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WAGENINGEN UNIVERSITY & RESEARCH

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Wildcard Connected Circularity – Agrologistics of side flows: the missing link for circularity by design

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Preface

This wildcard study was carried out by Wageningen Food & Biobased Research, Wageningen Livestock Research and the Animal Nutrition Group of Wageningen University. It was financed by strategic funding of Wageningen University & Research and the knowledge base of the Dutch Ministry of Agriculture, Nature and Food Quality (KB40). The study was executed within the Connected Circularity Investment Theme.

The circular bio-economy is based on three leading principles:

1. Our circular food systems are built on plant-based biomass obtained from land and water
2. By-products from plant-based biomass, known as waste flows, are to be avoided. If this is impossible, they must be redirected back into the bio-economy, with healthy soil as a priority. Furthermore, they can be used as biomaterials or cattle feed
3. The function and role of animals is to return biomass that is unsuited for human consumption into the food system

Transferring to a circular bio-economy cannot be done without significant changes, on all fronts. For example, it is currently prohibited to process food waste into animal feed. Underlying reasons include the risk of inter and intra-species transmission of (zoonotic) diseases and other microbiological and non-organic contaminations. To allow the inclusion of side[1] flows and co-products from the food system as animal ingredients, not only research and innovations to allow this processing to be done safely is needed, it must also be made acceptable for the stakeholders involved, including consumers. It may also require changes in legislation and private agreements within the agri-food system.

Annually, the Connected Circularity Investment Theme calls for ‘wildcard’ research ideas, that embody the multi-disciplinary research to connect knowledge across Wageningen University (WU) and Wageningen Research (WR) to develop new ideas and approaches. It looks for innovative, ground-breaking and high risk ideas with an explorative character. The wildcard “Agrologistics of side flows” focuses on the use of side flows for poultry feed. It explores resources, suitability and requirements from the animal nutrition and agrologistics point of view. The collaboration between WR and WU has directly inspired a number of related (new) projects, including the new PPS project LWV-20147 RENEW (BO-64-001-027) and PPS proposal on the use of Spent Brewer’s Yeast as animal feed within Ethiopia and other developing countries (submitted as PPS idea for 2022).

[1] https://www.wur.nl/nl/Landingspagina-redacteuren/nl/Onderzoek-Resultaten/Onderzoeksprojecten-LNV/Expertisegebieden/kennisonline/RENEW-Multidisciplinair-onderzoek-om-voedselverspilling-bij-food-service-en-retail-te-verminderen.htm

Summary

The wildcard project "Agrologistics of side flows: missing link for circularity by design", within the WUR Investment Theme Connected Circularity aimed to create building blocks for method development to evaluate the suitability of side flows for animal feed from a circular agrologistics perspective, focussing on Dutch poultry feed. As the current lack of data on volumes and composition of side flows heavily limits the options to create quantitative agrologistics modelling techniques, the researchers performed a literature review to analyse available side flows, poultry production systems, and agrologistics opportunities. To put the literature findings into perspective, a workshop with additional WUR experts was organised using the Circular Agriculture Test (Kringlooptoets) approach. Acknowledging the complex nature of designing circular agri-food systems, while at the same time limiting the scope to poultry feed, design principles and options could be structured into a 7-step method. The qualitative description of these building blocks can guide farmers and animal feed manufacturers to evaluate suitable matches for poultry feed and the necessary agrologistics.

Step 1: Availability of side flows as feed
Step 2: Direct or indirect routes for the use of side flows
Step 3: Suitability of side flows
Step 4: Legal requirements
Step 5: Positive business case
Step 6: Environmental impact: comparative analysis and trade-offs with other feed sources and uses of side flows
Step 7: Social acceptance by consumers and other food system stakeholders

Applying the method creates unique circularity by design options for unique poultry farms (specified for various types of chicken) utilizing unique side flows, taking into account context-related opportunities and requirements. Although the description is focused on poultry feed, it provides the building blocks to evaluate any side flows for any animal production system and on any farm.

1 Introduction

Chicken egg and chicken meat production in the Netherlands is an efficiency-based animal production system which meets the demand for chicken products domestically and for export. The international market is focussed on production costs, and this has resulted in a system with high grow/laying rates and an efficient feed conversion within the currently used poultry breeds. Within a circular bio-economy, animal production plays an important role, and major questions converge on the scale, sourcing of resources, environmental impact, welfare issues and socio-economic aspects to close the loop within the agri-food system. The three leading principles within the circular bio-economy are based on:

1) Our circular food systems are built on plant-based biomass obtained from land and water.
2) By-products from plant-based biomass, known as waste flows, are to be avoided. If this is impossible, they must be redirected back into the bio-economy, with healthy soil as a priority. Furthermore, they can be used as biomaterials or cattle feed.
3) The function and role of animals is to return biomass that is unsuited for human consumption in to the food system[2].

The need for circularity is driven by the assertion that the current agri-food system is not sustainable, and shows many 'leaks' and inefficiencies. An indicator for this inefficiency is the staggering amount of food waste arising from the value chain from farm to fork. Global estimates amount to 1/3rd of all food produced that is not consumed by humans. Within the EU, approx. 88Mtons ends up as waste (FUSIONS, 2016), whereas in the Netherlands, approx. 1.6-2.6 Million tons are wasted (Soethoudt & Vollebregt, 2020).

Next to prevention, a high-value, high-volume solution lies within diverting side flows from the food chain towards animal production. Utilising unsold food as animal feed, brings back those resources in the loop of food production, and replaces need for dedicated crop production. In the Netherlands, already a significant amount of side flows is being used in animal production. Of more than 300 animal feed resources, 43% of 16.7 million ton produced feed is based on co-products and former feedstuff (e.g., bread and bakery products, cereals, confectionary, potato peels, beet pulp) (NEVEDI, 2019[3]).

However, there still is a large potential source of side flows, coming from the whole chain, including unharvested and crop residues at the farm, retail, out-of-home sector and households, that are currently not used, or not allowed to be used as animal feed. Due to technological, economic and/or legal constraints. By closely investigating the potential captured within these resources and their significance within a circular bio-economy, potential future pathways can open up, whilst addressing food/feed safety and environmental concerns as well as the profitability of the sector. The EC-funded H2020 project REFRESH (www.eu-refresh.org) estimated there is a potential 7 Mtons of side flows within the EU that are suitable for use as animal feed, but currently not being used (Luyckx et al., 2019[4]). This accounts for approx. 1/6th of the United Nations Sustainable Development Goal 12.3 of halving food loss and waste by 2030.

The Project "Agrologistics of side flows: missing link for circularity by design" is funded by Ministry of Agriculture, Nature and Food Quality via the WUR Investment Theme programme Connected Circularity. The **aim of the project** is to create building blocks for method development to evaluate the suitability of side flows for animal feed from a circular agrologistics perspective. The project's **scope** focuses on the use of side flows for Dutch poultry feed, from a circular agrologistics perspective.

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[2] https://www.wur.nl/web/show/id=13638428/langid=110099
[3] NEVEDI Grondstoffenwijzer 2019: https://assets.nevedi.nl/p/229376/Grondstoffenwijzer%20Nevedi%202019%20LR2.pdf
[4] Luyckx, K., Bowman, M., Woroniecka, K, Taillard, D., Broeze, J. (2019) Technical guidelines animal feed – the safety, environmental and economic aspects of feeding treated surplus food to omnivorous livestock. www.eu-refresh.org

The idea is to facilitate farmers in realizing circular concepts on their farms by developing a method that evaluates the applicability of local food and agricultural side flows as raw materials (closing-the-loop) in additional circular concepts. The research contributes to the design of these circular concepts by describing a method (tooling) that evaluates the applicability of any set of food and agricultural side flows that jointly can be used as full set of raw materials in additional food systems. Availability and local sourcing are contributing to effective agrologistics. Applying the tooling creates unique circularity by design options for unique chicken farms utilizing unique side flows, taking into account context-related opportunities and requirements. Although the description is focused on poultry feed, it provides the building blocks to evaluate any side flows for any production process and on any farm.

In order to achieve this, the following research questions were formulated:
1. What are available side flows (or waste) at farms, catering industry, consumers, etc.?
2. What are feed requirements of poultry production systems?
3. What are agrologistics opportunities to use side flows for poultry feed?
4. What are considerations to create building blocks for the evaluation of suitability of side flows for the use of poultry feed from a circular, agrologistics perspective, opening up the unique potential of any unique set of available side flows?

The study is primarily based on literature review, a workshop on the Circular Agriculture Test 2.0 ("KringloopToets 2.0") and discussions within the interdisciplinary research team. The research team consists of 4 experts from Wageningen Livestock Research, Wageningen Food & Biobased Research and WU – Animal Nutrition.

Reading the report
The report is organised according to the tasks described above.

- Section 1: Side flows in the Netherlands
- Section 2: Poultry feed requirements
- Section 3: Agrologistics opportunities
- Section 4: Building blocks

2 Section 1: Side flows in the Netherlands

Recapping the relevant side flows available from various types of agri- and industrial processing, these can be broadly divided into two groups according to Sadh et al. (2018[5]), see also the figure including an impression of agro-industrial side flows (here indicated as waste and residues) below.

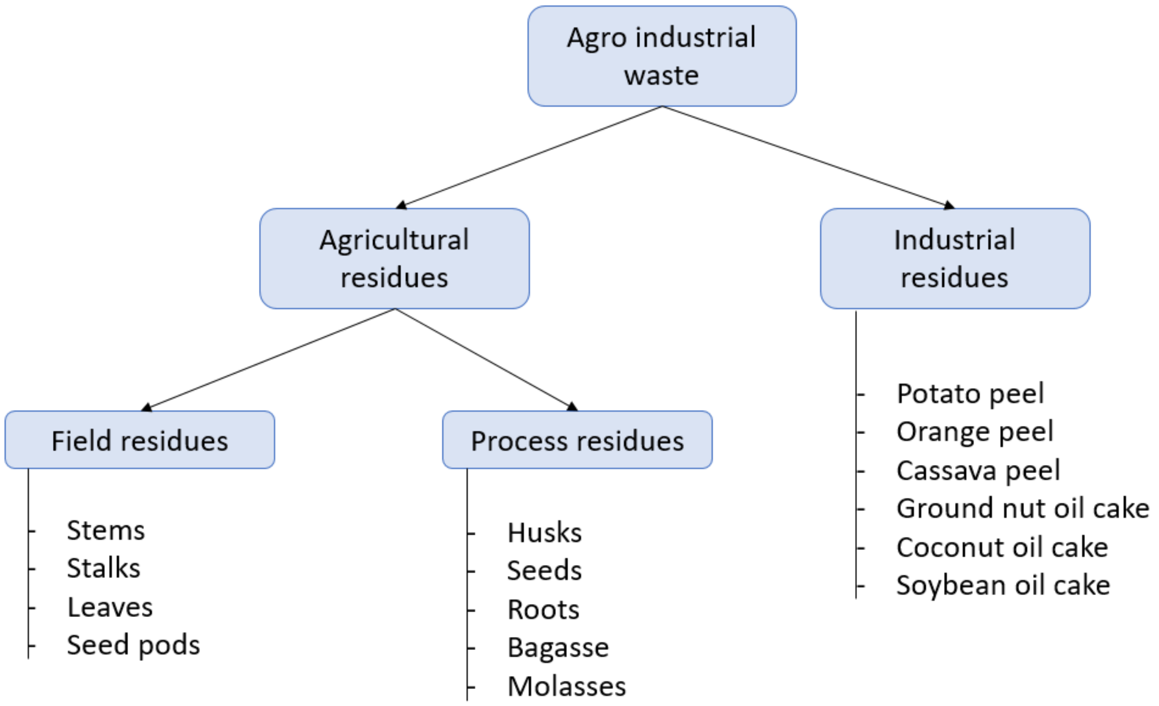

Figure 1: Different sources of agri-industrial waste flows
Source: Adapted from Sadh et al., 2018

Agricultural (including livestock) companies and agri-processing industries continuously produce large amounts of residues. These can be divided into agriculture residues and industrial residues. Agriculture residues can be further divided into field residues and process residues. Field residues are residues that stay behind in the field after crop harvesting. These field residues consist of leaves, stalks, seed pods, and stems, whereas the process residues are residues present even after the crop is processed into an alternative valuable resource. Through the food processing industries like juice, chips, meat, confectionary, and fruit industries, a large amount of organic residues and related effluents are produced every year.

[5] Sadh, P, Duhan, S., Dhuan, J. (2018). Agro-industrial wastes and their utilisation using solid state fermentation: a review. Bioresources and Bioprocessing, 5, 1.

- **Agricultural residues:** Side flows from production processes meeting the general GMP/GMP+[6] and HACCP requirements are already being used as animal feed ingredients to a large extent. Their use applies to either dry from and mixed in (dry) concentrates, and typically target chicken or pig production systems. Also, wet side flows can be utilised, mixed on-farm with specifically composed matching concentrated feeds making a complete ration for the particular animals. Examples hereof are e.g. leftover from bread and pastry production which can easily be mixed with other (dry) ingredients to make a regular poultry feed[7]. Wet products come from e.g. potato and wheat processing.

- **Industrial residues:** Side flows from (industrial) production processes or leftovers from kitchen, catering or restaurants wastes. Many of these side flows are potentially valuable feed ingredients but cannot be used under current feed and food safety rules as risks of contamination cannot be entirely excluded. In some cases, problems with intra-species feeding / cannibalism principles amongst poultry may occur.

