>2.5</td>
<td>3.92</td>
<td>5.26</td>
<td>20  50 100</td>
</tr>
<tr>
<td></td>
<td>Scrap</td>
<td></td>
<td></td>
<td></td>
<td>80  50 0</td>
</tr>
<tr>
<td>Sugar</td>
<td>Sugar beet pulp</td>
<td>16.5</td>
<td>0.61</td>
<td>1.27</td>
<td>59  91 100</td>
</tr>
<tr>
<td></td>
<td>Molasses</td>
<td></td>
<td></td>
<td></td>
<td>24  5 0</td>
</tr>
<tr>
<td>Potato</td>
<td>Potato Peels</td>
<td>9.5</td>
<td>1.05</td>
<td>1.66</td>
<td>77  99 100</td>
</tr>
<tr>
<td></td>
<td>Peels</td>
<td></td>
<td></td>
<td></td>
<td>23  1 0</td>
</tr>
</tbody>
</table>

The allocation percentage applied for each product derived from the crop.

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Fig. 2. Land requirement for feed production on different allocations and for grain-based feed related to the amount of pork consumed.
food residue represents approximately 60% of total food residue from the food industry in the Netherlands. The remaining food residue is, however, difficult to link directly to the Dutch consumption because the Netherlands exports large amounts of food. On the other hand, the Netherlands imports large amounts of food that yield food residue in other countries. When it is assumed that an 81 g of pork from food residue of Dutch consumption represents 60% of the entire food residues suitable for feed than 135 g of pork per day or approximately 27 g of animal protein can be produced from food residue. This amount is close to the recommended protein intake of 30 g/day, but still far from the actual consumption of 75 g/day.

Food residue from the food industry is not the only material that is suitable for feed. Other food related sectors, e.g. the food trade sector (retailers), the food preparation sector (restaurants, hospitals, household) and the agricultural sector also generate food residue, e.g. exceeded shelf life, cooked waste (swill), vegetable fruit and garden waste, food left-over and crop residues. Some of these food residues are currently fed to livestock while others are not allowed due to health regulations (e.g. swill) or are not economically feasible (e.g. vegetable household waste), therefore, the potential amount of pork that could be produced from food residue exceeds the amount calculated here.

7.2. Pork vs. other livestock

The pig with its intermediate feed conversion ratio is used as an example to produce human edible proteins. This simplification overlooks the use of other domestic animals and the use of livestock to produce more than essential amino acids. Other domestic animals such as cows and poultry have, respectively, higher and lower feed conversion factors. From the same amount of feed less meat comes from keeping cows and more from keeping poultry. Cows and poultry also produce milk and eggs, respectively, which have a lower feed conversion than meat. Therefore, we expect that in a more common situation, where multiple livestock species are used to produce different types of animal products which yield a wider variation in suitable human nutrients, the available animal foods for humans produced out of food residue by livestock will be close to the values calculated in this study.

7.3. Effect of dietary changes on food residue

Consumption of vegetable or vegetable-based foodstuffs generates organic residues higher up in the food production chain. Historically animals were already fed organic residues produced on farms and by local villagers. Nowadays, consumers in industrialized countries consume, however, more processed foods and industrially prepared meals, so-called ready-to-cook, ready-to-heat and ready-to-eat meals. More food residues are, therefore, generated at the food industry instead of at the consumer. As a result the heterogeneity, quality and availability of food residue as a feedstock for feed increased.

The consumption of the foodstuff yielding food residue studied has been rather constant over the last decades. However, it is possible that the consumed amount changes or that these foodstuffs will be substituted, for instance, when the sugar consumed in the Netherlands is not produced from sugar beet any longer but from sugar cane. As a result of such dietary changes the amount of food residue per capita and the amount of animal food products produced from it can change.

