Annexes to:

D6.10 Valorisation spreadsheet tools

Learning tool for selected food side flows allowing users to indicate life cycle greenhouse gas emissions and costs

Documentation

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Table of Contents

List of Tables

List of Figures

Executive summary

Introduction

Based on the guidelines provided in the REFRESH report *"Generic strategy LCA and LCC"* (Davis et al. 2017) [1], we developed FORKLIFT (FOod side flow Recovery LIFe cycle Tool), a simplified learning tool in a spreadsheet format, which provides a basic footprint analysis of greenhouse gas emissions and costs.

FORKLIFT valorisation approaches have been modelled for the following selected food processing sideflows: apple pomace, brewers spent grain, rape seed press cake, tomatoes pomace, abattoir blood and whey permeate.

This report documents in detail, how each of the selected food sideflow valorisation approaches have been modelled in the FORKLIFT tool.

As a prelude, we include detailed descriptions of the tool and how to use it. For each sideflow a brief background indicates the availability of wider information on the volumes and fate of these materials.

The intention of FORKLIFT tools

FORKLIFT has been developed to help stakeholders gain a general understanding and to highlight the environmental impacts and costs for selected valorisation routes of a given side-flow. Being a learning tool, it is not intended for full footprint analysis to be communicated. It can be considered as a first step in understanding the dynamics of selected parameters usually controlled by the generator or the user of the side-flow. The model can be used by policy makers, researchers, professionals, businesses, and other interested stakeholders.

Valorisation routes for the six of the prioritised Top 20 food waste streams (Moates et al 2016) have been implemented in the spreadsheet tool FORKLIFT to provide illustrative examples of the how critical parameters that can be influenced by the stakeholders, such as energy demand (reflecting the equipment used) and supply (reflecting geography/location), transport mode and distances as well as capital and labour costs interacts. The implemented cases represent valorisation routes on a high TRL level, reflecting real options for a stakeholder. The cases have been selected in a way that the also can serve as guidance for new valorisation options. E.g. extracting valuable compounds or producing feed or energy, assuming the hot spots are similar.

How can users apply the FORKLIFT tool

By using FORKLIFT the user can gain an understanding of a system from an environmental and cost view. The user of the tools has the possibility to compare

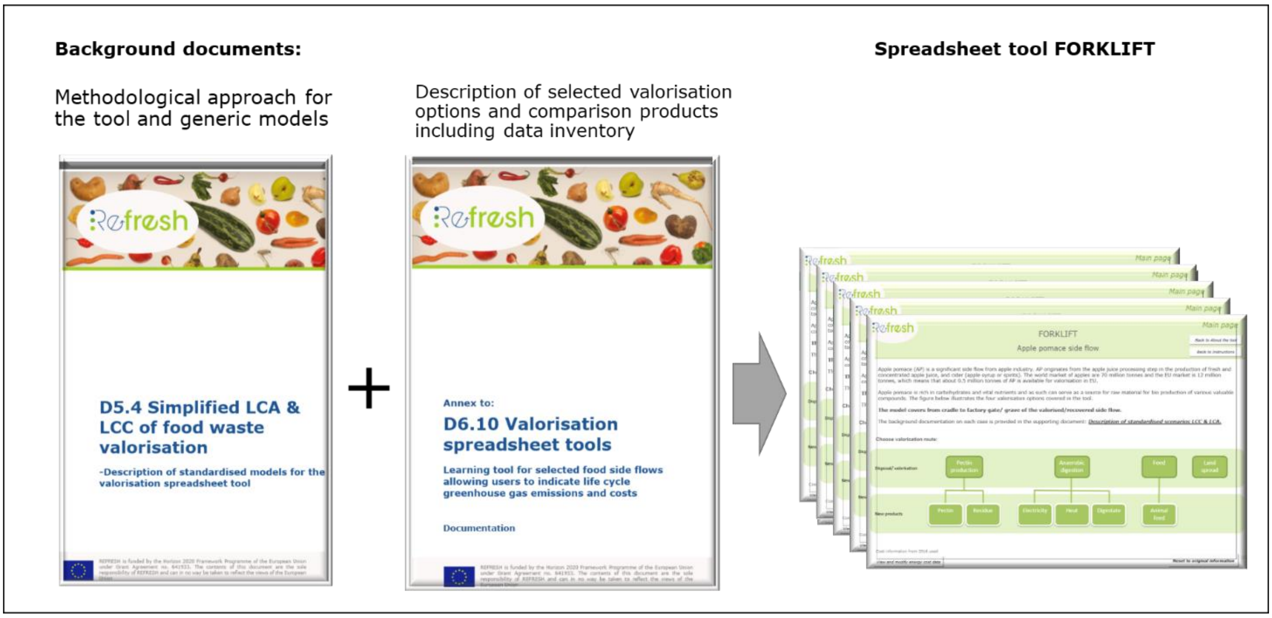
[1] https://eu-refresh.org/generic-strategy-lca-and-lcc

static systems which are reasonable to consider and change default values according to his/her contexts' specific situation (e.g. country, means of transport, heat source). Effects of the change are immediately shown in the result figure which enables the user to try different parameters and watch the effects. Emissions and costs of the valorisation option are shown in relation to a range of indicative comparison products. Which kind of product on the market will really be comparable is up to the user.

Scope of Forklift models

Specifically, FORKLIFT has a cradle-to-factory gate perspective, starting from the point of generation of the side flow up to its valorisation. GHG emissions from the upstream processes, before the side-flow was generated, are allocated between the main product and side-flow, based on their actual or estimated economic value for the generator of the side flow (economic allocation). Side-flow price, however, directly represents the costs of upstream processes. The tool does not consider future market developments and the impact of potential large-scale changes on infrastructures. For capturing such changes, the user is recommended to apply a full consequential LCA-LCC assessment following the guidelines provided in the REFRESH report *"Generic strategy LCA and LCC"(Davis et al 2017)*[2].

Figure i: The FORKLIFT toolbox: Methodological approach, description of the valorisation routes and data sources and modelling assumptions, the web-based spreadsheets tools for evaluation of GHG gases and costs



[2] https://eu-refresh.org/generic-strategy-lca-and-lcc

What can we gain by using the FORKLIFT tool?

FORKLIFT spreadsheets are easy to use which enable the user to change different parameters and to try out how these changes affect the life cycle costs and emissions. The spreadsheet tool can point towards areas of high impact (hotspots) and can support decisions for interventions. It is therefore a suitable learning tool with the additional effect of making it possible to compare the results with alternative systems available on the market. A stakeholder that generates or utilises a side-flow can interpret the results regarding the effects of interventions themselves, as they are also often the ones who know the market conditions best.

The tool clearly shows that many parameters influence the outcomes and that it is not easy to conclude general statements as the conclusion if an option is environmentally or economically feasible is highly dependent on the context (country, energy sources, substituted products at the markets). Thus, it may serve as an important complement to a food use hierarchy.

Also, by covering different food side-flows, which are different in terms of nutrients, fats, proteins, carbohydrates and fibres, a range of examples from across the food industry are covered. This can be helpful for demonstrating the significance of context to stakeholders with broader perspectives, perhaps with advisory, research, consultancy or remits concerning policy.

Due to time and resource constraints only six sideflows have been modelled in forklift, out of a total of nine sideflows with inventories that were researched. For posterity the documentation and inventories for the remaining three groups, orange pomace, carcass fats and proteinaceous matter and potato processing residues, that were not used for Forklift models have also been included in the annexes for reference.

In FORKLIFT quantitative data has been gathered and streamlined and made available for the user in a user-friendly format for selected important side flows and thus the model to some extent fill the gap between qualitative models (e.g. the food use hierarchy) and quantitative models.

Finally, and most importantly, the tool may enhance stakeholders' possibilities to pinpoint environmental and cost related hotspots in a given context. As such it can support the stakeholder in the pre-feasibility or concept stage to inform decisions on efforts to obtain more information on valorisation process/waste management options without having a full inventory at hand. This contributes to the development of more economic and environmentally sustainable handling of different food-side flows in the future.

1 Annex 1. The FORKLIFT toolbox

1.1 Introduction

The REFRESH project aims at contributing towards the EU Sustainable Development Goal 12.3 of halving per capita food waste at the retail and consumer level and reducing food losses along production and supply chains, reducing waste management costs, and maximizing the value from un-avoidable food waste and packaging materials.

This goal can only be achieved if food is produced using the available resources efficiently and effectively from an economical and environmental perspective. This includes the prevention of unwanted side flows from the food supply chain, as well as utilising any value from such side flows to the best effect. Such an increase in resource efficiency will have an economic effect and reduce the pressures on climate, water and land use in a wider perspective.

Generally, a new valorisation route for side flows from the food supply chain will be associated with impacts (monetary and environmental), for example for capital investments or developing new technologies. In the long run, however, this may lead to better resource utilisation which will manifest itself in lower running costs and less environmental impact. To allow informed decision making at all levels, from individual stakeholder to policy level, robust, science-based approaches are required.

Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) are well documented and generic approaches for assessing the environmental and cost dimensions of a system. Both LCA and LCC are characterised by allowing for a large flexibility in system scoping. To allow for comparison between different options consistent approaches are required. Furthermore, there is a need to bridge the gap between assessors who might have a deep knowledge of the systems they are assessing but are not in-depth method experts on LCA or LCC. Highlighting challenging methodological aspects and encouraging the practitioner to ask the most relevant questions contributes a simplified learning tool FORKLIFT (FOod side flow Recovery LIFe cycle Tool) has been developed.

While the REFRESH report “D5.3 Generic strategy LCA and LCC” (Davis et al 2017) provides guidelines on how to assess side-flows combining LCA and LCC FORKLIFT is aimed to provide stakeholders with a hands-on tool that can be used to help stakeholders gaining a general understanding and to highlight the environmental impacts and life cycle costs for selected valorisation routes supporting the understanding the dynamics of selected parameters usually controlled by the generator or the user of the side-flow.

1.2 Aims and Objectives

The aim was to develop an accessible web-based tool to improve LCA and LCC concepts in valorisation choices at the pre-feasibility stage for a variety of stakeholders. As such it addresses the

the following REFRESH objectives:

- Supply consistent LCA and LCC data for selected cases of valorisation routes to be used for the identification of the most sustainable and economically viable solution.
- Contribute to the development of the REFRESH decision support system and develop an accessible web-based tool providing consistent LCA and LCC data.