There is a wide potential for use of agro-industrial side flows, such as their use for biogas, biofuel and animal feed production. The possibility to use elements of these side flows for animal feed production depends on the current regulations, which in short divide waste flows into (1) flows of bioproduction from certified HACCP based industries that can be used as ingredient for animal feed and (2) waste flows which are currently not allowed to be fed to animals such as household and restaurant food leftovers, slaughterhouse waste, manure etc. These waste flows are still a potential source of nutrition for animals and can be upgraded to animal feed ingredients e.g. through bioconversion by use of insects. How effectively these can be used, also depends on other possible and competing applications, such as biogas.

In the Netherlands available organic side flows are exhaustively summarized in Elbersen et al. (2011[8]) and are integrally included in Annex 1. This report deals with virtually all side flows from the agri-food industry in the Netherlands, and its potential to produce energy and to replace fossil energy as a part of a more circular economy. However, even though the report provides insights on the composition (including cellulose, lignin, carbohydrates, fatty and protein contents), the data available are not sufficient to organise efficient agrologistics. They provide an indication of potential, but more detailed data, including location and other availability considerations are needed. This study by Elbersen et al. (2011) will be followed up by a new research project in the coming years (Monitoring Circulariteit van reststroombenutting[9]). The new project is part of the implementation of the MMIP (Meerjarige Missiegedreven Innovatie Programma) of the Dutch Ministry of Agriculture, Nature and Food Quality. The aim of this project is to develop a method to monitor aspects of circularity in the use of agro-industrial side flows (or, biomass residues). A database of all residues will be built, including an analysis of the contribution to circularity of the potential uses of these residues. This report will be published earliest by the end of 2021.

Another source on potential volumes of side flows comes from the annual food waste monitor, published by WFBR (Soethoudt & Vollebregt, 2 020[10]). This monitor described the volumes of food waste in the Netherlands within the food supply chain, including households. A trendline covering the 2009-2018 monitoring period is depicted below:

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[6] GMP+: Good Manufacturing Practice Plus is a certification scheme for quality systems within the food feed industry, that can be obtained for all segments in the food supply chain. It describes from A-Z how a product is composed and produced. The Plus is the addition of HACCP (Hazard Analysis Critical Control points). HACCP describes the quality management system and risk management analysis within food production and is obligated under EU regulation regarding Food Hygiene, covering all stages of the production, processing, distribution and placing on the market of food intended for human consumption. An overview of the relevant legislation is available via: https://ec.europa.eu/food/food/biological-safety/food-hygiene/legislation_en. More information on certification: www.gmpplus.org, www.kiwa.com

[7] The feed company Nijsen Company (https://nijsen.co/en/) prepares a completely circular feed for the Kipster egg production systems (https://www.kipster.farm/).

[8] Elbersen, W., Janssens, B., Koppejan, J. (2011). De beschikbaarheid van biomassa voor energie in de agro-industrie. Wageningen Research, Wageningen, The Netherlands.

[9] See project summary at kennisonline: https://www.wur.nl/nl/Onderzoek-Resultaten/Onderzoeksprojecten-LNV/Expertisegebieden/kennisonline/Circulariteit-van-reststroombenutting.htm

[10] Soethoudt, H., Vollebregt, M. (2020) Monitor Voedselverspilling, update 2009-2018. Wageningen Food & Biobased Research

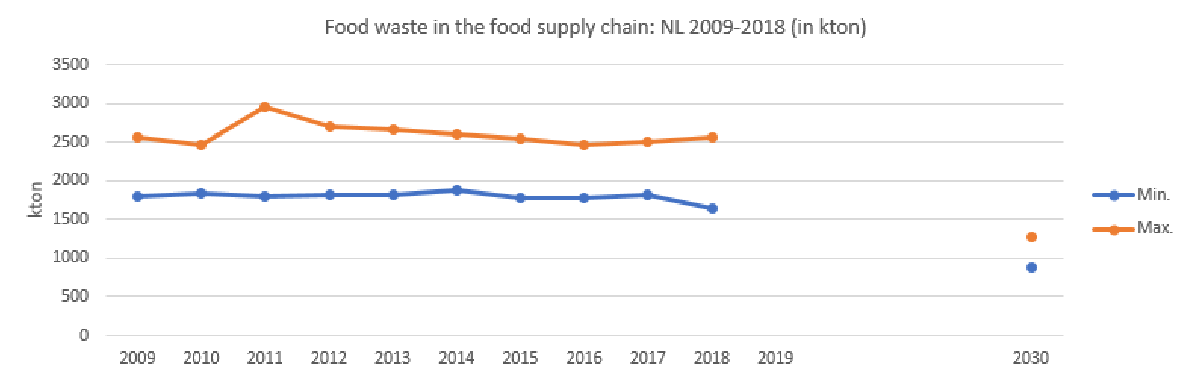


Figure 2: Food waste in the food supply chain: NL 2009-2018 (in kton)
Source: Reworked and translated from Soethoudt & Vollebregt, 2020

However, these amounts include the current use of industrial side flows for animal feed (see the Table below for a split in the food waste per destination). Also, due to the definitions and scope used within this monitor, there is no information available on where the side flows originate, their composition or their availability as animal feed ingredient, making it difficult to estimate their potential as animal feed ingredient.

2018	Avoidable		Potentially avoidable	
In kiloton	Minimum	Maximum	Minimum	Maximum
Animal feed	258	258	140	140
Anaerobic digestation	27	105	145	145
Composting	63	143	437	639
Incineration	536	998	0	
Landfill/sewege	11	141	0	
Total	927	1645	722	927

Table 1: Amounts of avoidable and potentially avoidable food waste per destination in the Netherlands (ref. year 2018)
Source: Reworked and translated from Soethoudt & Vollebregt, 2020

There are (online) tools available that provide more details on the composition of surpluses and side flows, such as the Food Waste Explorer (https://eu-refresh.org/foodwasteexplorer and www.foodwasteexplorer.eu). These types of databases provide insights into the potential, high value valorisation of side flows and surpluses, but still the lack of data on volumes and availability aspects feed the call for more research.

Hence, there is a lack of information on what part of the total available and allowed side flows is currently already being used as ingredient in animal feed. Animal feed is not the only application of side flows, there are also diverted bio-energy and composting applications. The underlying allocation mechanism is heavily influenced by market circumstances: sometimes it is commercially more interesting to utilize side flows for bio-digestion instead of animal feed ingredients. If market prices change, choices for utilization may change again. When the current regulation changes, and when more side flows are allowed to be used, the mechanism will change again. As feed ingredients are typically selected based on costs and nutritional properties, the attractiveness of using side flows will be influenced by how they compensate for savings at waste disposal level. Additionally, it is also affected by their potential to deliver higher value at the intermediate or end-product level (e.g. specifically branded eggs sold at premium price). This becomes feasible if components of the side flows are suitable and recognized as functional ingredients with health promoting benefits. They could serve for example as prebiotic, probiotics or even immune modulator. Their economic value then increases, and could potentially also reduce the need for inclusion other feed additives.

The potential of replacing dietary ingredients in animal nutrition in the Netherlands and wider EU is high. The Netherlands plays an important role in trade and use of all types of feed ingredients[11]. Of all imports of plant-based protein in the Netherlands, 89% is exported again to other European countries, and of the 11% used in the Netherlands, 83 % is mixed in animal feed. Most of these proteins are soya bean meal, obtained after oil extraction from soya beans and are used as soybean meal cakes in animal feed. The largest share of this is consumed by dairy cattle, followed by pigs and poultry. Percentage of protein from imported sources is, on average, 53% for dairy cattle, 54% for pigs and 77% for broilers. This high dependency on imported protein sources for broilers, would make them an interesting and important target for making gains in improving circularity in animal feed production.

Improving the use of currently legally not yet allowed side flows as animal feed ingredients, requires adaptation of existing feed and food regulation. Currently processed insect products are only allowed in pet and fish feed production. It is expected that the EU will approve use of processed insect products in the course of 2021 for both poultry and pig feeds. In April 2021, the EU Standing Committee on Plants, Animals, Food and Feed (SCoPAFF) agreed on the proposed change to allow the use of Processed Animal Proteins (PAP) of poultry in pig feed, of pig PAP in poultry feed, and insect PAP as non-ruminant feed ingredient[12]. This does not automatically mean that more circular based feed ingredients will become automatically available as currently all insects for food and feed are already reared on side flows from the GMP+ and HACCP conditions within the agri-processing industry. Examples are spent brewers' grain and special insect feeds sold by feed companies for e.g. mealworm production, which are usually a mixture of grains and soy cake. Environmental gains and steps forward in circularity can be made if other, not yet approved side flows will be allowed in animal feed production. A Public-Private Partnership project SAFE INSECT 'Safe insect rearing on yet to be legally authorized residual streams' just started. This research focuses on the safety of various organic residual flows as a substrate for insect rearing and the safe application of these insects in food and feed. Moreover, the technical feasibility of the application is also taken into account in this project. The aim of the project is to arrive at a procedure that is required for legal authorization of residual flows for insect rearing. This with the underlying goal of adding value to a wide range of organic residual flows in the food chain as much as possible by 2030.

In conclusion, there is both a high expected potential as well as a lack of specific data to fully explore the use of side flows for poultry feed. The aforementioned REFRESH project estimates that the European potential for additional use of side flows from currently not allowed sources is approx. 7 Mton, almost 10% of the current food loss and waste levels, sitting at 88 Mton for the EU annually (Bowman & Luyckx, 2019[13]). As these quantitative data are missing, this study focusses on a qualitative description of underlying design principles for agrologistics of side flows for poultry feed.

[11] Nationale Eiwit Strategie. Ministerie van LNV, 2020. https://www.rijksoverheid.nl/documenten/kamerstukken/2020/12/22/nationale-eiwitstrategie

[12] See the consultation text on the Authorisation to feed non-ruminants with ruminant collagen / gelatin and with proteins from insects, pigs and poultry (europa.eu)

[13] Bowman, M., Luyckx, K.(2019) Avoiding food waste through feeding surplus food to omnivorous non-ruminant livestock. www.eu-refresh.rg

3 Section 2: Poultry feed requirements

This section provides insights on poultry production systems and feed requirements, as these define the nutritional needs and operational boundaries for introducing side streams as feed.

3.1 Description of poultry production systems in the Netherlands

This paragraph lists basic information on the Dutch poultry production systems currently in use as background reference for the showcase.

Production systems, number of chickens and farms

Poultry production systems can be divided in

- Layer farms: chickens kept for egg production
- Broiler farms: chickens kept for meat production (broilers)
- Parent stock farms: chickens kept for reproduction
- Rearing farms: chickens kept for rearing (layer / broilers parent stock)

There are several systems currently in use, characterized amongst other variables by the number of chickens kept per m^2 and in- and/or outdoor systems.

Indoors:

- Enriched or furnished cage (allowed until Dec. 2021): 750 cm^2 per chicken, 10-60 chickens per cage
- Colony Cage/aviary: 900 cm^2 per chicken, 30-60 chickens per cage
- Barn or Litter Brooding: 1500 cm^2 per chicken (9 chickens/m^2),

Combined / outdoors:

- Free range hybrid (barn + outdoor range): 4 m^2 per chicken (outdoor) and 9 chickens/m^2 (indoor)
- Organic: 4 m^2 per chicken (outdoor) + max. 6 chicken/m^2 (indoor)

Also, other (hybrid) or specialty systems exist.

Photos: top: enriched cage, middle: barn brooding, bottom: free range system.
Source: Karcher & Mench, 2018[14].

[14] Karcher, D.M. & Mench, J.A. (2018) Overview of commercial poultry production systems and their main welfare challenges. In: Mench J.A., (ed). Advances in Poultry Welfare. Elsevier, Amsterdam, The Netherlands. Pp. 3-25. https://www.sciencedirect.com/science/article/pii/B9780081009154000014

Number of chickens and farms in the Netherlands

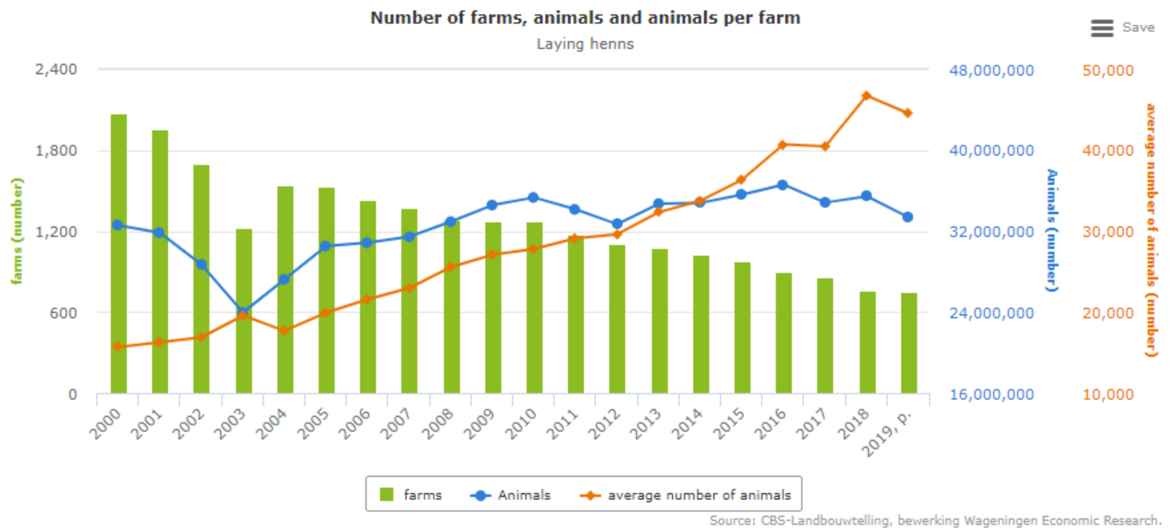
The total number of chickens in the Netherlands can be tabled as follows:

Year	2000		2020	
Total number of chickens	**104,014,665**		**101,863,117**	
Layer hens	44,036,400	42.3%	43,165,986	42.4%
Parent stock layer hens			1,674,306	1.6%
Broiler chicken	50,936,625	49.0%	49,228,507	48.3%
Parent stock broiler chickens	9,041,640	8.7%	7,794,318	7.7%
Total number of chicken farms	**3,860**		**1,766**	
Layer farms	2,292		856	
Parent stock layer farms			48	
Broiler farms	1,094		637	
Parent stock broiler farms	520		248	

Table 2: Chickens and chicken farms in the Netherlands 2000-2020

Source: Source data from CBS, adapted in table

Based on the declining number of farms and a relative lower reduction in the number of total chickens, the number of chickens per farm has grown considerable between 2000 and 2019, which is also substantiated in the data presented in figure 3. On average, layer farms keep approx. 45.000 laying hens per farm, whereas broiler farms typically have 76.000 birds. There are usually several barns per farm.