7.4. Effect of allocation

This study showed that independent of the allocation methods used the environmental impact of grain-based feed is always higher than food residue-based feed. However, depending on the allocation used, the environmental impact of food residue-based feed can vary considerably. Besides variation in environmental impact due to different allocation methods changed regulation can have an effect as well. For instance, prices fluctuate largely which affect the ascribed environmental burden of a product greatly. Two examples are provided to show that presently available food residue could change in value from highly valued basis of livestock feed to unwanted wastes. In the Netherlands arable farmers bought manure from livestock farmers. Using an economic allocation approach the environmental impact of manure is allocated to the arable products. However, in 1996, a mineral accounting system was introduced to reduce eutrophication. Under this system the input and output of nitrogen and phosphate for each farm is computed. Any imbalances result in farms paying fines. Because livestock farmers produce large surpluses of manure, they must pay arable farmers to use their manure. In such a system the environmental impact of manure is allocated to the livestock products. A second example shows how insights in food safety can also change the economic value and thus economic allocation. Bovine spongiform encephalopathy (BSE) in cows, for instance, led to a ban on the use of slaughter residues for feed purposes [35]. Before the BSE affair, abattoir fines had to pay to get rid of the slaughter residues. Mentioned examples imply that presently available food residues can change in value from highly valued basis of livestock feed, to unwanted wastes. Such changed regulations may have large consequences for the derived environmental impacts of meat.
Currently, nutritive rich food residue is mainly used as feedstock for feed. However, food residue can also be used for different purposes. Elferink [29] and Nonhebel [36] compared systems that yield both energy and protein foods. These studies showed that incinerating food residue instead of feeding is considerably less efficient in terms of energy and land requirements.

7.5. The environmental impact

In this study we focussed on land use and energy use as environmental indicators. Other environmental impacts are related to the production of animal food products as well. The use of pesticide, fertiliser, manure and water, for instance, are also affected by the feedstock used and will show a similar relation as found for land and energy. However, some impacts are hardly affected by changes in the feedstock used. For instance, feed composition can influences the manure quality and quantity and thereby the emissions of methane (CH$_4$), ammonia (NH$_3$) and nitrous oxide (N$_2$O) [37]. However, methane, ammonia and nitrous oxide emissions depend mainly on the manure excretion of the livestock and the management of the manure [37]. Although, feed determines largely the environmental impact of animal food products not all impacts are related to feed composition. Therefore, the results of this study only show the effect of feed related environmental impacts.

7.6. Implications of results

This study suggests more ways to reduce the environmental impact of food. From a natural resource perspective feeding waste is a very efficient way of producing food. The results found in this study can be simplified to the schematic representation shown in Fig. 4. If feeding food residue is seen as waste treatment the environmental impact is low, section A—B. This implies that up to point B, meat production is a very efficient way of processing food residue. When the amount of food residue varies due to diet changes or substitution of foodstuffs the position of point B will change correspondingly. Beyond point B, all food residues are fed, feed crops are required to produce enough meat to comply with current consumption. Consequently the environmental impact increases in section B—C. This also means that an increase in meat consumption would mean a stronger increase in the environmental impact than currently assumed. This is because the amount of food residue available per person is already fed. Therefore, grain-based feed is required to produce an additional demand. This effect is represented by section C—D. On the other hand, when meat consumption is reduced the environmental impact drops more rapidly. This effect will, however, only occur if feed industries first remove feed crops from their feeds when demand diminishes.

The Dutch food consumption is more or less comparable with other western diets. Therefore, other countries will yield comparable food residue as a result of their diets. Consequently meat can be produced from these food residues as well.

8. Conclusion

Consumption of food generates food residues. Feeding these food residues can be regarded as waste upgrading that yields meat. The amount of meat per person is substantial. When corrected for the total share of food residue in feed the amount of meat is equivalent to the amount of animal proteins advised by health organizations. However, current Dutch consumption is much higher.

The environmental impact of pork produced from food residue-based feed depends largely on how these residues are valued and accordingly allocated. New insights in food safety and economical trends will continue to lead to value changes in food residue for livestock feed and thus in environmental impact. However, the environmental impact of pork produced from grain-based feed is always higher than from food residue-based feed. Therefore, feeding food residue keeps the environmental impact of foods low. When food residue is no longer available feed grains are required. At current animal food consumption levels all food residues generated per person are already used for feed purposes. This means that a further increase in animal food consumption requires grain-based feed. Therefore, increase in consumption will lead to a relatively larger increase in the environmental impact of animal foods than in the past. To reduce the environmental impact of western diets various studies and policy measures focus on reducing animal food consumption [38–42]. Such a decrease in consumption can lead to a faster decrease in the environmental impact of animal foods than currently expected. However, for this to occur feed crops need to be the first feedstock component taken out of feed.

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