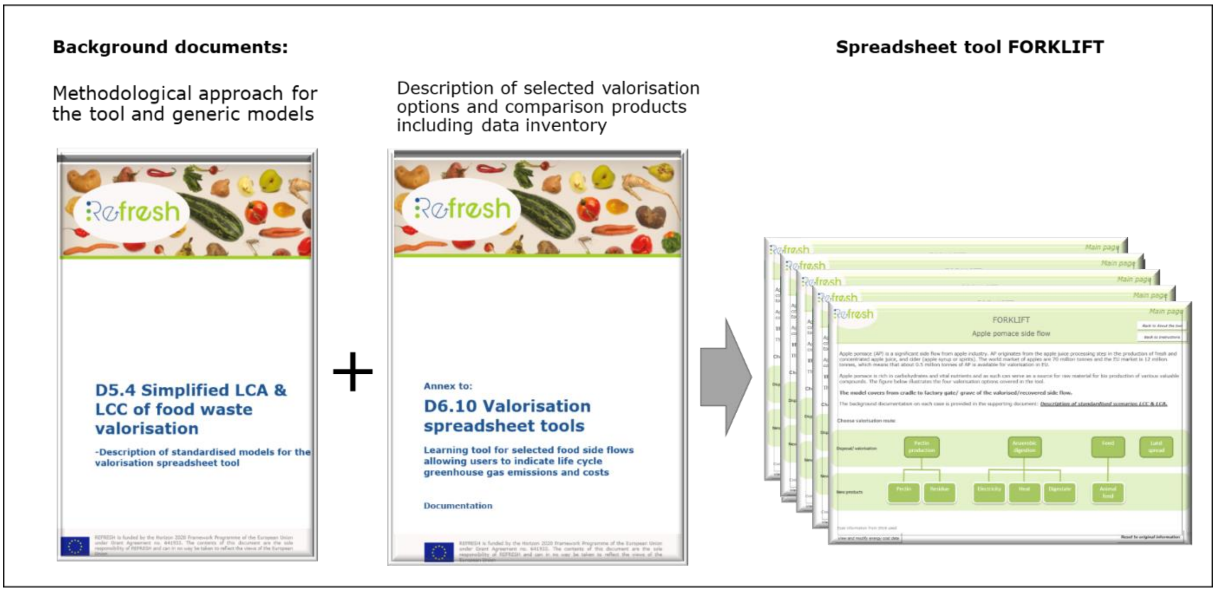
To support robust LCA and LCC based decision making, a considerable level of detail and model refinement can be demanded. In this respect it is often not possible to make a tool particularly user-friendly tool. This is especially so where users do not have prior experience or training in LCA's. This is a known challenge when developing simpler tools to indicate full LCA decision level information (Arzoumanidis et al 2017)

Therefore, the aim of FORKLIFT has evolved into a conceptual learning tool that is designed to bridge the gap between the detail required for LCA decision support and accessible lifecycle thinking, where there is a potentially broad stakeholder remit in mind. This is the case for REFRESH where stakeholders may include policy makers, researchers, professionals, businesses and other interested parties.

The specific objective of this report is to provide the background documentation on the implemented cases in the REFRESH FORKIFT tool.

For a more complete understanding this documentation should be read alongside with D5.4 Simplified LCA & LCC of food waste valorisation -Description of standardised models (Östergren et al 2018) for the valorisation spreadsheet tool, providing the reasoning behind the modelling approach

Figure 1: The FORKLIFT toolbox: Methodological approach, description of the valorisation routes and data sources and modelling assumptions, the web-based spreadsheets tools for evaluation of GHG gases and costs



1.3 Problem framing and side-flows

The results obtained from FORKLIFT respond to the question "*What are the potential environmental implications and cost implications of a valorisation route of a side flow?* Specifically, it provides the GHG and costs for one tonne of side flow being valorised/disposed to XX. Where XX is/are the end-product(s) of the selected valorisation route.

Side-flows of the food supply chain (FSC) are defined as a material flow of food and inedible parts of food from the food supply chain of a driving product. The stakeholder in the FSC producing this flow tries to have as little as possible of it. The principle 'the less, the better' applies to these flows (Davis et al. 2017).

The choice of side flows implemented in FORKLIFT are based on recommendations by experts/stakeholders within REFRESH provided in "Top 20 Food Waste Streams" (Moates et al, 2016) and "Valorisation appropriate waste streams" (Sweet at al. 2016) based on the following criteria:

- Difficult to prevent;
- Large volumes and/or significant environmental impacts;
- High valorisation potential;

Selected side-flows for the assessment are: apple pomace, blood from slaughtering, brewers' spent grain, tomato pomace, whey permeate and rapeseed press cake.

Valorisation options representing REFRESH Situations 2-4 (Figure 2) were identified through an in-depth literature survey and experts/stakeholder's knowledge within REFRESH (Moates et al, 2016). Only mature technologies were considered (scope was determined to be TRL9).

1.3.1 Comparing products

To give an indication of the impact of other products the footprint of products with similar functionality are shown in a static system. This is an LCA approach that assumes the proportion of all materials energy flows and resulting greenhouse gases and costs from goods and services attributed to the production process stay the same. The selection of products to compare were selected on the basis of the collective knowledge of the group to enhance the learning potential.

Criteria used were:

- The comparison products should be a combination of market alternative products providing the same specific function, as well as high and low impact alternatives.
- The footprints should reflect commercial production of a comparison product.
- Data quality should be sufficiently good for the purpose.

The products were compared based on equal functionality.

Figure 2: Scope of the spreadsheet tool developed (Davis et al., 2017)

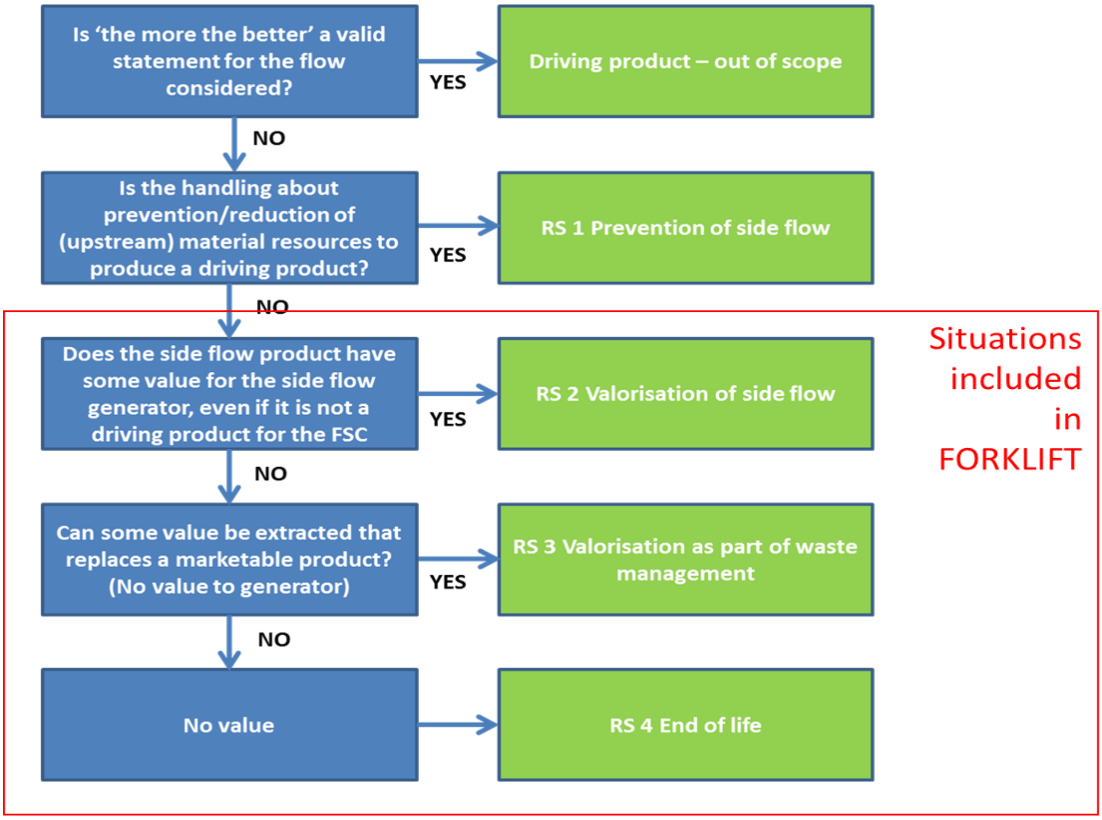


Figure 3 and Figure 4 provide an overview of the selected side flow and valorisations options included in the spreadsheet model as well as comparing products.

Figure 3: Valorisation and disposal options included in the spreadsheet tool 'FORKLIFT' – part I