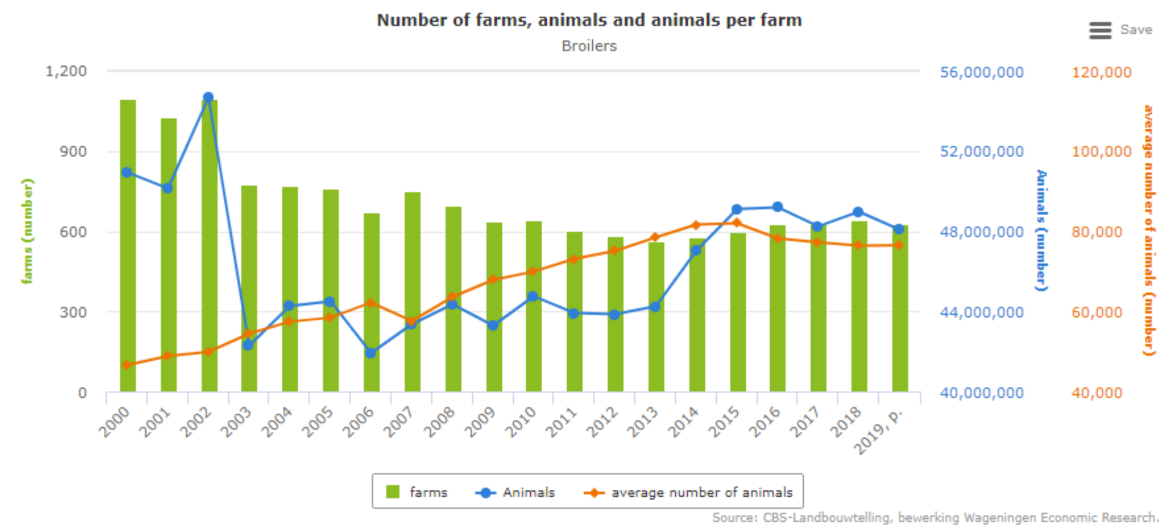


Figure 3: Number of farms, animals and animals per farm, layer & broiler chickens (2000-2019).

Source: agrimatie.nl

Production cycles

There are approximately 750 farms with laying hens in the Netherlands, with on average 45,000 laying hens per farm (total number of layers 33.7M)[15]. Laying hens (pullets) are first reared on rearing farms, until they are about four months of age, when they are transferred to layer farms where they are kept for a laying period of 15 to 18 months.

The number of broiler farms in the Netherlands is about 625, with on average 76,000 birds (total 47.5 M, annual production approx. 350 M broilers). The broilers are sold at 5 to 6 weeks of age, upon which the broiler house needs to be cleaned and prepared for a next flock. On average, 6 to 7 batches of broilers can be produced annually on a broiler farm.

On top of this, there are close to 200 parent stock farms in the Netherlands, producing hatching eggs for both layers and broilers, but their numbers are much smaller. Furthermore, there are a number of rearing farms, rearing layers from day 1 to approx. 18 weeks, when the hens start laying eggs themselves.

Geographical spread in the Netherlands

The province with the highest density of poultry in the Netherlands is Noord-Brabant (26.2%), followed by Gelderland (16.6%) and Limburg (15.4%). The lowest density is located in Zuid-Holland (0.6%), Noord-Holland (1.6%) and Zeeland (2.0%). See for an impression of the geographical spread figure 4 below.

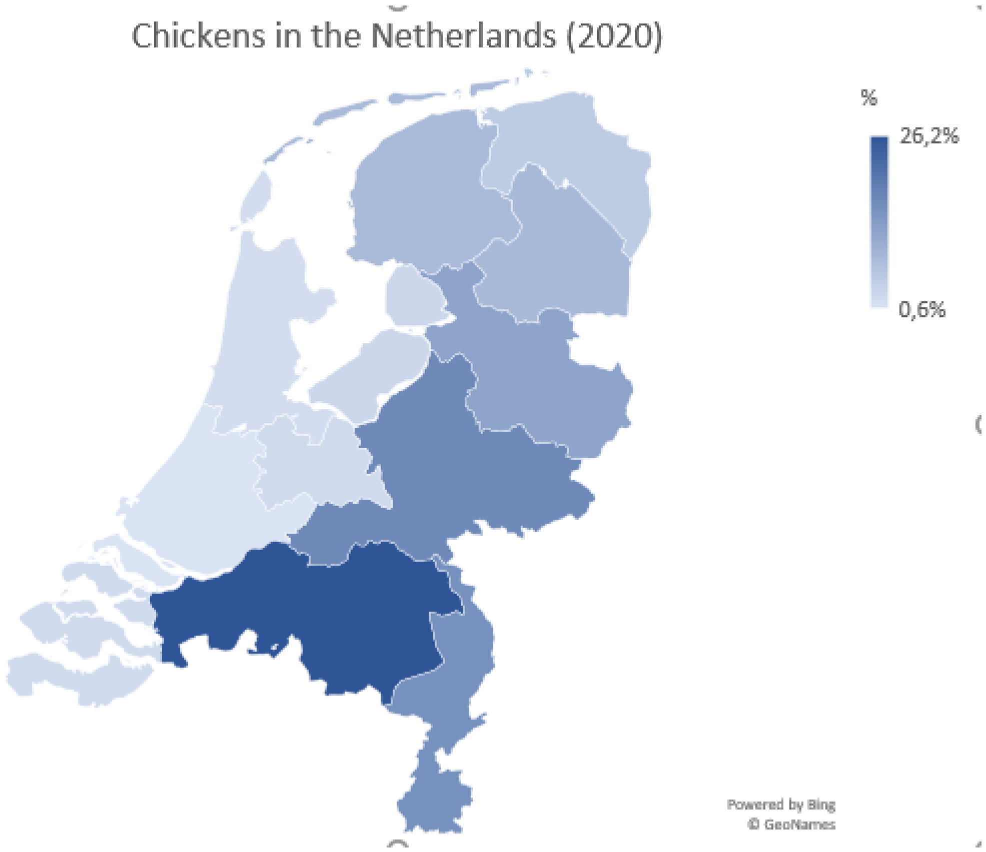


Figure 4: Geographical spread of poultry (per Dutch province), reference year 2020

Source: Based on CBS online database information (Statline), map of the Netherlands created using Microsoft Bing GeoNames (c)

[15] https://www.agrimatie.nl/SectorResultaat.aspx?subpubID=2232&sectorID=2249

Production cycles and feed requirements

Layer hens are usually fed two or three types of feed throughout the whole laying period which starts at 18 weeks of age and lasts for 12 – 15 months. Feed provided varies e.g. in composition of amino acids and amount of calcium, depending on the age and productivity of the layers. Average feed consumption per bird is 100 grams daily, leading to a daily use of feed per layer farm of 4.5 tons daily.

Broilers are reared in two different manners: regular, in which they grow relatively fast for 5 to 6 weeks, until they reach slaughter weight of approx. 2.2 kg live weight. There is increasing market interest for slow growing broilers, which grow slower for 7 – 8 weeks and are slaughtered at 2.4 kg. The number of broiler farms with slow growing broilers is growing fast due to increased market demand. The table below provides an overview of differences between regular and slow growing broilers.

Parameter	Poultry breed	
	Regular (2013)	**Slow-growing**
Production period (days)	40	56
Delivery weight (grams)	2,265	2,400
Rejects (%)	3,3	2,5
Growth/animal/day (grams)	56	42
Feed conversion *	1.64	2.07

** Cumulative feed conversion (kg feed supplied to the farm / kg animal product weight at slaughter minus birth weight (chicks)*

Table 3: Differences between regular and slow-growing broilers

Translated from source: KWIN 2016, in Tabellenboek Veevoeding 2016 voedernormen Pluimvee en voederwaarden voedermiddelen voor Pluimvee. Centraal Veevoeder Bureau.

The daily feed consumption for regular broilers increases from 20 grams on average in the first week, to 150 grams in the 6th week (see table 4 below).

Age (week)	Feed consumed per bird (kg)	Cumulative feed consumed (kg)	Average body weight per bird (kg)	Average body weight gain per bird (kg)
Week 1	0.167	0.167	0.185	0.185
Week 2	0.375	0.542	0.465	0.28
Week 3	0.65	1.192	0.943	0.478
Week 4	0.945	2.137	1.524	0.581
Week 5	1.215	3.352	2.191	0.667
Week 6	1.434	4.786	2.857	0.666

Table 4: Standard broiler feed chart, including the expected weight/growth gains

Source: www.livestocking.net/standard-broiler-feed-chart-growth-weight

They are being fed different types of feed, depending on their age and usually get 3 or 4 different types of feed ("phase feeding"). Phase 1 is from 0-10 days, phase 2 from 10-28 and phase 3 from 28-slaughterweight (35-40 days for regular broilers). With an average feed conversion rate of 1.6 a regular broiler will eat approx. 3.5 kg of feed. Of this amount, 0,2 kg will be eaten in phase 1 (pre-starter and starter diets), 1.0 kg in phase 2 and 2.3 kg in phase 3. When considering replacing ingredients by insect products, the most appropriate phases are 2 or 3. Within phase 1, broilers can experience many incidents affecting the development of organs, stabilizing gut microbiota, shifting from maternal immunity to self-immunity (supported by vaccination). In addition, reaching a certain body weight at day 6 or 7 directly affects the body weight gain at the end of production. In phase 3, the largest part of the total volume is consumed by the chickens (65%).

This applies when insects are used to provide a substantial part of the protein in the diet. Insects are also considered to have beneficial effects on animal health, though this is still under research. If the insect products can also be used as functional ingredients, total volumes used for this purpose will be less and the positive effects of the functional ingredients will be most relevant at a young age.

It is unclear whether a high circular feed diet will (and if so, how it will) affect the growth rate of broilers, or the egg mass produced by laying hens. If that is the case, the full genetic potential of the birds may not be reached and may have influences on breeding strategies. The feed efficiency differences between conventional feed and different degrees of circular feed are currently unknown, and need further research. If lower efficiencies are associated with circular feed, their uptake within primary production will likely need additional incentives next to cost efficient conversion rates.

With close to 350 M broilers reared annually in the Netherlands, total feed consumption for phase 3 is approx. 0.9 M ton. With an average of 16% protein in the feed, a total of 150,000 tons of protein is needed for phase 3 feed per annum. This amount cannot be fully replaced by insect protein, due to possible negative influence on performance (growth, feed conversion rates). The causes of this negative influence are not fully clear yet, though presumably related to chitin content, coloring, taste etc. (Dorper et al., 2020[16]) the potential demand for insect when restricted to maximum 25% of the protein in the diet is 40,000 tons. When feeding black soldier flies on side flows (with on average 65% moisture), a total of 200,000 tons of side flows can be used to produce this amount of protein. In this case, 40,000 tons of insect protein might replace 5,000 to 6,000 ha of soya bean production. A multifold of this volume is needed, when insect proteins will also be included in feeds for layer hens and for pigs. With over 15 M pigs fattened in the Netherlands, 450,000 tons of protein are needed, which gives room for another at least 100,000 tons of insect protein (when using insect protein as 20-25% of the total protein provided). More research is required on identifying optimal inclusion levels, clearly differentiating between inspect products based on their nutritional value and health-stimulating effects, and comparing the potential of insect products across species (Dorper et al., 2020).

3.2 Assessment of suitability of feed ingredients for poultry feed

The nutritional requirements of poultry consist of energy, protein, and vitamins. Other, non-nutritive feed substances are water and grit (used in the chicken gizzard to grind food). Energy is supplied through carbohydrates, crude fiber and fat. Not all energy consumed by the chickens is used, energy that can be used is called metabolizable energy (ME). Protein consists of various amino acids. The essential amino acids for poultry are arginine, glycine, histidine, leucine, isoleucine, lysine, methionine, cystine, phenylalanine, threonine, tryptophan and valine. Out of these, the ones critical in practical diets are arginine, lysine, methionine, cystine and tryptophan, and the minimum quantities of each of these amino acids should be met, even if the total protein percentage of the feed is adequate. A lack of these essential amino-acids may cause health issues so should be compensated through other sources. The feeding value of ingredients for poultry depends on various factors, such as nutrient composition, nutrient digestibility, toxins (some ingredients should be heated to treat toxins), palatability and nutrient balance.