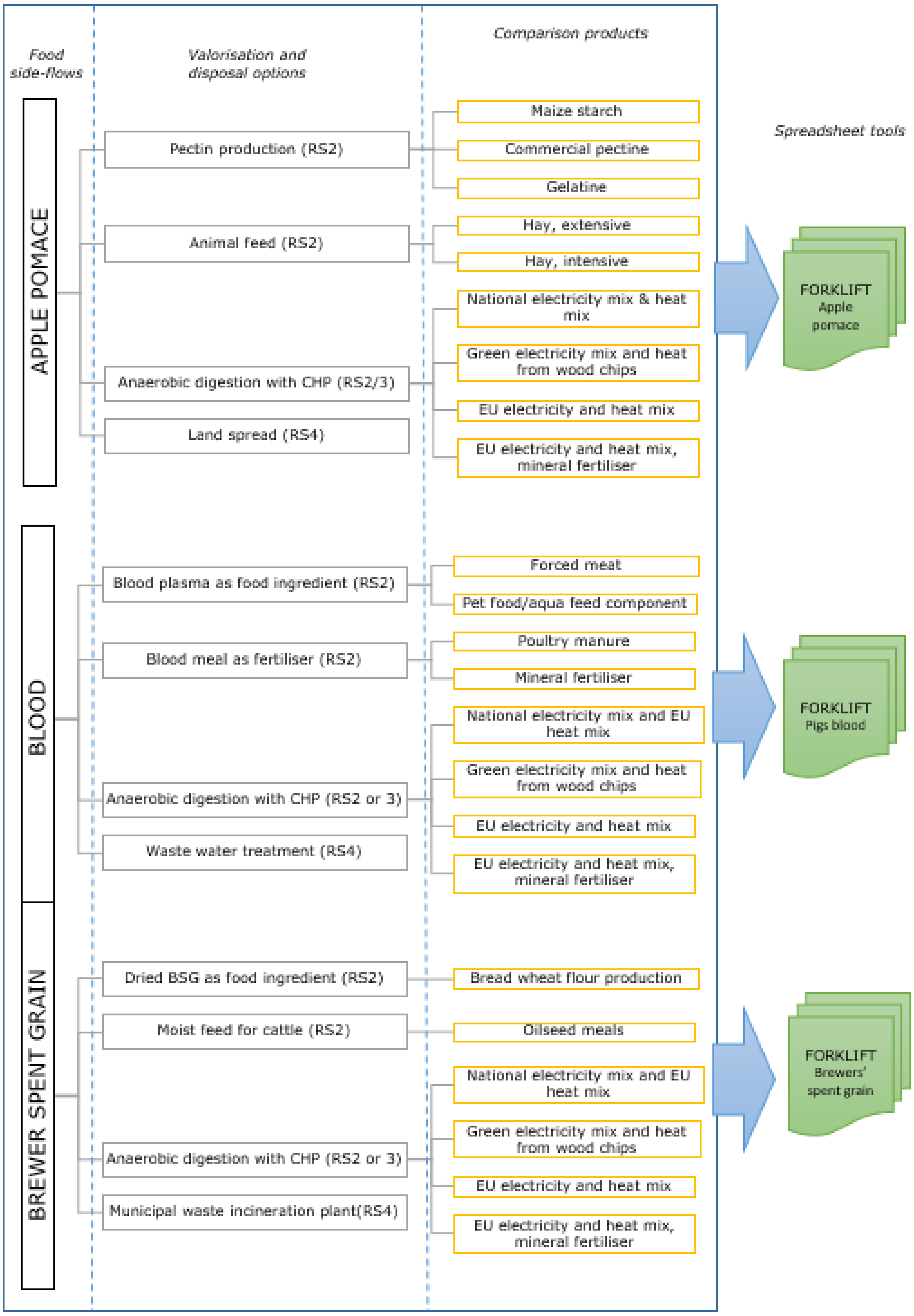
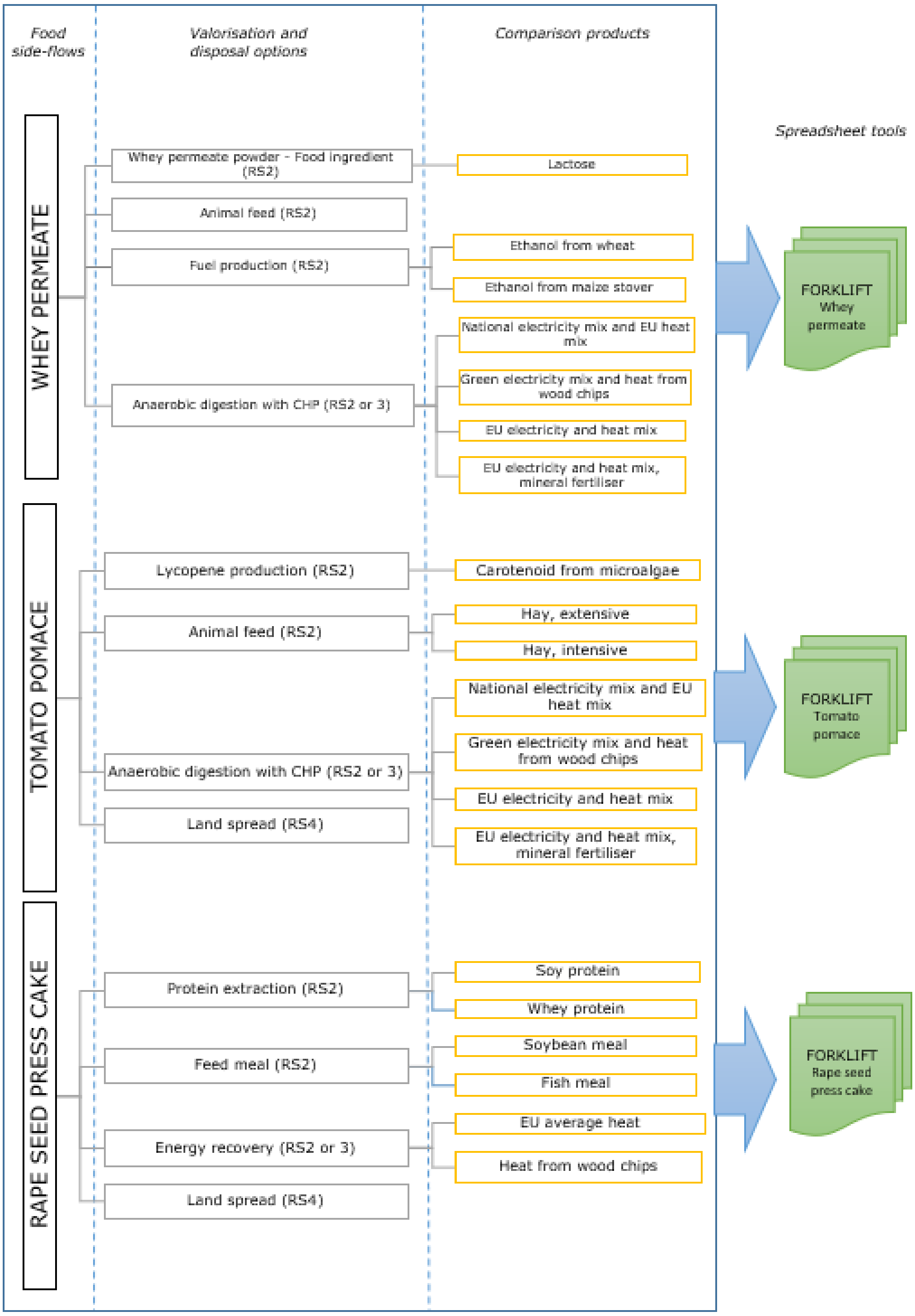


Figure 4: Valorisation and disposal options included in the spreadsheet tool 'FORKLIFT' – part II



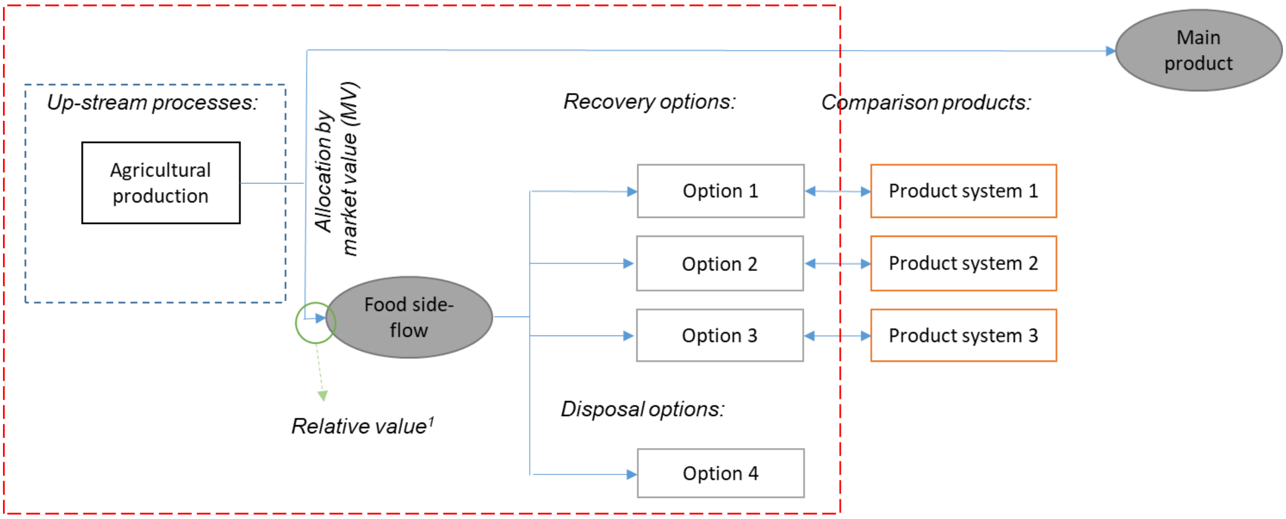
1.4 Main theoretical considerations

Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) are generic approaches for assessing the environmental and cost dimensions of a system. LCA summarises all environmental impacts associated with the life cycle of a product and an E-LCC (environmental-LCC) summarises all costs associated with the life cycle of a product including those involved at the end of life. In an E-LCC the costs must relate to *real* money flows. Externalities that are expected to be internalised must also be included. An E-LCC is a costing method that can be integrated with LCA (i.e. having same functional unit and system boundaries) forms the base for the FORKLIFT tool.

The core approach in the FORKLIFT tool is based on the framework presented in the REFRESH report "Generic strategy LCA and LCC-Guidance for LCA and LCC focused on prevention, valorisation and treatment of side flows from the food supply chain" (Davies et al., 2017). The calculations provide a footprint of a current valorisation disposal option considering current knowledge, infrastructures, and market conditions (2017). The data collected refer to EU (average) or selected single EU-countries.

For greenhouse gases, the global warming impact potentials over 100 years (GWP_{100} IPCC 2007) has been assumed. For costs, the most recent data available was used for all the items considered (see section 5.3).

Figure 5: REFRESH generic system boundaries for the FORKLIFT tool



[1]Relative value = Market value of the food side-flow / (market value of the product portfolio (all side-flows and main products) x100

Multi-output allocation generally follows the requirements of ISO 14044 (ISO, 2006a, b). As side flows are per definition co-products of multi-output processes, allocation is required at the processing stage as shown in Figure 5. Economic allocation was chosen as the appropriate method, allowing the user to include the relative value of side flow with respect to the product portfolio of the given product being processed (e.g. apples) at the point of sell. For example, if the side flow is apple pomace the value of the apple pomace at factory gate (point of sell for the side flow) is divided by the value of the apple pomace and apple juice (the product portfolio with reference to apples).

For the environmental impacts, the impact of the main product(s) *at farm gate* was used as a proxy for the total environmental impact before allocation. As far as E-LCC is regarded, the user can include the value/price of the side-flow as a proxy of the economic burden if the value at factory gate is not known.

The modelling approach does not apply any allocation at end of life (RS4). As the goal of the study is to assess valorisation, only the total impact associated to valorisation is quantified. Additional functions are specified, but not allocated.

For the full methodological documentation D5.4 and D5.3 should be consulted

1.5 Limitations

The FORKLIFT tool is subject to limitations that need to be explicit to guarantee a robust interpretation of results:

- FORKLIFT assesses a static system. Large-scale interventions are only reasonably possible for large-scale studies, with fewer options and clear market interventions.
- FORKLIFT *does not provide results* on policy recommendations, as this would demand consequential modelling. However*, it reveals hotspots of the different valorisation options and gives insights on effects of certain choices.*
- FORKLIFT is based on generic data but the process inventory data used in key default parameters has been based on particular case/scales. There may be scaling impacts which is why parameters are modifiable. However Forklift does not replace carbon footprint or cost calculations for specific decision-making at company level.

Thus, FORKLIFT should not be used as a precise tool for investment decisions nor for external communication of impacts and costs. However, it can reveal hotspots of the different valorisation options and give indications on effects of certain choices.