Digestibility is also affected by the presence of ANF (Anti Nutritional Factors). These are substances in the feed that have a negative impact on the nutritional quality of the protein and thus on the digestibility. An example is lectin, a carbohydrate-binding protein which affects pancreatic functions and can be found in various legumes. Lectin can be made dysfunctional via heat treatment. Another example is rape seed, of which several varieties have a high content of erucic acid and glucosinolates that are of concern for animal and human health, but those problems are gradually eliminated or largely reduced through traditional genetic selection[17]. All side flows that could potentially serve as poultry feed, should also be tested for ANF.

To provide an adequate feed, it is necessary to formulate a ration, that includes adequate amounts of all the ingredients, to meet the nutrient requirements of the bird. Young birds for example will need more and better digestible protein ingredients than older birds. The balance between the nutrients determines the suitability of a particular compound feed (the ME). A properly formulated ration is essential for good animal health and performance and efficient farm management and also to minimize emission of nitrogen and phosphate to the environment.

[16] Dorper, A., Veldkamp, t., Dicke, M. (2020) Use of black soldier fly and house fly in feed to promote sustainable poultry production. Journal of Insects as Food and Feed, published online 27 August 2020.
[17] https://www.feedipedia.org/node/52

To formulate a feed, it is necessary to know the digestibility of the various ingredients in the feed, for all types of poultry as digestibility of an ingredient will be different between broilers, layer, turkeys etc. Moreover, plant-based ingredients will change in composition and digestibility through time due to genetic improvement of crops, climate change etc. Therefore, continuous research on the digestibility of all ingredients is necessary.

Protein quality assessment of feed ingredients for poultry is achieved using in vitro or in vivo testing[18] (see also the visualization in the figure 5 below).

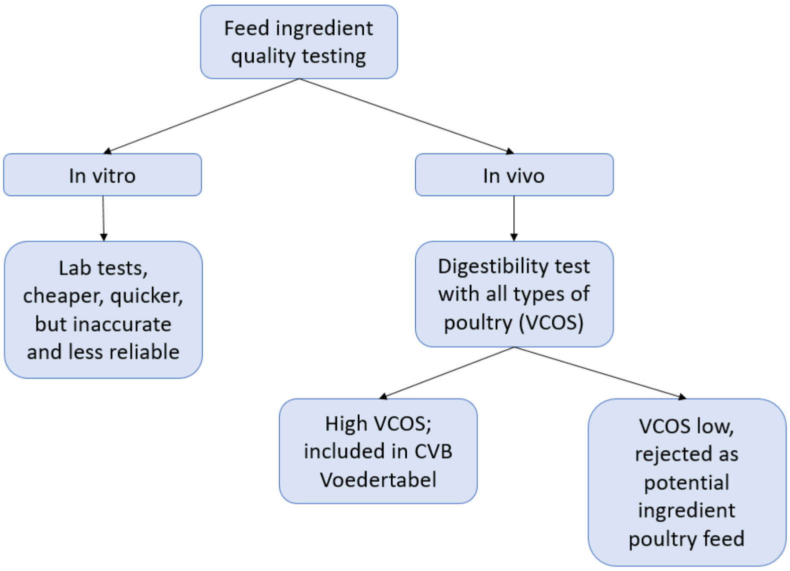


Figure 5: Visualisation of feed ingredient quality testing pathways
VCOS = Verteringscoefficient organische stof (digestion coefficient organic matter)
Source: Dervan & Classen, 2020

In vivo methods are usually more expensive and time consuming than the vitro method. Protein quality can also be evaluated using less expensive and time-consuming chemical methods, termed in vitro, e.g. by using the pepsin digestibility test. Even though the pepsin digestibility test uses enzymes to liberate the amino acids from the protein, it does not mimic normal in vivo digestive conditions. The results obtained with this method may be misleading if the samples tested contain fats or carbohydrates which they often do. Multi-enzyme tests have been proposed to overcome the problem encountered when using the pepsin digestibility test. These tests use a combination of enzymes in one or multiple steps customized to simulate the digestive process of the animal. Multi-enzyme assays can predict animal digestibility, but any inherent biological properties of the ingredients on the animal digestive tract will be lost.

This type of digestibility research has not been carried on potential poultry feed ingredients that are available in bio-waste flows that are not (yet) approved as animal feed ingredients. Taking laboratory results of energy and protein composition of these side flows is not enough to determine the possibilities to use these as poultry feed, additional digestibility trials need to be carried out, either in vitro or in vivo method. The outcome of such trials determines the feeding value of a particular side stream and serves as a guideline for animal nutritionists on the use of these newly tested ingredients in formulating feed for the different species.

[18] Dervan D.S.L. Bryan * and Henry L. Classen. (2020) In vitro methods of assessing protein quality for poultry. Animals, 10, 551; doi:10.3390/ani10040551

This line of research in the Netherlands is authorized by the Central Committee Animal Experiments (Centrale Commisie Dierproeven[19]). The most commonly used parameter of the suitability of potential feed ingredients is amongst other determined by the VCOS, which indicates the percentage of a feed ingredients that is digested. The required VCOS for poultry is higher than for pigs and cattle, making the choice of ingredients for poultry feed much more sensitive[20].

The side flows might act as functional ingredients, though that needs to be further investigated as described above. The complex composition of side flows, consistency and availability matters will also influence their use within poultry feed (see also the next section). The body of knowledge regarding the interaction between less digestible part of the diet in poultry, such as dietary fiber, tannin or even chitin of insects, and the immune system of the animal or gut microbiota is increasing. This might create more value for certain ingredients or possibility to process them further. Sometimes what we considered as ANF in the past, seems to be beneficial in the future. For example, the positive effect of insoluble dietary fiber on digestive regulation or their immune modulatory effects in poultry. These are highly in line with gut health and antibiotic-free production.

3.3 Feed safety concerns

Fears of re-emergence of Bovine Spongiform Encephalopathy (BSE or mad cow disease) after re-introduction of bone meal are amongst the reasons of the careful approach to reintroducing side flows from retail, catering industry and households (also called 'swill') as potential animal feed sources. As only ruminants are susceptible to BSE, the Dutch National Protein Strategy[21] recommends the cross-use of processed animal proteins (PAP) from pigs in poultry feed and vice versa. Analysis of the risk of safety issues using not yet legally approved side flows are investigated in various projects, such as the recently started *PPS projects "Safe insect rearing on yet to be legally authorized residual flows" (2021-2024)*[22] and "Food and feed safety and valorization of new and legally limited side flows for animal feed" (2020-2023)[23], which both are led by Wageningen Food Safety Research. The Connected Circularity Flagship "Ensuring quality and safety" [24] studies the scenario in which waste streams in the Netherlands are valorized to their fullest potential, and tries to identify the risks of several potentially dangerous substances, including the spread of pathogens and accumulation of heavy metals. The infographic below (from the flagship 2 project) depicts the key safety concerns related to creating a circular bioeconomy.

[19] https://www.centralecommissiedierproeven.nl/documenten/vergunningen/16/1/20/nts-2015319-vertering-pluimvee
[20] Kasper, G.J., G. van Duinkerken, M.M. van Krimpen, C.P.A. van Wagenberg, J. Kals, J.P.M. Sanders, C.L.M. de Visser, (2015) Efficiënter gebruik van voedermiddelen en (geïmporteerde) diervoedergrondstoffen. Wageningen Livestock Research
[21] See the summary here: https://www.rijksoverheid.nl/documenten/kamerstukken/2020/12/22/nationale-eiwitstrategie
[22] https://kia-landbouwwatervoedsel.nl/projecten/insectenteelt-op-wettelijke-niet-toegestane-reststromen/
[23] https://www.wur.nl/nl/Onderzoek-Resultaten/Onderzoeksprojecten-LNV/Expertisegebieden/kennisonline/Voedsel-en-voederveiligheid-en-valorisatie-van-nieuwe-en-wettelijk-beperkte-reststromen-voor-diervoeder.htm
[24] https://www.wur.nl/en/Research-Results/Onderzoeksprojecten-LNV/Expertisegebieden/kennisonline/Flagship-2-Ensuring-quality-and-safety-1.htm

Figure 6: Ensuring quality & safety within a circular bioeconomy
Source: Connected circularity Flagship 2

The safety of feed depends on prevention of various contamination factors. They can consist of biological contamination (bacterial pathogens), chemical hazards (e.g. pesticides), mycotoxins and drug residues. Potential sources of feed safety concerns are summarized in the figure 7 below.

Figure 7: Sources of contamination in animal feed
Source: https://www.feedipedia.org/content/feeding-safe-feed-livestock-safeguards-human-health

A circular bioeconomy identifies additional risks related to food and feed safety due to cumulative effects associated with multiple loops in the reuse of biomass sources. Feed safety concerns and risk reducing measures are already integral part of the agrologistics system for animal production. It is regulated by the GMP+ Feed Certification Scheme. GMP stands for "Good Manufacturing Practices" and the + for the integration of HACCP (Hazard Analysis and Critical Control Points).

The GMP+ Feed Certification scheme 2020 is based on six basic principles:
1. Ensuring a high level of global feed safety
2. Primary responsibility rests with the certified company
3. Certified companies share responsibility
4. Connect as a scheme with internationally accepted standards
5. Commitment and transparency
6. Certification by independent Certification Bodies

Deciding on using side flows or not within poultry feed depend on a number of choices, including political preferences and sustainability criteria. If priority is given to policies on circularity, this will stimulate the use of side flows for animal feed. E.g. governments can put into force regulations that require a particular percentage of circular ingredients, comparable to e.g. E-10 petrol (10% bio-ethanol mixed with conventional petrol). If circularity is built up in the context of an efficient and cost-effective value chain, choices may be different as the price of ingredients matters more as a determinant of the cost price.

Adding new ingredients to poultry feed could potentially lead to additional risks for the safe use of animal feed. Despite all current feed safety measures, feed manufacturers are highly worried about the risks such as salmonella and mycotoxins put on their business. Also, feedstock and other ingredients for feed manufacturers are important mechanical carriers to introduce pathogens to poultry flocks. Streaming all these new ingredients into the feed and poultry industry might requires new measures, tools, and monitoring systems to guarantee all safety aspects.

3.4 Other limitations

The use of side flows in poultry production systems is limited by the fact that poultry is usually fed with dry meal or pellets only, whilst pigs are better digesters of wet feed and therefore there is a higher potential to include side flows in pig feed than in poultry feed.
Poultry can consume wet feed, and certainly broilers do appreciate wet feed, but due to the higher moisture content in the feed, they do not always eat enough dry feed and growth is often slower than with dry feed. Feeding wet feed to poultry has increasingly been getting more attention as part of the growing attention for circularity and new research activities have been started recently[25].

The dry matter content of some wet side flows is highly valuable for poultry, but the costs of drying it often makes it commercially un-interesting as an ingredient of poultry feed. This is e.g. the case with brewer's yeast, for which a pilot project to adapt feed manufacturing equipment to mix this product in acceptable quantities in wet form will be carried out in 2021[26]. Commercially, a large feed company [27] has recently started selling a feed for layer hens with higher (20%, as compared to 10-12% normally) moisture percentage.

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[25] Source: Personal communication, Emily Frehen, animal nutritionist of ABZ Diervoeding and PhD student WUR
[26] https://research.wur.nl/en/projects/smp-2117-sustainable-and-circular-use-of-agro-processing-in-ethio
[27] https://www.agrifirm.nl/aanbod/soliq/

4 Section 3: Agrologistics opportunities

To understand the opportunities and requirements for suitable and appropriate agrologistics, it is necessary to define agrologistics as a key component to an agri-food system. It is associated with the application of logistics methods and provisions in the field of agricultural production, aimed at minimizing labour costs, resource costs, transport costs, by optimizing transportation routes, and ultimately reducing the cost of agricultural products. The peculiarity of transport is that it does not process raw materials and does not create products, but by means of transport, services are provided for the delivery of relevant products to its consumer with a minimum duration of time, with the solution of related issues (customs, documentation, cargo safety, etc.) (Kurbatova et al., 2020)[28], therefore, logistics and agro-logistics are more than the transport of goods. It is the movement of material flow related to the transport of agricultural products, which provides full coverage of the population needs in essential foods providing human psychosocial needs. The moment of timely delivery acquires a crucial role in some cases. It becomes obvious that agrologistics is an important competitive advantage for companies aimed at uninterrupted supply of their products to an intermediate or final consumer, and also acts as an important factor in ensuring the food security of the country (Kiladze, 2017[29]). Historically, logistics has been considered an issue deserving modest priority in each organization; it was merely regarded as a cost component. Nowadays (especially in the developed world), logistics is seen as a value-adding process that directly supports the primary goal of the organization, which is to be competitive in terms of a high level of customer service, competitive price and quality, in terms of compliance with rules and regulations, in terms of being able to satisfy extensive qualitative service and information requirements imposed by consumers and other stakeholders of the supply chain and finally in terms of flexibility in responding to market demands (Van der Vorst et al., 2007[30]).

Logistics is that part of the supply chain process that plans, implements and controls the efficient, effective flow and storage of goods, services and related information from the point-of-origin to the point-of-consumption in order to meet customer requirements (Lambert et al., 1998[31]) and satisfies the requirements imposed by other stakeholders such as the government (new rules and regulations such as the General Food Law) and the retail community (e.g. Global Food Safety Initiative).

Included within this definition are logistics decisions related to network design (e.g. plant site selection), sourcing, order fulfilment (including demand forecasting), transportation management, inventory management, materials handling, and return goods handling. In addition, aspects of product development such as designing packaging variants of products and associated product labels are also important. Key to optimal decision making is information management, that is gathering relevant data in the chain using all kinds of technological and information systems and distributing this data to chain participants so it can be used in business intelligence applications. In the definition a supply chain refers to a series of (physical and decision making) activities connected by material and information flows and associated flows of money and property rights that cross organizational boundaries (Van der Vorst et al., 2007[32]). The supply chain not only includes the manufacturer and its suppliers, but also (depending on the logistics flows) transporters, warehouses, retailers, service organizations and consumers themselves (Chopra & Meindl, 2012[33]).

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[28] Kurbatova, S., Aisner, L., Vlasov, V. (2020) Agrologistics: the concept, significance, types. IOP Conference series, 918, 12136

[29] Kiladze, A. (2017) Agrologistics in the agriculture system: from history to the prospects. Espacios, 38, 32, pp. 7-19

[30] Van der Vorst, J. G. A. J., Beulens, A. J. M. and Van Beek, P. (2000) "Modelling and simulating multi-echelon food systems", European Journal of Operational Research, Vol. 122 No. 2, pp. 354-366.

[31] Lambert, D. M. and Cooper, M. C. (2000) "Issues in supply chain management", Industrial Marketing Management, Vol. 29 No. pp. 65-83.

[32] Van der Vorst, J.G.A.J., C. Da Silva and J.H. Trienekens (2007) Agro-industrial Supply Chain Management: Concepts and Applications, FAO Agricultural Management, Marketing and Finance, Occasional Paper 17, March 2007, 56 p.

[33] Chopra, S., Meindl, P. (2012) Supply chain management: Strategy, planning and operation. Pearson.

Agrologistics concerns all activities in the supply chain to match product supply from the farm with market demand for those products. It aims at getting the right agro-product, at the right place, at the right time, according to the right specifications (including quality and sustainability requirements) at the lowest cost. Actors in these types of chains understand that original good quality products might be subject to quality decay because of an inconsiderate action of another actor.

It is clear that next to the traditional logistics management objectives, such as cost reduction and responsiveness improvement, sustainable agro-logistics management requires a different management approach that also considers intrinsic characteristics of food products and processes next to sustainability considerations (Seuring & Muller, 2008; Ahumada & Villalobos, 2009; Soysal et al., 2012).

In short, agrologistics are defined by their goal to deliver the right product, with the right volume, the right quality, at the right time at the right place. It ensures a timely transit through nodes of the food system, and describes how actors and processes are interlinked within that system. It can be used to create optimised decisions related to allocation of the use of resources against a set of performance indicators. These indicators typically are time and money, but can also include sustainability indicators such as energy use, GHG emission, water use, land use, biodiversity, security etc., under the assumption that suitable parameters are included and appropriate data are available. Soysal et al. (2012) created an overview for key logistics objectives in sustainable agro-logistics management, see figure 8 below.

	Key aims		Drivers & Enablers	Explanation	Key logistics issues	Literature
Logistics Management	Cost reduction		Economic crisis resulting in low prices Globalisation resulting in world-wide competition Automation resulting in more efficient processes	The ability to minimize total global network costs from the source of supply to its final point of consumption.	Network design, Distribution channel choice, Outsourcing, Operational excellence, Inventory positions choice, Transportation alternatives and constraints, Production choices, Incorporation of uncertainty, Use of information technology.	(Beamon, 1998) (Cachon and Fisher, 2000) (Christopher and Juttner, 2000) (Chopra, 2003) (Chopra and Meindl, 2010) (Fisher, 1997) (Gunasekaran *et al.*, 2008) (Lambert and Cooper, 2000) (Simchi-Levi *et al.*, 2009)
	Improved responsiveness		Demand for more product variety, high frequent deliveries with short lead times and small batches Increased demand uncertainty New ICT tools that facilitate more advanced information exchange	The ability to have a flexible and robust system that satisfies customer orders in time and responds quickly to the dynamics of the global marketplace. Additionally, to cooperate and collaborate with the other supply chain members in a way that facilitates movement of information in timely, reliable and accurate manner.		
Agro-Logistics Management	Improved food quality		Demand for safe and high quality food products Health consciousness of consumers Year round availability of food Demand for more convenience products Technological improvements	The ability to control product quality in the supply chain and deliver high quality food products in various forms to final consumers by incorporating product quality information in logistics decision making.	**All the above +** Homogeneity controls, Dynamic inventory management, Dynamic control of goods flow, Cold chain management, Multiple temperature consideration for multiple products, Product interferences consideration, Monitoring temperature history, Customer requirements consideration, Use of specific quality decay models, Waste management.	(Akkerman *et al.*, 2010) (Blackburn and Scudder, 2009) (Dabbene *et al.*, 2008) (Hafliðason *et al.*, 2012) (Trienekens and Zuurbier, 2008) (Van der Vorst *et al.*, 2000, 2002, 2007, 2011) (Van Donselaar *et al.*, 2006)
	Reduction of food waste		Demand for high quality products with long shelf lives Increased food security concerns Pressure from global organizations	The ability to collaborate in the supply chain network to reduce food that is discarded or lost uneaten because the quality has deteriorated.		
Sustainable Agro-Logistics Management	Improved sustainability	Environmental concerns	Growth of world population Climate change Limited natural resources Escalating sustainability awareness	The ability to reduce environmental impacts (e.g. GHG emission, energy use, water use, air pollution, deforested land, land availability and noise) of operations and to facilitate new energy sources such as biofuels.	**All the above +** Use of impact assessment tools, Sustainable food production consideration, Sustainable inventory management consideration, Sustainable transportation management consideration, Traceability possibility of products.	(Bettley and Burnley, 2008b) (Chaabane *et al.*, 2012) (Dekker *et al.*, 2012) (Fritz and Schiefer, 2009) (Helms, 2004) (Linton *et al.*, 2007) (Nepstad *et al.*, 2006) (Wang *et al.*, 2011) (Wognum *et al.*, 2011)
		Social concerns	Increased child labour Employment Escalating sustainability awareness	The ability to reduce societal impacts (e.g. nutritional content of products, employment opportunities, farm income) of operations.		
	Improved	traceability	Recent food crises Legislation	The ability to have complete visibility of all relevant product and process characteristics in the chain allowing to track and trace products throughout all stages in a supply chain.		

Figure 8: Key logistics objectives in sustainable agro-logistics management

Source: Soysal et al., 2012[34]

[34] Soysal M., J.M. Bloemhof-Ruwaard, M.P.M. Meuwissen, and J.G.A.J. van der Vorst (2012) A review on quantitative models for sustainable food logistics management, Int. J. Food System Dynamics 3 (2), 136-155.

Next to conventional logistics, additional aims, drivers and enablers come into play to improve food quality and reduce food waste (Soysal et al., 2012). These are:

(i) batch homogeneity controls along the chain,
(ii) dynamic inventory management that tracks the quality of products,
(iii) dynamic control of goods flow that adopts conditions and logistics to optimize market fulfilment (e.g. redirecting products to other markets having lower quality requirements),
(iv) cold chain management that considers temperature or enthalpy controlled carriers and depots,
(v) multiple temperature consideration for multiple products,
(vi) product interferences consideration (e.g. bananas produce ethylene that accelerates the ripening process of other fruits),
(vii) monitoring temperature history for accurate quality predictions, (viii) customer requirements consideration for specific markets,
(viii) use of specific quality decay models in logistics decision routines, and
(ix) waste management practices that consider food spoilages.

Next to the key logistics issues for the traditional and food quality related indicators, there are some additional logistics issues that need to be taken into account to improve sustainability and traceability (Soysal et al., 2012). These are:

(i) use of impact assessment tools (e.g. Life Cycle Assessment Analysis (LCA) assesses impacts of operations associated with all stages of a product's life starting from-cradle-to-grave),
(ii) sustainable food production consideration (e.g. using efficient machines that can reduce water use consumption or choosing production locations considering deforestation, land use issues, closed loop systems),
(iii) sustainable inventory management consideration (e.g. controlling energy use of cooling stocks in facilities (Akkerman et al., 2010)),
(iv) sustainable food transportation management consideration (e.g. considering GHG emissions, fuel consumptions of different transportation modes, new energy sources such as biofuels or noise, air pollution caused by vehicles (Dekker et al., 2012)), and
(v) traceability possibility of products for improving transparency in FSCs (e.g. use of safety focused traceability systems).

Within the traditional logistics management objectives, a chain perspective with consecutive, linear processes is used (see figure 9 below).

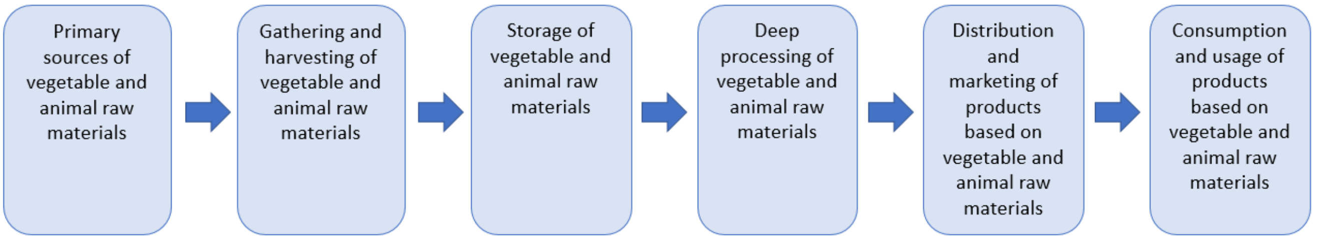

Figure 9: Key stages of the movement of agricultural material flow within agrologistics chain
Source: Van der Vorst & Snels, 2014[35]

[35] Van der Vorst, J., Snels, J. (2014) Developments and Needs for Sustainable Agro-Logistics in Developing Countries. World Bank, Washington.

As argued in the previous section, adding consideration of sustainability and circularity requires a different perspective of the organisational structure of the agri-food system. For this study, the three principles for the bioeconomy, as described in the WUR Investment Theme Connected Circularity are applied:

1. Our circular food systems are built on plant-based biomass obtained from land and water
2. By-products from plant-based biomass, known as waste flows, are to be avoided. If this is impossible, they must be redirected back into the bio-economy, with healthy soil as a priority. Furthermore, they can be used as biomaterials or cattle feed
3. The function and role of animals is to return biomass that is unsuited for human consumption into the food system

The concept of circular food systems is further explained by Van Zanten et al. (2019) and sees the use of animals primarily within converting by-products from the food system and grass (fibrous) resources into valuable food and fertiliser (manure). The animal production system then contributes significantly to the human food supply, while at the same time reducing the environmental impact of the entire food system. By converting these so-called low-opportunity-cost feeds, farm animals recycle biomass and nutrients into the food system that would otherwise be lost to food production. Rearing animals under this circular paradigm, however, requires a transition from our current linear food system towards a circular one. From the agrologistics perspectives, this also means a literal shift from chains to circular systems, with increasing complexity, dependencies and interlinkages. The figure below visualises the concept with its feedback loops for co-products (side flows), utilising multiple roots via agriculture and animal production.

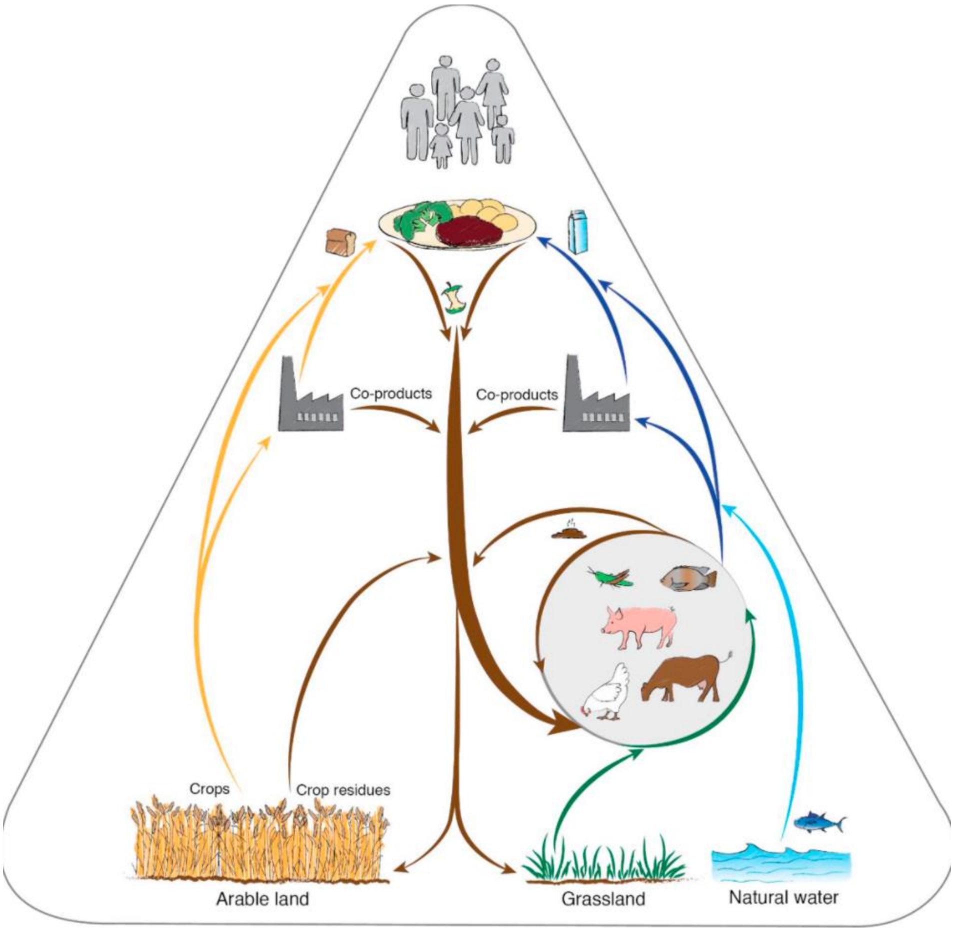

Figure 10: Biophysical concept of circularity
Source: Van Zanten et al., 2019[36]

[36] Van Zanten, H., Van Ittersum, M., De Boer, I. (2019) The role of farm animals in a circular food system. Global Food Security, 21, 18-22

Within the circular food system, arable land is primarily used for food production; biomass unsuited for direct human consumption is recycled as animal feed; by-products and manure are used to maintain soil fertility. In this way, nutrients are recycled and animals contribute to a circular food system, while sustainably feeding the future population. However, a remaining question is how much co-products (or: side flows, by-products and waste flows) can substitute dedicated feed crops and avoid wastes? How much food could be derived from livestock fed solely with side-flows? This will depend largely on:

- the quantities and quality of side flows available,
- the types of animals targeted,
- how effectively they convert the feed into animal products and
- the availability of necessary (processing) technologies.
- The consistency of side flows over time and stability of supply
- Safety and biological spoilage aspects

Shifting from linear towards circular agri-food systems requires from agrologistics to create additional loops to connect sources and uses. Key design principles for circular agrologistics are based on

- Avoiding waste
- Redirecting unavoidable waste flows into the bioeconomy, via soil, biomaterials or feed

When side flows are removed from the food chain, their destination decides if the application is considered 'waste'. The circular bio-economy dubs these removed flows as 'co-products'. Within this study, the more generic terminology of side flows is used. When side flows, are removed from the bio-economy, e.g. via incineration or land-fill, the associated sources that were needed to create the original biomass (including energy, emissions, fertiliser, capital, labour, water, land use, etc.) also become waste.