1.6 Outline of the spreadsheet tool

The tool enables the user to work on three levels:

Level 1 (Overview page)

On the Overview page of each valorisation option the total GHG emissions and costs for utilising 1 tonne of side flow are shown based on the economic value of the side flow and the selected country. The user has the possibility to enter parameters for disposal, labour and capital costs here. The impacts of functionally equivalent products are shown here.

Level 2 (Detailed results -no changes)

On the "Detailed results" page the user can investigate hotspots in a simple format to understand which part of the process contributes the most to the GHG emissions and costs.

Level 3 (Detailed results – with changes)

By changing parameters: on the "Detailed results" page the user can investigate single parameters and can see the effects on the overall results.

1.7 Step-by-step, how to use the tool

1.7.1 Getting started

a) Save the master file to your computer before starting to work with the file.
b) The tool is navigated by using navigation buttons in each view. Information on specific items can be reach by clicking on (i), where information is provided
c) On the **"Main page"**, select the valorisation option of interest. You are now forwarded to the overview page of the selected valorisation option. Scenarios using different utilisation options can be saved during the session by clicking on "save this scenario".
d) If wanted, it is possible to update the pre-set cost data using the link on the **"Main page"**.
e) On the **"Overview page"** of the selected valorisation option all required parameters are set by the user.
    i. If the side flow is a part of the business portfolio at the site where it is generated, please provide an estimate of its relative importance expressed in *% of the total revenue from the specific raw material portfolio value*. A default value of 0 % is assumed in a new session.
    ii. Choose country. The country determines the *GHGs and cost of the electricity mix **and** cost of labour*, default is a *European average.*
    iii. Add disposal, labour and capital cost if relevant and known.

1.7.2 Results in their simplest format

The results are presented in two diagrams on the overview page: lifecycle GHG emissions (kg CO_2 eq./tonne utilised side flow) and the life cycle costs (Euro/tonne utilised side flow). The results of similar products (in grey, on the right) are all scaled so it is the function that is compared, e.g. the energy generated from making biogas of a side flow is compared to the same amount of energy from other sources.

1.7.3 Detailed results and refining the results

To check and refine the calculations click the "Check/amend detailed information" button which takes you to the **"Detailed results page"**.

a) Graphs: The graphs provide the detailed results split into 'Processing', 'Transport' and 'Upstream processes' and 'Capital costs'.
b) Refining calculations: Pre-set critical parameters that can be influenced by the user can be refined to better fit the actual situation, e.g. energy use, transport distances, energy mix and fuels used.

1.7.4 Save scenarios

a) Save a scenario by using the provided link on the **"Overview page"**.
b) To view the saved scenarios, use the link provided on the **"Overview page"**. A maximum of 10 scenarios can be saved. The scenarios can be cleared from the **"Saved scenarios page"**.
c) To save the results from a session save the Excel file with a new name.

1.7.5 Further details on the tool

The tool covers the calculation of greenhouse gas emissions and costs of processes from cradle to factory gate or grave of the valorised /recovered side-flow. This implies:

- GHG emissions and costs of processes up-stream (allocated by economic value to the side-flow)
- GHG emissions and costs attributed to Transports
- GHG emissions and costs attributed to the Valorisation Process
- GHG emissions and costs of products having the same function (Comparison products).

Calculations

GHG –emissions and the total (chain) costs per tonne side-flow to be valorised are calculated based on the most important processes in terms of GHG emissions and costs for each valorisation option including energy use, transports and packaging if relevant. On the cost side, labour and capital costs are optional.

Upstream processes, i.e. before the generation of the side flow

GHG emissions and costs from the upstream processes, before the side flow was generated, are allocated between the main product and side flow, based on their economic values, set by the user. If no value is set, no share of upstream GHG emissions or costs is allocated. An increased value (revenue) of the side flow will lead to an increased footprint of the valorised product and decreased footprint(s) of the main product(s) and other co-product(s), and vice versa. The price payed to the generator of the side flow represents the share of upstream costs.

Processing calculations

The process calculations are greatly simplified and customised for each valorisation option (see the detailed documentation provided in the supporting documentation of the models in D5.4). In most cases, the processing can be modelled from the net energy input split into heat and electricity. Energy values for the processes are included for guidance but can be changed by the user. The source of energy (heat) and electricity can be selected from a drop-down menu. For heat generation boiler efficiencies are considered in the calculations of GHG emissions and costs. For electricity use, country grid mixes are used. Pre-set values (GHG-emissions and costs) are based on European averages. The processing calculations also include landspreading and field emissions.

Transport calculations

Transport activities can be changed by the user using the detailed option. The type of transport (including two levels of load factors, LF, for the most common transport types) is selected from a drop-down menu and the estimated transport distance can be changed. The impact and cost of transport are calculated as a function of the weight of the side flow. Weight changes due to processing, are considered in the model.

Comparison products

The GHGs and costs of comparison products that are shown in the result figures are based on footprints and costs found in the literature and are unaffected by changes in the model. Thus, these should only be seen as an indication on whether the new process is essentially better or worse, since the variation in calculated footprints is highly dependent on assumptions made and costs of products vary significantly over time.

Disposal, Labour and Capital cost

This information is optional in the tool. If the process investigated requires capital investment or additional labour costs, this information can be added. If this information is included, it will also be included in the results. No defaults for this are given in the tool since these are considered to be subject to non-linear factors depending on process scales etc.

Tool management

The model is only for educational purposes and should not be used as a tool for investment decisions nor for external communication of impacts and costs. The user of the model is fully responsible for how the results are used.

2 Annex 2 Apple Pomace spreadsheet model

List of Abbreviations

AD Anaerobic digestion

AP Apple Pomace

IPPA International Pectin Producers Association

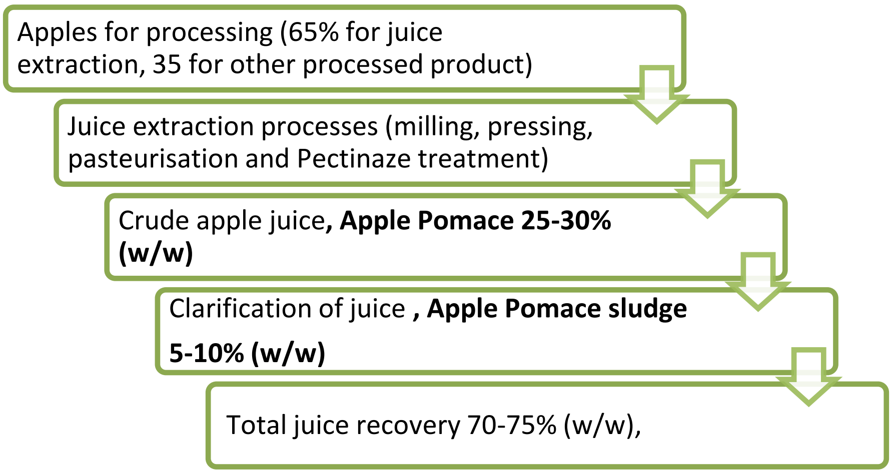
2.1 Background

2.1.1 Rationale

Apple pomace (AP) is a significant side flow from apple processing industries (Rabetafika et al 2014; Dhillon et al 2013) and has been identified as one of twenty food chain side flows considered suitable for valorisation by Refresh deliverable 6.1 (Sweet et al 2016) and 6.9 (Moates et al 2016).

AP originates from the production of fresh and concentrated apple juice, cider (apple syrup or spirits) (Figure 6).

Figure 6 Juice yield and amounts of apple pomace relative input of fresh apples



2.1.2 Information on potential and actual apple pomace quantities

The world market of apples is about 70 million tonnes according to FAO stat 2003-2013. The EU market for apples is about 13 million tonnes of apple including imports according to USDA's Foreign Agricultural Service[3] (Table 1) and about 4 million tonnes of these are processed (3,8 million tonnes 2016/2017). Following Dhillon et. al (2013), assuming that 65% are utilized for juice and cider extraction would mean that about 0,7 million tonnes of apple pomace is accessible for valorisation in EU27.

Table 1 Apple EU 27 Apple market showing the quantity for processing ('000 tonnes). (Source: USDA FAS[3])

Marketing Year	Production	Imports	Total Supply	Fresh Dom. Consumption	Exports	For Processing
2007/08	10335	889	11224	8054	740	**2430**
2008/09	12703	868	13571	8437	1196	**3937**
2009/10	12096	590	12687	8146	1214	**3327**
2010/11	10981	620	11601	7618	1010	**2973**
2011/12	12338	518	12856	8072	1503	**3281**
2012/13	12207	563	12770	7929	1568	**3273**
2013/14	11865	622	12487	7353	1573	**3562**
2014/15	13636	400	14037	7781	1792	**4139**
2015/16	12659	450	13109	7499	1590	**3852**
2016/17	12295	430	12725	7290	1515	**3820**

The world market of apples is about 70 million tonnes according to FAO stat 2003-2013. The

2.1.3 Composition of Apple pomace Information on potential and actual apple pomace quantities

The final composition of the AP depends on the process. For example in some cases skin stalk and seeds may be removed before the pressing step during juice extraction and the addition of pectinolytic enzymes will also affect the composition and pectin contents. (Rabetafika et al, 2014)

Specifically AP is rich in carbohydrates and vital nutrients and has been identified as a raw material for producing various valuable compounds such as organic acid (citric and lactic acid, enzymes, natural antioxidants, dietary fibre (e.g. pectin, cellulose, hemicellulose and lignin), aroma compounds, bioethanol and various biopolymers (Dhillon et al, 2013,Rabetafica, et al 2014)

Indicative composition of AP is provided in Rabetafica, et al (2014) are summarised in Table 2. The reported pectin and fibre content of apple pomace can vary significantly (e.g Adetunji Adekunle, Orsat, Raghavan, 2017; Rabatefika et al,

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[3]https://www.fas.usda.gov/data/fresh-deciduous-fruit-apples-grapes-pears-world-markets-and-t

2014; Dhillon et al. 2013) depending on extraction method, cultivars and pre-processing conditions, washing stages and drying temperature. Pectin yields ranging between 3.5–14.3 % w/w on dry matter basis AP or.5.50–11.70% of the dietary fibre content has been reported by Dhillon et al. (2013) and ranges between 15-20% w/w on DM bases were reported by Adetunji et al. (2017). Finally, the REFRESH food waste explorer provides a yield of 16,5 % w/w on DM bases. According to Rabatefika et al, 2014 conventional processing of AP using mineral acid results in a yield between 12,5 and 13,75 % based on DM content in lab scale. Process data from commercial pectin production are limited. Anecdotal evidence however indicates that 12% pectin yield is a reasonable estimate for conventional industrial applications. In addition to this, commercial pectin processors report a reduction in [citrus] pectin peel quality of 3% per hour residence time from juice extraction to washing/drying and also 1.2% loss of functionality per month from start of the harvest season (Sørensen 2015). So similar factors may also apply to apple pectin pomace which, notwithstanding differing extraction methods employed, could make yield comparisons problematic where residence time is not reported in scientific literature.