A key challenge for circular agrologistics is therefore to build knowledge on how to achieve a zero waste system, that is sustainable and economically attractive for the stakeholders of that system, from farm to fork. Typically, agrologistics research applies modelling techniques (ranging from simple linear regression towards Artificial Intelligence techniques) to either optimise or simulate different scenarios, reflecting options from practice, or projected over time. Within this report, we focus on the design of a agrologistics approach to describe options to match (potentially) available side flows with poultry feed requirements. Within the previous section, the requirements for safe and nutritious poultry feed, and the necessary volumes have been described. This report describes the design elements and considerations as building blocks for a side flow-based agrologistics design for poultry feed in the next chapter.

5 Section 4: Building blocks for the use of side flows as poultry feed within circular food systems

To gain more insights on the building blocks for the potential circular application of agri-food side flows from any supply chain segment as chicken feed, the project team organised a brainstorm session at 12 October 2020, using the Circular Agriculture Test (KLT - Kringlooptoets). The KLT approach is developed within the PPS "Kringlooptoets 2.0: ontwerpinstrument m nutrienten kringlopen te sluiten" (AF-18016) to gain insights in the measures and impacts of feed and foodstuff. The workshop was by Theun Vellinga (Wageningen Livestock research – Livestock and Environment[37]). Participants included 3 authors of this report (Adriaan Vernooij, Bas Hetterscheid & Hilke Bos-Brouwers), Wolter Elbersen, Julian Voogt and Martijntje Vollebregt (WFBR, researchers involved in circularity of side flows and food waste monitoring projects also cited earlier in this report). The KLT approach supports the creation of a shared understanding in the effect of measures that are intended to close loops within the agri-food system. It starts with outlining the organisation of resource flows in the agri-food system, by identifying the flows, production, consumption and sites for processing, trading and transport of products. The picture starts simple with vegetal and animal production and human consumption (see figure 14 below).

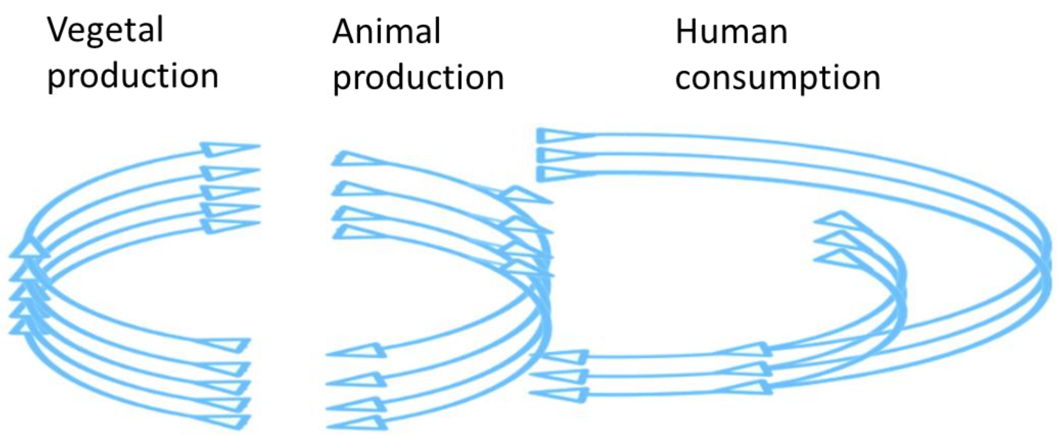

Figure 11: KLT starting picture of agri-food system
Source: Translated into English from Workshop KLT (Theun Vellinga), October 2020

[37] For more information on the KLL, see publications incl. Bremmer et al., 2021. Kringloopeffecten van het stoppen van import van diervoedergrondstoffen van buiten de EU: verkenning met behulp van de Kringlooptoets. https://www.wur.nl/nl/Publicatie-details.htm?publicationId=publication-way-353831323938

With the purpose of charting side flows for poultry production systems, the participants discussed a number of challenges and 'What-if?'-questions to chart consequences and interlinkages:

- How do we feed our livestock for the future? What are suitable and desirable feeding strategies?
- How do we integrate side flows and alternative (protein) sources (including insects) for sufficient, healthy and safe food?
- How do we define the scope and scale where 'it needs to happen'?
- What are the shared insights on the complexity of the issue and its solution pathways
- What if
    - We stop utilising feedstock from outside the EU?
    - We only want to source our feedstock for locally available side flows?

And considering

- What needs to happen to make this a reality?
- What are the effects and impacts of the new feed concept?

Circular systems basically try to solve wicked problems:

- Complex, multi-facetted
- Multi-directional definitions of the underlying problems
- Involves many stakeholders with different interests and different problem and solution perspectives: more than 1 'truth'
- Involves multiple geographical scales
- Not 1-size-fits-all, blue-print solution

Transfer points are needed to organise and connect the processes for production and consumption, distinguishing between primary and secondary processes with different stakeholders. To optimise the system, it is necessary to prevent and reduce losses. The figure below is the resulting conversation piece, depicting the use side flows for poultry feed.

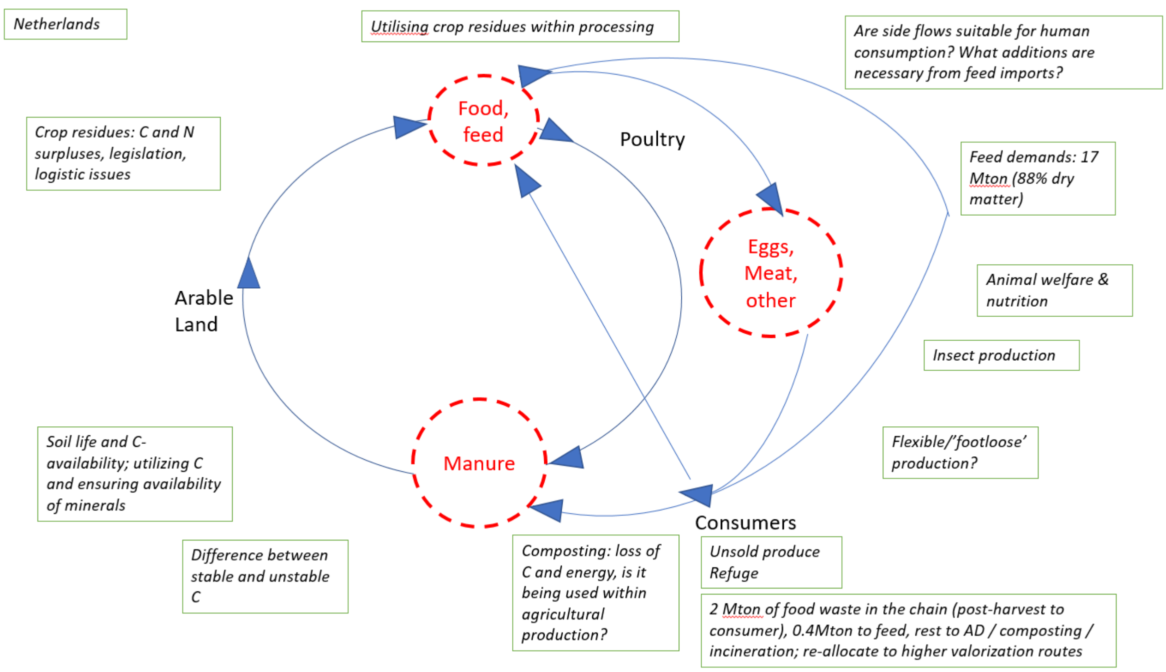

Figure 12: KLT workshop result

Source: Taken from and translated into English from Workshop KLT (Theun Vellinga), October 2020

Based on the literature review, the KLT workshop and project team meetings, the discussion in the workshop and project team meetings, the findings can be translated in the following, qualitative method design. It describes the following phases to guide a poultry farmer towards a circular feeding concept, by determining:

1. The available side flows from local and further ranging sources: what, when, how much, against what costs over time
2. The suitability as feed ingredients and the degree they meet with feeding requirements and required processing
3. Any missing ingredients/quantities that need to be additionally sourced
4. Organization of agrologistics to create sufficient, safe and sustainable feed at the farm

The animal production system is very diverse by nature, with many types of animal species, breeds and production systems. As indicated in the introduction section to this report, this study primarily focuses on the use of side flows for poultry feed. This immediately narrows the scope and scale for circularity, where interlinkages with other parts of the bioeconomy actually should be taken into consideration. However, by focusing on the needs, requirements and opportunities that arise for poultry feed, key building blocks for designing circular side flow agrologistics can be discerned for application within other livestock as well as an integrated approach for all livestock within the bioeconomy at various scales. This study serves as a showcase based on poultry.

Based on the circularity concept presented in the previous section, a number of considerations for the use of side flows as animal feed can be made. Overall, feed sources can be derived from (combinations of):

1. Types of food crops cultivated
2. Dedicated feed crops cultivated
3. **Crop residues**
4. Grassland (including hay and grass silage)
5. **Co-products from various stages** of the food system, including processing, wholesale, retail, restaurants, catering and households

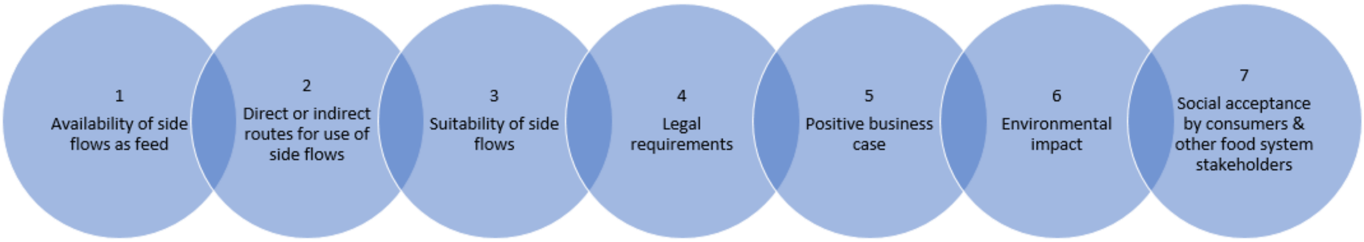

Figure 13: 7 steps towards determining the suitability of side flows as ingredients for poultry feed

No. 3 and 5 (highlighted above) have direct relevance for the use of side flows as animal feed. Assessing their appropriateness as poultry feed, the following steps need to be addressed.

In the previous sections, necessary building blocks and considerations for side flow agrologistics for circular poultry feed have been identified. Acknowledging the unlocked potential of currently under-utilised use of side flows used as animal feed ingredients paves the way for describing design principles to create a tool that evaluates the applicability of available side flows as raw materials in new circular feed concepts. As these specific side flows are characterised by a complex composition of mixed vegetal and/or animal fractions and relatively unpredictable availability in volume, time and space, there is a need to create a dynamic method that evaluates the applicability of any set of industrial and agricultural side flows that jointly can be used to meet the feeding requirements of poultry at farm level. The method includes locally sourced side flows (on farm / <10 km distance from farm) availability as well as further ranging transport distances for additional ingredients, in combination with the organisation of effective agrologistics. (Safeguarding) safety aspects plays a role in all 7 steps. The figure below illustrates the 7 steps towards determining the suitability of side flows as ingredients for poultry feed.

Step 1: Availability of side flows as feed

Assessing the availability of potential feed resources, based on:

1. Volume (total volume of side flows)
2. Composition (quality), including the concentration of energy, protein (amino-acids) and other nutrients (including dry matter and fat content) in each feed resource
3. Sources

   Potential (local) sources for side flows include:
   - Retail (supermarkets, specialty shops)
   - Catering / food services
   - Restaurants
   - Hotels
   - Households (incl. farmers)
   - Pre- and post-harvest crop residues on the field
   - Pasture rotation (with cows)
   - (Preproduction) insect management
   - Field margins, nettles, weeds, and similar
4. Continuity of supply over time
5. Competition with other uses of side flows (e.g. other species incl. pet feed, soil quality, biobased materials and/or energy, generation of bio-energy or production of pet food,)
6. Local sourcing and transport distance: one of the most defining indicators for sustainable use of side flows is captured by the distance between the origin of the side flows and the site of application. This distance plays a major role in the trade-off between valorising side flows and potential environmental cost savings.

Step 2: Direct or indirect routes for the use of side flows

Determining the routes for the use of side flows, based on:

1. Direct use of side flows: no processing or conversion step necessary, direct feeding
2. Indirect use of side flows
   a. Processing step(s) necessary for safeguarding feed safety (including issues with contamination, spoilage, transmittable diseases and microbial deterioration), transport/storage and nutrient disclosure
      i. Localised processing
         1. On site
         2. Near site
         3. Mobile processing units
      ii. Centralized processing at network hubs
   b. Via soil fertilization/ improvement and subsequent crop production
3. Intermediary step via insects production as animal feed (ingredient)

Step 3: Suitability of side flows

Meeting feeding/nutritional requirements of the dietary profile of poultry for maintenance, production, reproduction and growth functions of the animal. Based on:

1. Dietary profiles
   a. Layer hens
   b. Broilers
   c. Double-target breeds
   d. Parent stock
2. Stages of the production cycle
3. Duration of production cycle
4. Production systems
   a. Enriched / furnished cage
   b. Colony cage / aviary
   c. Barn brooding
   d. Free range hybrid
   e. Organic
   f. Other systems including specialty (e.g. Oerei, Oranjehoen) or hybrids

5. Compositions of the daily menu
    a. Fully based on side flows (no need for additional feed resources, e.g. from dedicated, imported feed crops)
    b. Partially based on side flows (mixed feeding scenarios with additional feed resources)
    And: anti-nutritional factors, dry/wet content
6. Acceptable conversion rate, including the maximum intake level of the animal and the desirable production level, and dependent on the species and breed: different species have different capacities to convert by-products and grass resources into valuable food for human consumption (Van Zanten et al., 2019).
7. Meeting animal welfare requirements, appropriate to natural search and feeding behaviours, and palatability of the feed

Step 4: Legal requirements (is it allowed?)
1. Legally allowed (e.g. animal feed regulation, food safety regulation, HACCP / GMP requirements): since approx. 20 years, the EU has banned the use of side flows from retail, restaurants, catering and households as animal feed. Recent research has shown that feeding these side flows (food waste) to non-ruminant livestock such as pigs and poultry can be done safely, when applying treatment technologies (including heating, acidification and fermentation). Technical guidelines have been published within the EU REFRESH project and currently possible changes in legislation are being discussed.
2. Not legally allowed under current regulation

Step 5: Positive business case
1. Cost-benefit efficiency
2. Price of each feed resources
3. Available technology of production system (capability to include side flows as feed resource)
4. Economy of scale

Step 6: Environmental impact: comparative analysis and trade-offs with other feed sources and uses of side flows
1. GHG emissions, including carbon sequestration, methane and nitrous emissions (Garnett et al., 2017[38])
2. Water use
3. Land use
4. Air quality
5. Bio-diversity

LCA and LC methodologies can potentially contribute to a better understanding of trade-offs within alternative scenarios, provided there is clear guidance on how to frame the goal and scope, covering different research questions, countries and supply chains involved. Also, data availability is a major concern and further research is needed to provide more readily available life cycle inventories and cost data on production of different commodities in specific markets, as well as models for better understanding market dynamics when introducing changes (e.g. reducing demand for conventional feed) (De Menna et al., 2019[39]). The scale at which we may target to close nutrient loops is determined by the interaction between various factors. Differences in agroecological and socioeconomic circumstances, for example, make some areas more suitable to producing certain types of food than others. These advantages may outweigh the emission impact of transport, implying that locally produced food may not always be the best choice from an environmental perspective. Closing nutrient loops also requires that new interactions are built between components of the food system, for example between cities and rural areas where food is produced. Cities are inevitably sources of large amounts of food waste and human excreta, which could be used as valuable nutrients for food production in urban farming systems that combine plant, insect and fish production. The optimal scale

[38] Garnett, T., Godde, C., Muller, A. Roos, E., Smith, P., De Boer, I., Ermgassen, E., Herrero, M., Van Zanten, H. (2017) Grazed and Confused? Ruminating on Cattle, Grazing Systems, Methane, Nitrous Oxide, the Soil Carbon Sequestration Question – and what it All Means for Greenhouse Gas Emissions. Food Climate Research Network (FCRN), Oxford, UK.
[39] De Menna, F., Davis, J., Bowman, M., Peralta, L., Bygrave, K., Herrero, L., Luyckx, K., McManus, W., Vittuari, m., Van Zanten, H., Ostergren, K. (2019) LCA & LCC of food waste case studies: assessment of food side flow prevention and valorisation routes in selected supply chains. www.eu-refresh.org

at which nutrients should be recycled in the food systems remains context specific, and requires an integrated analysis of the above mentioned factors (Van Zanten et al., 2019).

Step 7: Social acceptance by consumers and other food system stakeholders

1. Accepted by consumers
    a. Explicit branding of the side flow fed poultry products
    b. Provision of information on the use of side flows as poultry feed to the consumer
2. Accepted by other food system stakeholders
    a. Branding, certification, or 'business as usual'
    b. Certified processes to safeguard against potential contaminants and diseases
    c. Cross-sectoral collaboration with dedicated customers (system concepts)

Earlier research by Rahmani & Gil (2018[40]) identified relevant factors that influence the acceptance or rejection by consumers, including familiarity, knowledge, perceived risks, perceived benefits, experiences on food processes, involvement, trust between consumers and producers, information, naturalness, local origin, levels of processing, trust in food regulatory institutions, sustainability, safety, complexity, moral considerations, traceability, and transparency. The research demonstrated that informational strategies can contribute to the acceptance of valorised products by consumers. The provision of information has a larger likelihood for success, if it is continued until these kinds of food become familiar to the public. The outcomes of the experiments suggest that the acceptance of the studied valorisation methods (including gleaning vegetables and converting them into foods such as soups or creams extracting ingredients (vitamins) from product surpluses and using them for food enrichment; converting food-processing by-products to feed and feed supplements for animals intended for human consumption; and converting catering food surpluses to liquid feeds for pigs intended for human consumption (currently banned in the EU)) is complex and needs time because it requires removing any existing negative perceptions towards such methods. The findings suggest that a focus on framing the message in a positive way, pointing out the potential benefits for the consumer (such as taste, naturalness, local origin, environmental friendliness, animal welfare, social inclusion, etc.), creates more positive motivations towards acceptance. A remarkable result from the study is that although gleaning-based valorised products were deemed acceptable to be used within the setting of school lunches, the other valorisation methods were not, however, the participants did not view them as unsuitable for adult consumption. In contrast to their stated perception of valorised products as safe for health, presented with the option of giving these products to their children it evoked a negative response, 'just in case'... . To increase the confidence in the safe use of valorised food products, it can therefore be recommended to first focus on adult consumption on the short term. Furthermore, not only the consumers need to accept 'waste' as source for animal feed, the stakeholders of the production system need to accept it as well. Even with a solid economic and environmental benefit, this acceptance can make or break the successful application within (consumer) markets.

Further considerations

To encompass the full complexity and circularity of food systems, these interlinkages within the food system or the issue of competitive use of biomass resources should be addressed. Feeding side flows to animals should focus on those fractions of side flows, that are not / no longer suitable for direct human consumptions. When reshaping the concept of circular feed and the breeding of animals, Van Zanten et al. (2019) emphasize the focus on conversion efficiency of biomass that is not edible for humans.

Productivity and efficiency in livestock production have increased tremendously in the last decades. Several indicators demonstrate that further optimization of the productivity and efficiency in animal production is potentially still possible. The genetic potential is only partially utilized, the utilization of most nutrients appears to be low and there is a huge variation in performance among farms and within farms among animals (Den Hartog, 2009). In animals, the productivity is on average 30-40% below their genetic potential, because of suboptimal conditions and health status. Improvement can also be made on the raw material side. Available feed resources are not always used and significant amounts of feeds are wasted because of improper storage.

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[40] Rahmani, D., Gil, J. (2018) Valorisation of food surpluses and side flows and citizen's understanding. www.eu-refresh.org.

Moreover, novel feed resources need to be explored. New science and technologies seem to offer many opportunities for innovation. Key drivers are basically (gen)omics, microsystem- and nanotechnology and ICT. These mainstream technologies are the foundation of many application technologies which sometimes have already been implemented successfully in livestock production, including animal feeding and nutrition. In the future, such technologies will certainly offer opportunities for innovation in all parts of the chain. However, technology access and acceptance by consumers and society needs to be managed in a proper way. In conclusion, animal feed and nutrition are crucial in livestock production. Innovations have the potential to meet the challenges and to result in resource efficiency, healthy livestock and people, responsible production systems and optimal profit throughout the value chain (Den Hartog & Sijtsma, 2013[41]).

Alternative feed ingredients are typically evaluated in terms of their potential to substitute the conventional ingredients, such as fishmeal and soya beans. These ingredients are typically used because of to their high protein level and the good (amino acid) profile, meaning that they are fitting the animal's requirements. Nonetheless, it is desirable to lower the dependency on soya and fishmeal as both of these conventional feed ingredients also have negative effects on sustainability. Soybean meal production contributes to deforestation and the transport of the ingredient over long distances contributes to increased greenhouse gas emissions. Insects could be considered as intermediate, however, processed insects are not yet allowed in monogastric feed under EU regulation. Living insects' larvae are allowed in poultry and pig nutrition (Van der Heide et al., 2021[42]) in the Netherlands.

Other considerations for the agrologistics model include:

- When formulating the daily menu of poultry feed, decisions must be weighed against bottleneck ingredients, which are essential to the chicken's growth and health, such as specific amino-acids, and their present amounts in side flows. Alternatively, these bottleneck ingredients could be obtained from additionally sourced feed ingredients, and the menu can be optimised against other (macro-)ingredients that lead to a better performance against circularity indicators. It necessitates careful trade-offs in composing the daily menu.

- When transport of side flows needs to be arranged, how can this be optimised when multiple sources are needed for the daily menu? Transport arrangements could be made with the disposing parties, and/or customers of the animal products from the farm (avoiding empty transport on return routes). As transport distance matters for the sustainability performance of the feeding concept, it is necessary to avoid 'extra' transport costs and related environmental impact.

[41] Den Hartog, L., Sijtsma, R. (2013) Challenges and opportunities in animal feed and nutrition. Conference paper to the 11th World Conference on Animal Production, Beijing China (15.10.2013-20.10.2013). https://edepot.wur.nl/306279
[42] Van der Heide, M., Stødkilde, L., Værum Nørgaard, J., Studnitz, M. (2021) The potential of locally-sourced European protein sources for organic monogastric production: A review of forage crop extracts, seaweed, starfish, mussel, and insects. Sustainability, 13, 2303. https://doi.org/10.3390/ su13042303

6 Conclusions & next steps

This wildcard project aimed to create building blocks for method development to evaluate the suitability of side flows for animal feed from a circular agrologistics perspective, focussing on Dutch poultry feed. As the current lack of data on volumes and composition of side flows heavily limits the options to create quantitative agrologistics modelling techniques, the researchers performed a literature review to analyse available side flows, poultry production systems, and agrologistics opportunities. To put the literature findings into perspective, a workshop with additional WUR experts was organised using the Circular Agriculture Test (Kringlooptoets) approach. Acknowledging the complex nature of designing circular agri-food systems, while at the same time limiting the scope to poultry feed, design principles and options could be structured into a 7-step method. The qualitative description of these building blocks can guide farmers and animal feed manufacturers to evaluate suitable matches for poultry feed and the necessary agrologistics:

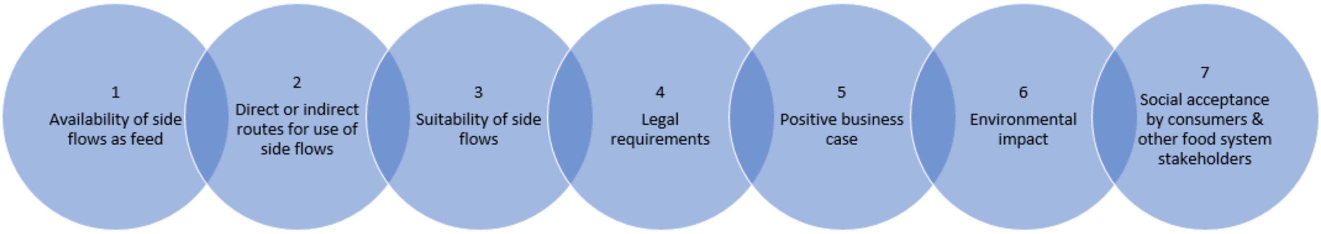

***Figure 14**: 7 steps towards determining the suitability of side flows as ingredients for poultry feed*

Applying the method creates unique circularity by design options for unique chicken farms utilizing unique side flows, taking into account context-related opportunities and requirements. Although the description is focused on poultry feed, it provides the building blocks to evaluate any side flows for any production process and on any farm.