Considering the content of insoluble dietary fibres values also vary, around 40% are reported for apple pomace by Sudha et al (2007) and Chen et al (1988).

Table 2. Indicative composition Apple Pomace in % of dry matter (Rabetafika, Bchir, Blecker& Richel, 2014)

	% of dry matter AP
Ash	0.6-1.9[1], 1.5-1.7[3]
Lipids	1.6-4.5[1,]
Protein	3.1-3.7[1], 2.8-4.1[3]
Pectins	11.7[2], 9.2-12.8[3]
Lignin	20.4[2], 13.8-17.1[3]
Hemicelluloses	24.4[2], 20.0-29.9[3]
Cellulose	43.6[2], 20.2-26.4[3]
Insoluble Dietary Fiber	56.5-81.6[1]
Soluble Dietary Fiber	4.1-14.3[1]

[1]Pomace;juice industry;[2]Pomace,juice industry;[3] Pomace, cider industry

2.2 Current valorisation options

According to the scientific literature AP has been considered for widely different value-added purposes (lab scale as well as commercial production options considered), for examples organic acids aroma compounds, enzymes, bio-ethanol, edible mushrooms, edible fibres, pectin recovery, natural oxidants, animal feed, insects diets textile dye removers, heavy metal adsorbents among others. (Dhillon et al, 2013).

The availability of information on the actual industrial use and fate of apple pomace produced across EU Member States is limited. In the UK, one of the largest apple processors operating in the cider industry has invested in an anaerobic digestion plant for treatment of apple pomace with energy recovery (0.4 MW electricity). Anecdotal evidence from correspondence with an industry representative suggests that smaller cider apple processors are likely to send pressed pulp as a moist feed seasonally during harvesting and pressing period. In this context pomace is used as either a forage extender or concentrate for ruminant livestock[4].

Apple pomace may be used as a source of pectin feedstock. The predominant raw material used for pectin in the EU, however, is the higher pectin yielding citrus peels, mainly imported from Brazil. In Europe five factories are listed at the homepage of International Pectin Producers Association (IPPA)[5]. Other production sites are found in China and the USA.

Apple pomace used by pectin plants in Germany is also processed into a de-pectinised apple pomace marketed as pelletised and powdered animal feed products in addition to apple molasses also used for animal feed[6]. In other circumstances, smaller scale apple juice processors may landspread apple pomace for feeding wild animals with little recovery (an example of this is was found in Sweden). Studies outside of the EU, from Quebec, Canada (Dhillon et al, 2013), however, suggests most apple pomace and apple pomace sludge (APS) are disposed of by landfill or composted (about 80%) and 20% is used as animal feed, with only a small amount being valorised to other products.

Limited quantitative data is available to determine the proportion of apple pomace that is landfilled, land spread or valorised across EU Member states. Where quantities are recorded, these are likely to be held by commercial entities and are unlikely to be publicly accessible.

2.3 Technical description of valorisation options modelled for apple pomace

2.3.1 Landspread

Landspread of apple pomace is considered principally for the purpose of disposal in the model. It is assumed to be carried out on existing agricultural land where there may be some benefits as a soil conditioner and recovery of some trace nutrients, but these are not the principle reason for this option. However, this is considered to be different from landfill as a municipal waste disposal option.

Comparable products

The comparable action was assumed to be “doing nothing” – since the benefits of land spreading of apple pomace is small. The disposal service is the principle product here. Comparison with other disposal options such as landfill or incineration are not considered viable options in this model due to regulatory and technical feasibility.

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[4] E.g. Moist apple pomace (26% dry matter) can be fed fresh but according to Crawshaw (2001) for practical purposes it is stored as silage.
[5] IPPA, http://www.ippa.info/commercial_production_of_pectin.htm
[6] Agro food solutions is a subsidiary company of Herbstreuth and Fix pectin producers http://www.agro-food-solution.de/en/produkte/herbavital-entpektinisierte-apfeltrester/index.htm

2.3.2 Feed

Apple pomace is assumed to be used as forage extender for ruminant livestock, providing energy and fibre. It is assumed that apple pomace is picked up (within 48 hours by the user. The user is responsible for the transport and get the pomace for free.

The case is based on the actual information retrieved by a small Swedish producer as one option for valorising apple pomace

Comparable products

A common feed for ruminants that also provides energy and fibre is hay, therefore two examples of production systems for hay have been chosen as comparison to apple pomace:

- Extensive hay production (using no mineral fertiliser)
- Intensive hay production (using mineral fertiliser).

The amount of hay is 560 kg which corresponds to the dry matter content of 1 tonne of wet apple pomace (28% DM).

2.3.3 Energy recovery

Apple pomace can be used as substrate (together with other substrates) for production of biogas. The effect of co-digestion with other substrates is not taken into account and thus the value should be considered as conservative.

This valorisation route leads to three specific utilities: electricity, heat and digestate (used as fertiliser). Energy recovery is calculated using a generic approach detailed in Östergren et al (2018) Table 3 and Table 4 provides an overview of the inventory used in the model.

Table 3 Biogas potential apple pomace, per tonne Fresh Matter (FM) with a Dry Matter content of 28%

Side-flows	Theoretical biogas yield in m3/t FM	Theoretical CH4 content in %	LHV in MJ/ MJ/t FM
Apple pomace	145,5	54,7	19.63

Table 4 Emissions and energy recovery Apple pomace, per tonne Fresh Matter (FM) with a Dry Matter content of 28%

Emissions AD kg $CO_{2\ eq}$/ t FM input	Net Electricity KWh/t FM input	Net Thermal energy KWh/t FM input	Digestate t FM/t FM input	Credit for digestate application kg $CO_{2\ eq}$/ t FM input
56,0	259,6	128.51	813.68	-6,50

Comparable products

The selected comparison products used in the model are:

- Electricity (country specific) and EU average heat production
- Electricity and EU average heat production
- Electricity and EU average heat production and production and application of mineral fertiliser (the digestate from the AD is spread on land, providing nitrogen, phosphorous and potassium to the soil)
- Hydropower electricity and wood chips

2.3.4 Pectin

AP pomace is assumed to be stabilised by drying before being processed

To prevent degrading quality, pomace drying requires specific temperature limits, industry sources indicate 2 hours at 105°C or less.

Energy consumption references for direct fired and fluidised bed citrus pectin dryer indicate efficiencies of around 55-60% of theoretical minimum energy required for heat of water evaporation (8.3.4). Larger drying operations may be able to recover heat. For eample in feed pomace drying operations higher temperature dryers exhaust can be used to drive waste heat evaporators. Although at a lower temperature to standard feed drying, this application may not be feasible for pectin pomace.

For apple pomace however, literature indicates that drum driers are used (e.g. Shalini and Gupta, 2009), however further qualification may be necessary. Drum driers are common in the food industry for a variety of products including fruit and vegetable pulp (Rodriguez; Vasseur; Courtois, 1996, Tang, Feng and Shen 2003) Tang et al, 2003 report typical efficiencies for drum dryers in the food industry to be in between 60-90%, which similar to reported generic efficiencies for drum driers by Strumitto, Jones, Zytta (2006). An efficiency being 75 % was assumed in the model. No information on energy recovery was found in the literature relating to drying of apple pomace. Stumitto et al (2006) suggests typical heat recovery for drum driers in the range of 50- 90% is possible. Considering that mild drying conditions are required (low outlet temperatures) a recovery of 50% of the outlet energy was assumed. The recovery level was confirmed as reasonable by process specialists from the modelling team.

There are several methods described in the scientific literature for extracting pectin such as conventional acidic extraction, hot compressed water extraction, ultrasound assisted extraction and microwave assisted extraction and water-based extraction with extrusion pre-treatment which all have a documented yield between 12 and 20% (wt% dry weight) (Rabetafika, et al. 2014). The average yield reported for industrial processes is 12 % pectin (at a typical quality with a moisture content less than 12%) by weight relative to the dried apple pomace[7]. Higher values may be reported if yield is calculated based on its function (typically its gelling property[8]) rather than the quantity of pectin, or, if apple pomace is washed carefully to remove sugars before pectin extraction. The model pectin recovery process is assumed to reflect the acidic extraction (acid hydrolysis) used in conventional commercial pectin production in large scale factories[9] and a 12% yield on DM content with a moisture content less than 12% of the dry pectin.

As part of the pectin extraction process, sugars and secondary plant compounds are also extracted from the apple pomace and may be concentrated into food sweeteners, aromas or feed molasses. These are likely to be recovered from the pomace pre-treatment and recycling of alcohol from the aqueous alcohol solutions used in precipitation and purification stages (typically between 50 -70% isopropanol with water). The volumes of alcohol used and then recycled from the precipitation and purification stages and related energy demands from the distillation processes are not known. These recovery processes are the proprietary information of commercial pectin processors It is assumed that an efficient heat recovery processes is employed for distillation and recycling of alcohol (Figure 7). The energy usage of the drying process of the pectin were calculated based on the same assumptions as for the pomace drying assuming a 70% solution of isopropanol (see Annex 11) and an initial solid content of 55% and a moisture content of the pectin being 10% (see Annex 11).

The energy use for distillation for recovery of alcohol used on both the precipitation and purification steps in the model is assumed to have negligible contribution to the assessment employing a closed loop recovery of alcohol (see Figure 7). The assumption was validated against pilot data from extraction of pectin from red cabbage residues (REPRO FOOD-CT-2005-006922 and Östergren 2009). Considering the steps after separation of phytochemicals being enzymatic treatment, alcohol precipitation (isopropanol) and recovery of the isopropanol and conventional drying (without heat recovery) it was found that the 90% of the process energy could be attributed to the drying step of the pectin and 10% to the extraction and precipitation step[10].Although the calculations are very rough it can be concluded that they clearly indicate that the drying of precipitate will determine the environmental impact and costs of the processing step.

Apart from the pectin, the process also yields residues that can be used for animal feed. This is mostly the insoluble de-pectinised fibre fraction that remains. No applicable references or sources were found to substantiate the net yield of de-pectinised insoluble apple fibres per tonne of apple pomace. A rough estimate was obtained from by subtracting the amount of pectin extracted from the estimated

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[7] Personal Communication Dr. Hans-Ulrich Endress , General secretary of the International Pectin Producers Association

[8] In 1959 the American Pectin Committee developed a "SAG test" for determining the grade strength of pectins (Baker et al., 1959). A typical standard measure of gel strength used in the pectin industry is 150° SAG.

[9] IPPA, http://www.ippa.info/commercial_production_of_pectin.htm

[10] Enzymatic treatment of the liquid fraction: 4,5 kWh/kg pectin, precipitation including recirculation of the isopropanol: 18kWh/kg pectin, conventional drying approximately 212 kWh/kg pectin REPRO D3.5, 2011 (REPRO FOOD-CT-2005-006922).

amount of insoluble dietary fibres (IDF) according to Table 2 assuming the lower limit of 56,4% IDF. This level is also in the rage given by Endreß H.-U. (2000).

In addition, as part of the pectin extraction process, sugars and secondary plant compounds are also extracted from the apple pomace and concentrated into food sweeteners, aromas or feed molasses. These are likely to be recovered from the pomace pre-treatment and/or recovery of liquid alcohol from the precipitation and purification stages. These recovery processes are the proprietary information of commercial pectin processors and have been excluded from the model due to uncertainties in the relative volumes involved, economic values and the allocation of the related evaporative duty and energy consumption.

Figure 7 Pectin production[9]

Comparable products

Pectin was compared to average data for European production of pectin. The mass of pectin was assumed to be equivalent gelatine or modified starch based on gelling capacity. The calculation and references for the data are provided in Annex 11. The actual GHG-emissions from pectin production is the property of the producers (Thrane, Hansen, Fairs and Dalgaard , 2011 provides a range between 1-12kg CO_2 eq./kg for large scale industrial produced hydrocolloids including pectin. Thrane et al (2011) states that the process itself is most important and that process aids may contribute significantly. Considering that we know that the pectin process is well established and that the recovery process of alcohol is efficient we have used a conservative estimate of 1 kg CO_2/kg unmodified pectin in the model. Note that the upstream storage and transportation is not included in model, thus for pectin imported from, for example, China, the impact of the upstream overseas transports needs to be considered separately.

- Pectin
- Gelatine, 1kg per kg pectin
- Modified starch from corn, 1kg per1 kg pectin
- Hay, 125 kg per tonne AP

2.4 Description of the FORKLIFT spreadsheet model for apple pomace

2.4.1 Generic information

The model calculates the GHG emissions and costs associated with the handling of 1 tonne apple pomace having a dry matter content of 28% (Rust and Buskirk,2008). An average value of 330 kg CO_2eq GHG emissions has been assumed for the production and transport of 1 tonne of apples to the juice processor. The upstream burden is calculated though economic allocation in accordance with REFRESH report D5.4 Simplified LCA & LCC of food waste valorisation (Östergren et al 2018).

It should be noted that actual net value (revenues plus costs avoided from the alternative disposal as a waste), from side-flows of food or drink producers compared to the main products are generally considered to have a much lower value. Therefore, the proportion of the upstream GHG burden allocated to the valorisation approach is also typically low relative to its processing impacts since economic allocation is applied. Since the upstream burden is an approximation (includes apple growing only but not processing) large allocation factors will decrease the accuracy of the model.

An overview of the spreadsheet tool and option included in the model is provided in Figure 9 and in the next section the sub- models are described. The full inventories are provided in Annex 11 as supplementary information.

Critical parameters were qualitatively assessed using the model developed previously in D5.4 Simplified LCA & LCC of food waste valorisation -Description of standardised models (Östergren et al 2018). Note that the matrix also includes parameters that cannot be changed (Annex 11) as an information to the user. The reason for keeping them constant is that they are generic numbers used in several models to allow comparison between different side flows. The assessment of the critical parameters is based on the *relative* impact of a parameter compared to the total impact of the valorisation process modelled.

Figure 8 Assessment of critical parameters

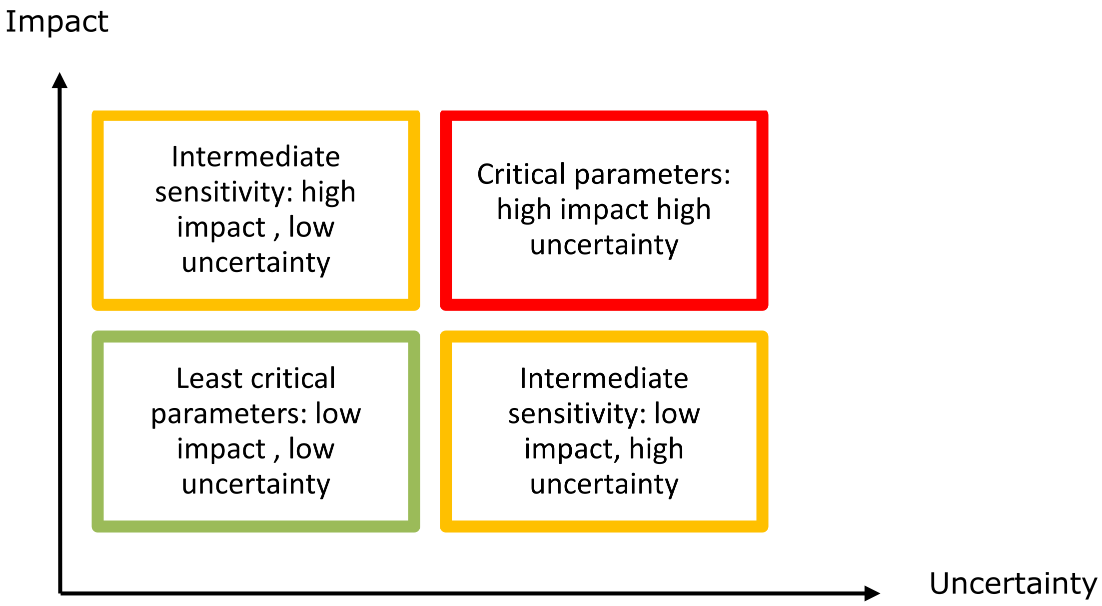
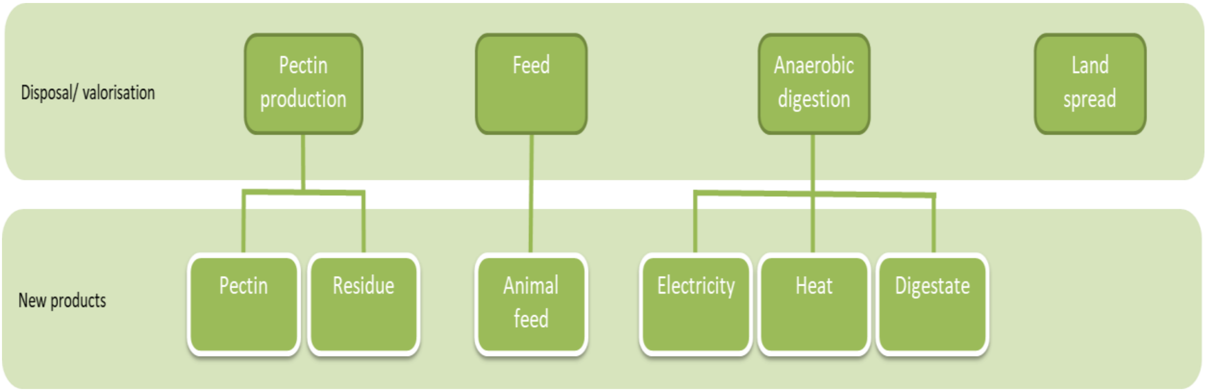


Figure 9 Overview of the apple pomace spreadsheet model in FORKLIFT.



Costs for energy, electricity and fuel can be modified from the main page. Pre-set values are dated between 2015-2018. See Annex 11.

2.4.2 Land spread model

Figure 10 The land fill option for apple pomace in FORKLIFT

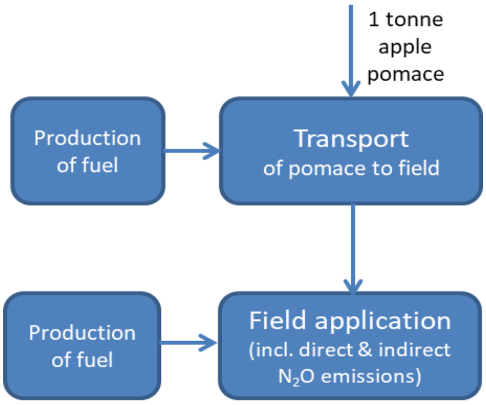


Figure 10 illustrates the processes that are considered in the simplified calculations of GHG emissions and costs of this option for handling apple pomace for land spread. The system starts with transport of the apple pomace to the field by truck. In this scenario it is assumed that the apple pomace carries no economic value, and therefore the side flow does not carry any environmental impact or cost from the upstream processes (production and transport of apples to the juice producer).

The apple pomace is spread by use of tractor onto the field. The climate impact of direct and indirect emissions of nitrous oxide (N_2O) is considered in the calculations.

Regarding the use of truck and tractor, the GHG calculation covers the emissions of producing the fuel and combustion in the truck/tractor. The cost considers the cost of the fuel.

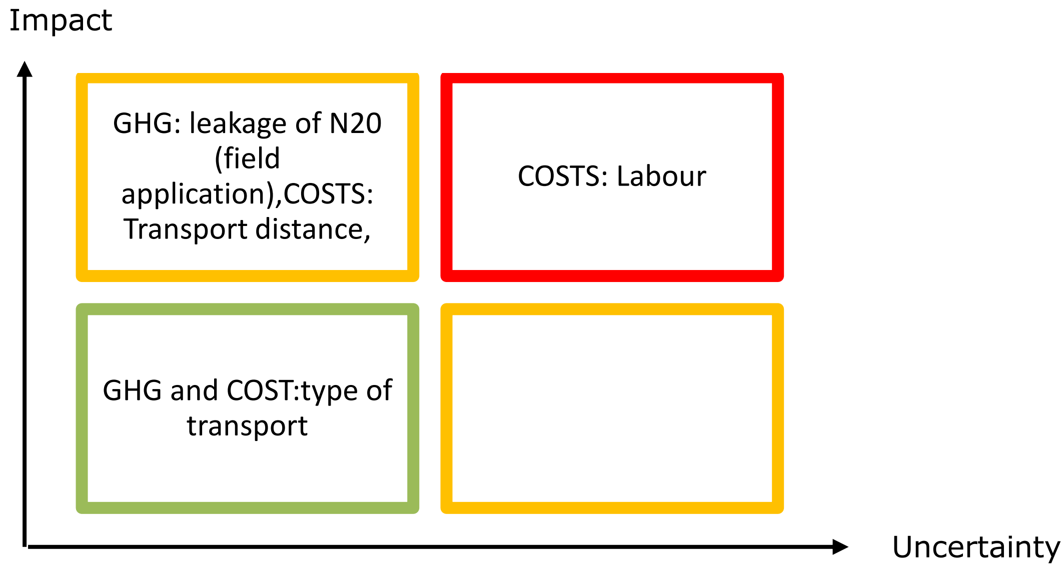
In this valorisation option, no product is produced, and hence no comparison products are provided.Figure 11

Parameter being modelled are provided in Table 5 additional data are provided in Annex 11. The assessment of critical parameters matrix is provided in Figure 11.