There is no single actor within the circular bioeconomy that dictates the allocation of side flows available in the system, who ensures that all these side flows are used against their maximum potential. Therefore, the outcomes of the system are an aggregation of individual decisions by many stakeholders on many levels, and are likely to be sub-optimal. They have imperfect information on the system's performance over time, resembling playing chess on 100 boards simultaneously. The outcomes of this study can help determining considerations and consequences of side flow allocations in the shift towards a circular bioeconomy. Transitions in any part of the system will lead to unforeseen and unpredictable consequences within other parts of the system. This issue will not resolve itself entirely if and when more data on side flow volumes and composition become available through new research. The challenge is to create modelling techniques that capture all the circular design building blocks, weighing factors and trade-off that shape feed practice. This future model will also need to take into account preferences and principles from the stakeholders involved. This leads to questions on which uses are preferred above others. The answers should be fed with scientific, systemic insights, but may never lead to zero waste in practice. Using the building blocks described in this study will increase the awareness on the role of animal feed within this transition.

Next steps

This report describes the building blocks for a circular feed design, from a feed nutritional and supply chain development perspective. Optimisation is not new to animal production systems, however, circular feed provides extra opportunities within resource allocation and feed composition that is in turn improving the economic, social and environmental business case. Future research is called for to further detail the limitations, constraints, opportunities and implementation aspects of circular feed concepts.

The Wildcard study inspired the development of new, relevant project proposals as well as stimulated the collaboration between the different disciplines of supply chain development and animal feed nutrition. When optimising against circularity requirements, the reallocation of side-flows from the food supply chain to the short cycle of animal feed opens up many opportunities, for science and society. It brings the overall objectives of a circular bio-economy within grasp and produced tangible outputs as 'circular feed'. Specifically, the recently started PPS 2021 project LWV-20147 RENEW (BO-64-001-027) and the PPS proposal on the use of Spent Brewer's Yeast as animal feed within Ethiopia and other developing countries (submitted as PPS idea for 2022) benefitted from the Wildcard results and collaboration.

7 Annex 1: Side flows, composition and energy content

Naam	Upstream/downstream/ 1e verwerking	Herkomst	DM	Cellulose	Hemicellulose	Lignine	totaal ruwe celstof	Zetmeel	Suikers	Vetten	Eiwitten	onbekend	Ash	Dubbeltelling niet-lignocel deel bij biofuels?	HHV (MJ/kg dry)	LHV (MJ/kg wet)
Drijfmest Vleesvee	upstream	Vleesverw. industrie	8%	20.4%	11.8%	14.3%	0.0%	0.0%	0.0%	3.3%	15.5%	16.8%	17.9%	nee	16.65	-
Stapelbare mest	upstream	Vleesverw. industrie	55%	20.4%	11.8%	14.3%	0.0%	0.0%	0.0%	3.3%	15.5%	16.8%	17.9%	nee	16.03	6.65
Dierlijke vetten cat 1 en 2	eerste verwerking	Vleesverw. industrie	100%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	ja	39.34	36.88
Dierlijke vetten overig	eerste verwerking	Vleesverw. industrie	100%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	ja	39.34	36.88
Ongeb. mest en maaginhoud	eerste verwerking	Vleesverw. industrie	15%	20.4%	11.8%	14.3%	0.0%	0.0%	0.0%	3.3%	15.5%	16.8%	17.9%	nee	16.65	0.31
Diermeel cat 1	eerste verwerking	Vleesverw. industrie	96%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	12.3%	53.3%	2.7%	31.7%	nee	13.85	9.31
Diermeel cat 2	eerste verwerking	Vleesverw. industrie	96%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	12.3%	53.3%	2.7%	31.7%	nee	13.85	9.31
Visafval schone stromen	eerste verwerking	Visverwerkende industrie	20%	0.0%	3.1%	0.0%	0.0%	0.0%	0.0%	17.5%	56.1%	4.5%	18.8%	nee	17.46	1.38
Visafval mengstromen	eerste verwerking	Visverwerkende industrie	20%	0.0%	3.1%	0.0%	0.0%	0.0%	0.0%	17.5%	56.1%	4.5%	18.8%	nee	17.46	1.38
drijfmest Melkvee	upstream	Zuivelindustrie	8%	20.4%	11.8%	14.3%	0.0%	0.0%	0.0%	3.3%	15.5%	16.8%	17.9%	nee	16.65	-
Zuivelrestanten, 2e spoeling	eerste verwerking	Zuivelindustrie	4%	0.0%	0.0%	0.0%	0.0%	0.0%	71.4%	0.9%	13.3%	6.2%	8.2%	nee	15.62	-
Zuivelrestanten, misproductie	eerste verwerking	Zuivelindustrie	13%	0.0%	0.0%	0.0%	0.0%	0.0%	35.4%	31.5%	25.4%	0.0%	7.7%	nee	22.65	0.62
Schroten (soja)	eerste verwerking	Olien en vetten	88%	7.5%	5.6%	0.8%	0.0%	0.0%	9.4%	2.1%	51.6%	15.7%	7.3%	nee	16.22	12.62
Zeefafval	eerste verwerking	Olien en vetten	89%	0.0%	0.0%	0.0%	20.3%	0.9%	5.7%	2.1%	39.0%	24.2%	7.8%	nee	16.17	12.64
Bleekaarde	eerste verwerking	Olien en vetten	89%	0.0%	0.0%	0.0%	20.3%	0.9%	5.7%	2.1%	39.0%	24.2%	7.8%	nee	16.17	12.64
Vetzuren	eerste verwerking	Olien en vetten	100%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	nee	39.34	36.88
Olien en vetten uit crush	eerste verwerking	Olien en vetten	100%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	nee	39.34	36.88
Olien en vetten uit raffinage	eerste verwerking	Olien en vetten	100%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	nee	39.34	36.88
Hullen, schillen	eerste verwerking	Olien en vetten	89%	42.8%	17.9%	2.4%	0.0%	0.0%	1.7%	2.5%	13.4%	13.9%	5.3%	nee	16.88	13.37
Frituurvetten aardappelindustrie	eerste verwerking	Aardverw industrie	100%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	ja	39.34	36.88
Aard., overschotten	eerste verwerking	Aardverw industrie	20%	2.8%	5.0%	1.0%	0.0%	73.3%	2.1%	0.4%	9.9%	-0.1%	5.6%	nee	16.63	1.14
Aardappelstoomschillen	eerste verwerking	Aardverw industrie	15%	0.0%	9.2%	2.3%	0.0%	44.4%	2.3%	0.4%	14.3%	19.9%	7.2%	nee	16.07	0.17
Aardappelsnippers rauw	eerste verwerking	Aardverw industrie	22%	0.0%	0.0%	0.0%	2.3%	67.4%	0.5%	0.0%	8.3%	18.3%	3.2%	nee	16.77	1.48
aardappel zuiveringsslib	eerste verwerking	Aardverw industrie	20%	14.8%	9.1%	5.8%	0.0%	43.2%	2.1%	0.4%	5.3%	-5.7%	25.0%	nee	13.24	0.56
Aardappeldiksap	eerste verwerking	Aardverw industrie	3%	0.0%	0.0%	0.0%	0.0%	0.0%	5.7%	0.0%	34.3%	28.2%	31.8%	nee	10.84	-
Aardappelpersvezels	eerste verwerking	Aardverw industrie	17%	25.7%	7.2%	2.7%	0.0%	32.1%	0.8%	0.4%	7.5%	19.2%	4.4%	nee	16.73	0.52
G+F uitval afzetklaar maken na oogst	eerste verwerking	tuinbouw en ind.groenten	10%	2.8%	5.0%	1.0%	0.0%	73.3%	2.1%	0.4%	9.9%	-0.1%	5.6%	nee	16.63	-

Naam	Upstream/downstream/ 1e verwerking	Herkomst	DM	Cellulose	Hemicellulose	Lignine	totaal ruwe celstof	Zetmeel	Suikers	Vetten	Eiwitten	onbekend	Ash	Dubbeltelling niet-lignocel deel bij biofuels?	HHV (MJ/kg dry)	LHV (MJ/kg wet)
Veilingafval G+F (geen bloemen)	eerste verwerking	tuinbouw en ind.groenten	10%	2.8%	5.0%	1.0%	0.0%	73.3%	2.1%	0.4%	9.9%	-0.1%	5.6%	nee	16.63	-
Snijderijen	eerste verwerking	tuinbouw en ind.groenten	10%	2.8%	5.0%	1.0%	0.0%	73.3%	2.1%	0.4%	9.9%	-0.1%	5.6%	nee	16.63	-
Natte gewasrest akkerbouw	upstream	tuinbouw en ind.groenten	10%	2.8%	5.0%	1.0%	0.0%	73.3%	2.1%	0.4%	9.9%	-0.1%	5.6%	nee	16.63	-
Natte gewasrest tuinbouw	upstream	tuinbouw en ind.groenten	10%	2.8%	5.0%	1.0%	0.0%	73.3%	2.1%	0.4%	9.9%	-0.1%	5.6%	nee	16.63	-
Rooihout van fruitbomen	upstream	tuinbouw en ind.groenten	50%	44.0%	26.0%	28%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.3%	nee	19.81	8.00
Industriegroenten	eerste verwerking	tuinbouw en ind.groenten	10%	2.8%	5.0%	1.0%	0.0%	73.3%	2.1%	0.4%	9.9%	-0.1%	5.6%	nee	16.63	-
Industriefruit	eerste verwerking	tuinbouw en ind.groenten	10%	2.8%	5.0%	1.0%	0.0%	73.3%	2.1%	0.4%	9.9%	-0.1%	5.6%	nee	16.63	-
NL Tarwe voor energie	upstream	maalindustrie	87%	2.5%	10.7%	1.1%	0.0%	69.8%	2.7%	1.7%	12.1%	-2.4%	1.8%	nee	17.62	13.88
Tarwegries en zemelen	eerste verwerking	maalindustrie	87%	9.7%	31.9%	3.9%	0.0%	22.7%	7.6%	4.0%	17.0%	-2.5%	5.8%	nee	17.22	13.22
Maiszemelgrint	eerste verwerking	maalindustrie	88%	14.0%	42.9%	2.6%	0.0%	34.0%	2.5%	4.1%	12.3%	-19.2%	6.8%	nee	17.06	13.08
Hydrolysaat (ingeschat)	eerste verwerking	Zetmeelind.	20%	9.0%	29.9%	3.6%	0.0%	29.9%	5.8%	4.2%	18.1%	-6.3%	5.7%	nee	17.34	1.28
Bierbostel	eerste verwerking	Bierproductie	22%	16.3%	35.2%	5.9%	0.0%	7.5%	0.9%	8.1%	26.2%	-4.4%	4.3%	nee	18.57	1.94
Biergist	eerste verwerking	Bierproductie	12%	1.3%	4.7%	0.6%	0.0%	1.1%	0.3%	4.2%	49.9%	30.3%	7.6%	nee	16.49	-
Koffiedik in industrie	eerste verwerking	Koffieindustrie	60%	59.8%	0.9%	16.4%	0.0%	0.0%	0.0%	15.0%	13.0%	-7.1%	2.0%	nee	21.97	11.33
Koffiedik ingezameld	downstream	Koffieindustrie	60%	59.8%	0.9%	16.4%	0.0%	0.0%	0.0%	15.0%	13.0%	-7.1%	2.0%	nee	21.97	11.33
Suikerbietenpulp	eerste verwerking	Suikerindustrie	22%	21.0%	22.3%	2.1%	0.0%	0.0%	7.5%	1.0%	9.1%	29.3%	7.7%	nee	15.76	1.28
Melasse, biet	eerste verwerking	Suikerindustrie	72%	0.0%	0.0%	0.0%	0.0%	0.0%	61.6%	0.2%	14.5%	10.8%	12.9%	nee	14.53	8.46
Suikerbietenreststromen	eerste verwerking	Suikerindustrie	14%	22.3%	24.1%	1.8%	0.0%	0.0%	5.0%	0.5%	8.7%	30.9%	6.7%	nee	15.80	-
Suiker	eerste verwerking	Suikerindustrie	100%	0.0%	0.0%	0.0%	0.0%	0.0%	105.3%	0.0%	0.0%	-5.3%	0.0%	nee	16.99	15.87
Uien overschot als ui ingezet	eerste verwerking	uien	13%	0.0%	0.0%	0.0%	0.0%	0.0%	5.7%	0.0%	34.3%	28.2%	31.8%	nee	10.84	-
Uien restafval	eerste verwerking	uien	13%	0.0%	0.0%	0.0%	0.0%	0.0%	5.7%	0.0%	34.3%	28.2%	31.8%	nee	10.84	-
Cacoadoppen	eerste verwerking	Cacaoverw. industrie	88%	17.7%	11.3%	18.0%	0.0%	8.1%	0.4%	5.7%	18.3%	11.0%	9.5%	nee	18.20	13.82
Tabaksafval	eerste verwerking	tabaksproducenten	90%	59.7%	8.6%	19.6%	0.0%	0.0%	0.0%	0.4%	1.6%	4.6%	5.6%	nee	18.17	14.46
AWZI slib	eerste verwerking	verschillend	9%	0.0%	0.0%	0.0%	70.0%	0.0%	0.0%	0.0%	0.0%	0.0%	30.0%	nee	11.98	-
Putvetten	downstream	Horeca	6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	ja	39.34	-
Frituurvetten ingezameld	downstream	ingezameld	100%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	ja	39.34	36.88
ODP en productuitval	eerste verwerking	VGI industrie	49%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		2.0%	nee	16.32	6.31
Swill	downstream	Horeca	25%	2.8%	5.0%	1.0%			2.1%	0.4%	9.9%	5.5%	0.0%	nee	17.66	2.28
Voedingsresten in restafval	downstream	Consumenten	49%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	80.0%	20.0%	nee	15.94	5.75
Voedingsreststr in GFT	downstream	Consumenten	49%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	80.0%	20.0%	nee	15.94	5.75

Source: Elbersen et al. 2011

To explore the potential of nature to improve the quality of life

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