Table 5 Adjustable model parameters for land spread of 1 tonne Apple Pomace (AP)

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transport single tractor trailer 50% Load	20	km	Selected transport options are provided, distances can be set freely.
Labour and capital costs	0	EURO	Set by the user

Figure 11 Assessment of critical parameters for land spread



2.4.3 Energy recovery using anaerobic digestion (AD)

Figure 12 illustrates the processes that are considered in the calculations of GHG emissions and costs for using the apple pomace to produce biogas. The environmental impact and cost from the upstream processes (within the dotted line) are included if the juice or cider processor receives a direct economic benefit (revenue) from the side-flow.

The pomace is transported to the AD plant by truck.

Regarding the use of fuel, the GHG calculation covers the emissions of producing the fuel and combustion in the truck, as well as emissions from production of heat and electricity from combustion of the biogas. The cost takes into account the cost of fuel for transport.

In this valorisation option, 260 kWh electricity and 128 kWh of heat are the products according to the calculations described in D5.4 Simplified LCA & LCC of food waste valorisation (Östergren et al 2018). Alternative ways of producing heat and electricity are also provided (see previous section).

The assessment of critical parameters is provided in Figure 13.

Figure 12 Energy recovery from apple pomace

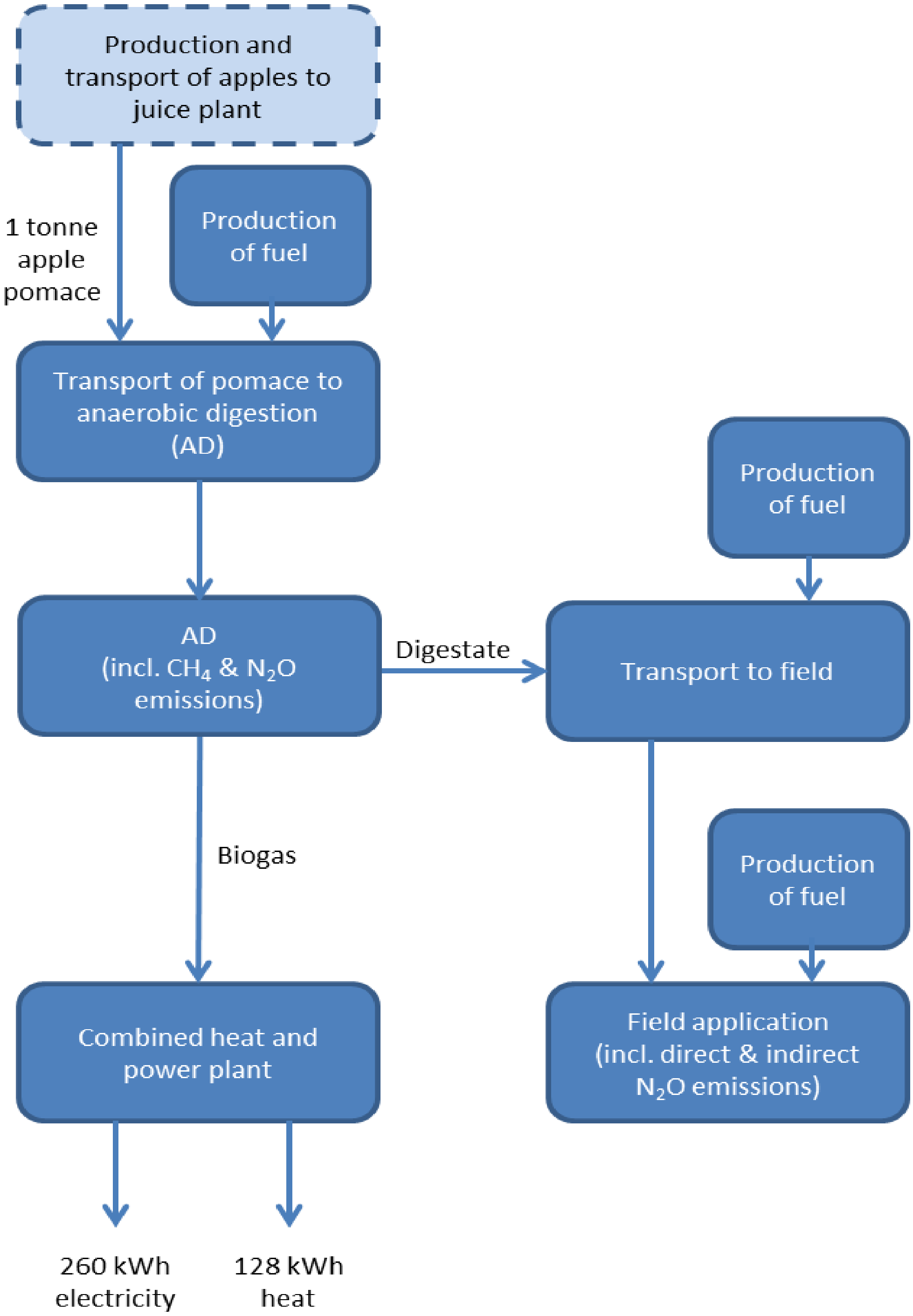
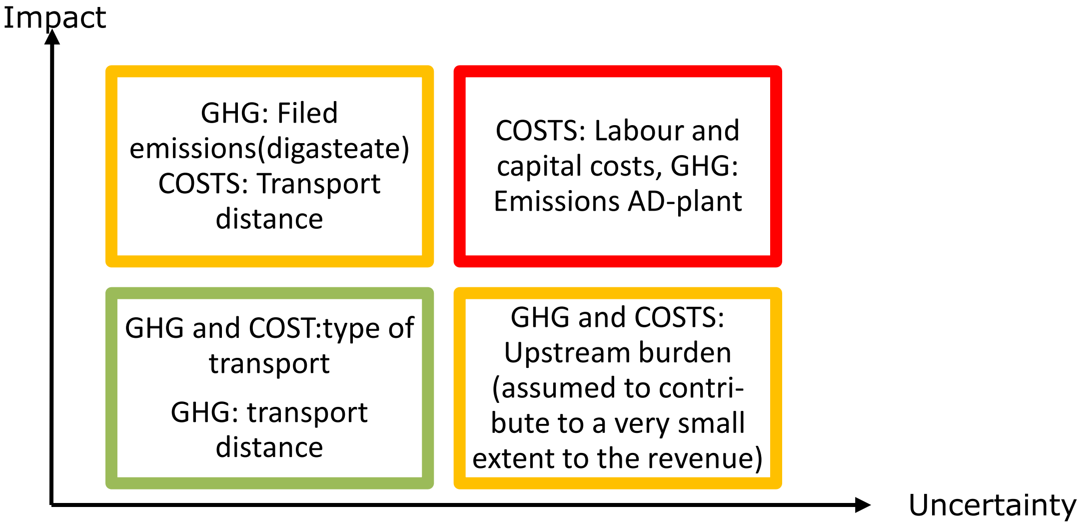


Table 6 Adjustable model parameters for biogas and energy production (AD) from 1 tonne Apple Pomace (AP)

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transport of digestate to the filed (tractor single trailer 50% Load Fraction (LF))	20	km	A pre-selection of transport options is provided, distances can be set freely.
Transport of Apple pomace to the AD plant (tractor single trailer 50% Load Fraction (LF))	20	km	A pre-selection of transport options is provided, distances can be set freely.
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

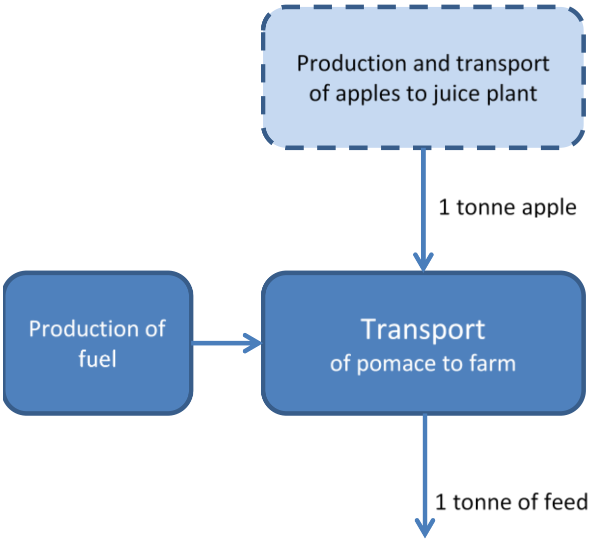
Figure 13 Assessment of critical parameters for biogas and energy production (AD)



2.4.4 Feed

Figure 14 illustrates the processes that are considered in the calculation of GHG emissions and costs for using the apple pomace as feed. The environmental impact and cost from the upstream processes are included if the apple pomace carries an economic value (therefore in dotted line).

Figure 14 The feed option for apple pomace in FORKLIFT



The pomace is transported to the farm by truck. Regarding the use of truck, the GHG calculation covers the emissions of producing the fuel and combustion in the truck. The cost considers the cost of the fuel.

In this valorisation option, 1 tonne of feed is the product, providing mainly fibre and energy to the cows.

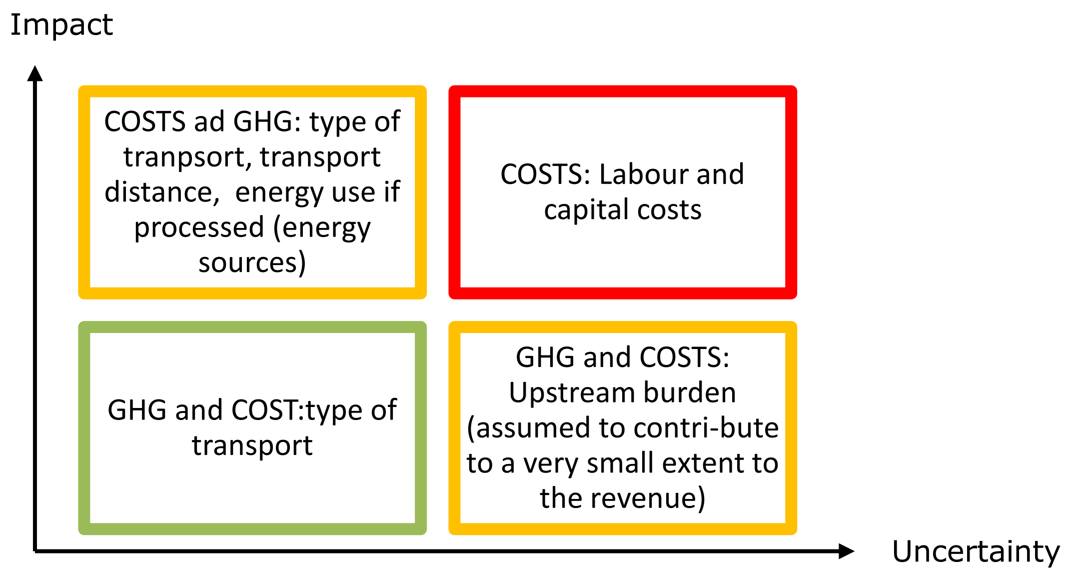
A common feed for cows that also provides energy and fibre is hay, therefore two examples of production systems of hay are provided as comparing product (see section 2.3). The modelling parameters are provided in Table 7 and the assessment of critical parameters is provided in Figure 15

Table 7 Adjustable model parameters for feed production using 1 tonne Apple Pomace (AP)

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transports tractor single trailer 50%	20	km	A pre-selection of transport options is provided, distances can be set freely.

Parameter	Default value		Comments
Load Fraction (LF)			
Electricity use	0	kWh/tonne AP	May be added if addition handling is required.
Heat use	0	kWh/tonne AP	May be added if addition handling is required.
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 15 Assessment of critical parameters for feed production of apple pomace



2.4.5 Pectin production

Figure 16 illustrates the processes that are considered in the calculation of GHG emissions and costs for using the apple pomace to produce pectin. Table 8 provides the data that can be adjusted by the user in the model. The assumptions made in the calculation are provide in previous section and describes in more detail in Annex 11. The environmental impact and cost from the upstream processes are only included if the apple pomace carries an economic value (therefore in dotted line).

The pomace is first stabilised by drying to prevent spoilage during transport and storage and then it is assumed to be transported to the pectin plant by truck.

At the pectin plant, the pomace undergoes several processing steps involving e.g. mixing with hot water and processing aids (mineral acid), concentration by removing water and precipitation and further purification by mixing with aqueous alcohol according to Figure 7. The energy consumption of these steps can be added if available.

In the calculation of GHGs and cost, only the production of heat and electricity is considered in the pectin plant (additives and process aids are not considered in this model). Apart from the pectin, the process also yields residues that can be used for animal feed.

Regarding the use of fuel, electricity and heat in the transport and pomace drying stages, the GHG calculation covers the emissions of producing the fuel and combustion in the truck, as well as emissions from production of heat and energy. The costs include that of electricity, and fuel for transport and heat.

In this valorisation model 1 tonne of pomace is processed and dried to around 10% moisture from which 33 to 34 kg of pectin is produced at less than 12% moisture. (see 2.3). Further 1 tonne of pomace (fresh weight) was assumed to give 125 kg (based on DM) of de-pectinised (moist) residual fibre to be used as cattle feed. For simplicity the fibre yield is taken as independent of pectin yield in the model).

Some common gelling agents are also presented in the result figure as comparison products (see section 2.3). The modelling parameters are provided in Table 8 and the assessment of critical parameters are found in Figure 17.

Figure 16 The pectin production option for apple pomace in FORKLIFT

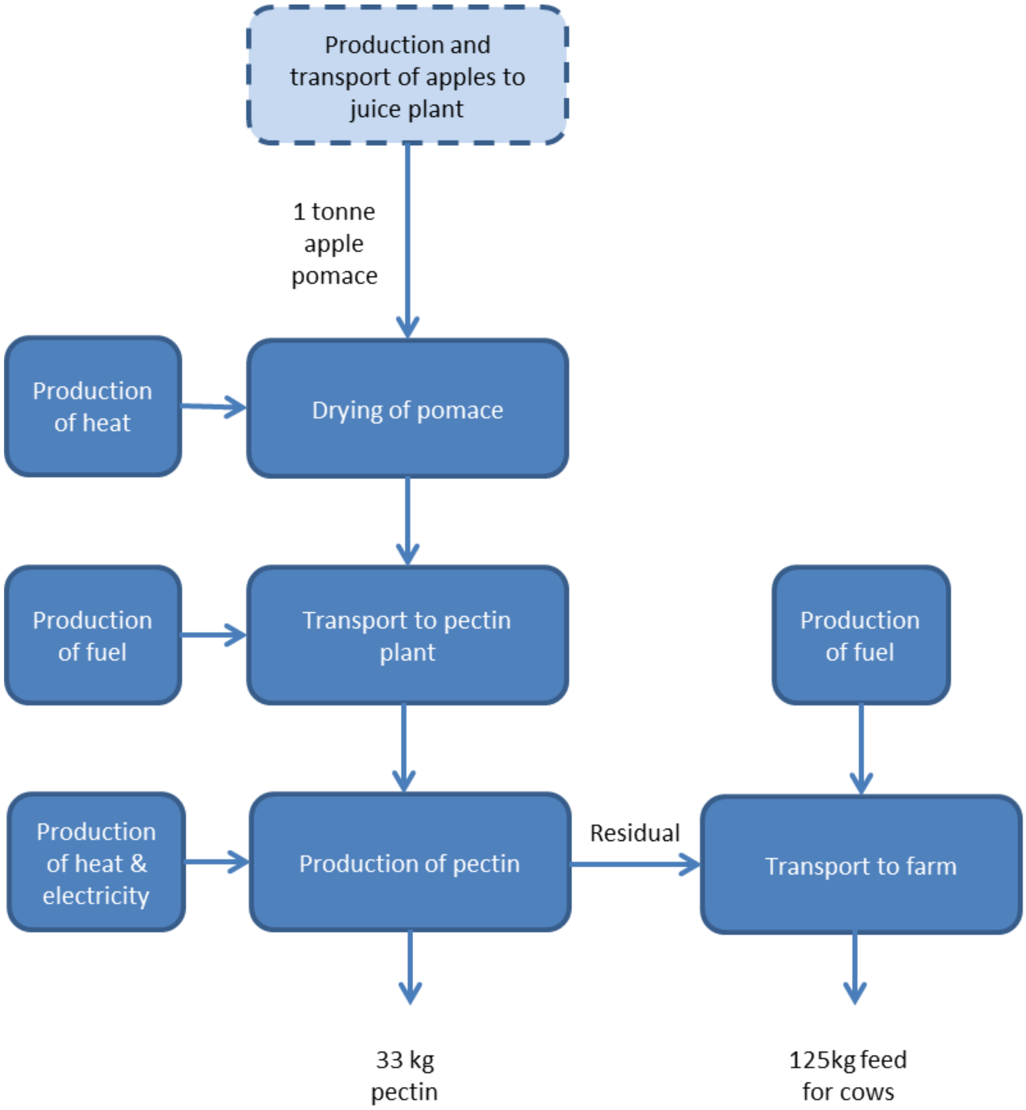
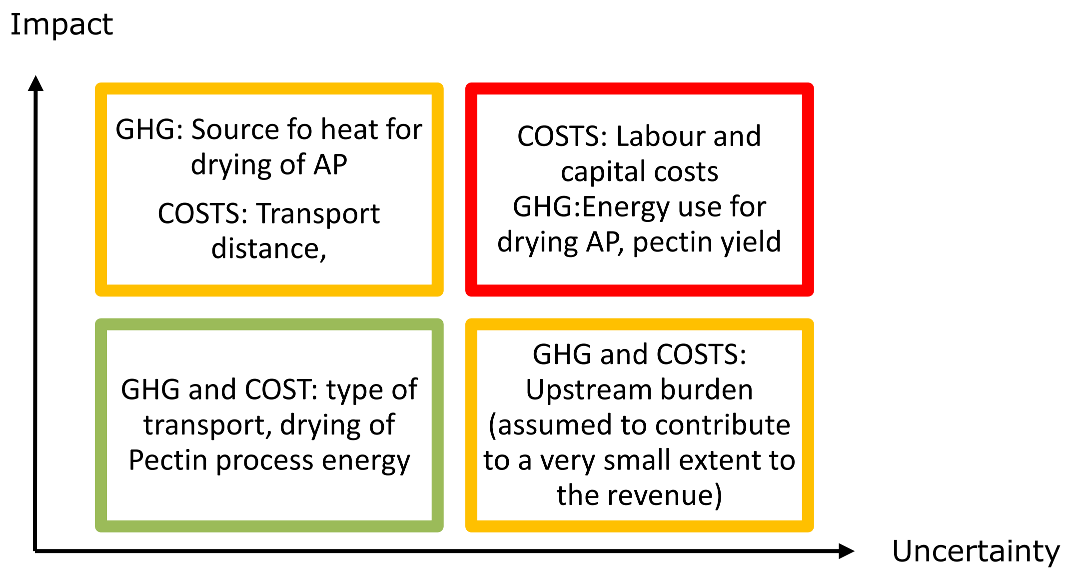


Table 8 Adjustable model parameters for pectin and fibre production using 1 tonne Apple Pomace (AP).

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transport of dried apple pomace (Rigid truck, 20-26 t, Euro 4, 50% LF)	200	km	A pre-selection of transport options is provided, distances can be set freely.
Transport of feed (Tractor single trailer 50% Load Fraction (LF)	20	km	See above.

Parameter	Default value		Comments
Electricity use drying AP	2,8	kWh/ tonne AP	Assumed value (1%)
Heat use for drying AP	281	kWh/ tonne AP	This is based on a theoretical assumptions of 50% recovery
Pectin yield	12%		Corresponds to 33 kg pectin with a moisture content assumed to be 10%
Fuel used for generating heat when drying AP	Light fuel oil		A pre-selection of fuels is provided (biogas, natural gas, har coal, wood chips from forest, EU-average heat)
Heat used for pectin extraction (excluding drying)	0		Optional data on energy use of the extraction process to be set by user if available. Sums up with the heat used for pectin drying in the model
Electricity use for pectin extraction (excluding drying)	0	kWh/ tonne AP	Optional data on energy use of the extraction process to be set by user if available. Sums up with the heat used for pectin drying in the model
Heat use for pectin drying	3,7	kWh / tonne AP	Included as a part of the total process heat for extracting pectin.
Electricity use for pectin drying	0,04	kWh/ tonne AP	Included as a part of the total process electricity for extracting pectin. Estimate
Fuel used for heat generation in pectin drying	Light fuel oil		Covers both drying of pectin and extraction process.
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 17 Assessment of critical parameters for pectin production



3 Annex 3 Brewers' spent grain spreadsheet model

List of abbreviations

AD	Anaerobic digestion
BSG	Brewers' spent grain
DDGS	Dark Distillers' Grains and Solubles
GHG	Greenhouse gas
HL	Hectolitre (100 litres or 0.1 m^3)
HHV	Higher heating value of gross calorific value (total heat available from combustion reaction)
IPPC - BREF Notes	Integrated Pollution Prevention and Control - Best Available Techniques Reference Notes. (see IPPC Regulations)
LHV	Lower heating value or net calorific value (minus latent heat absorbed by combustion reaction products)
MDDG	Malt Distillers' Dark Grains

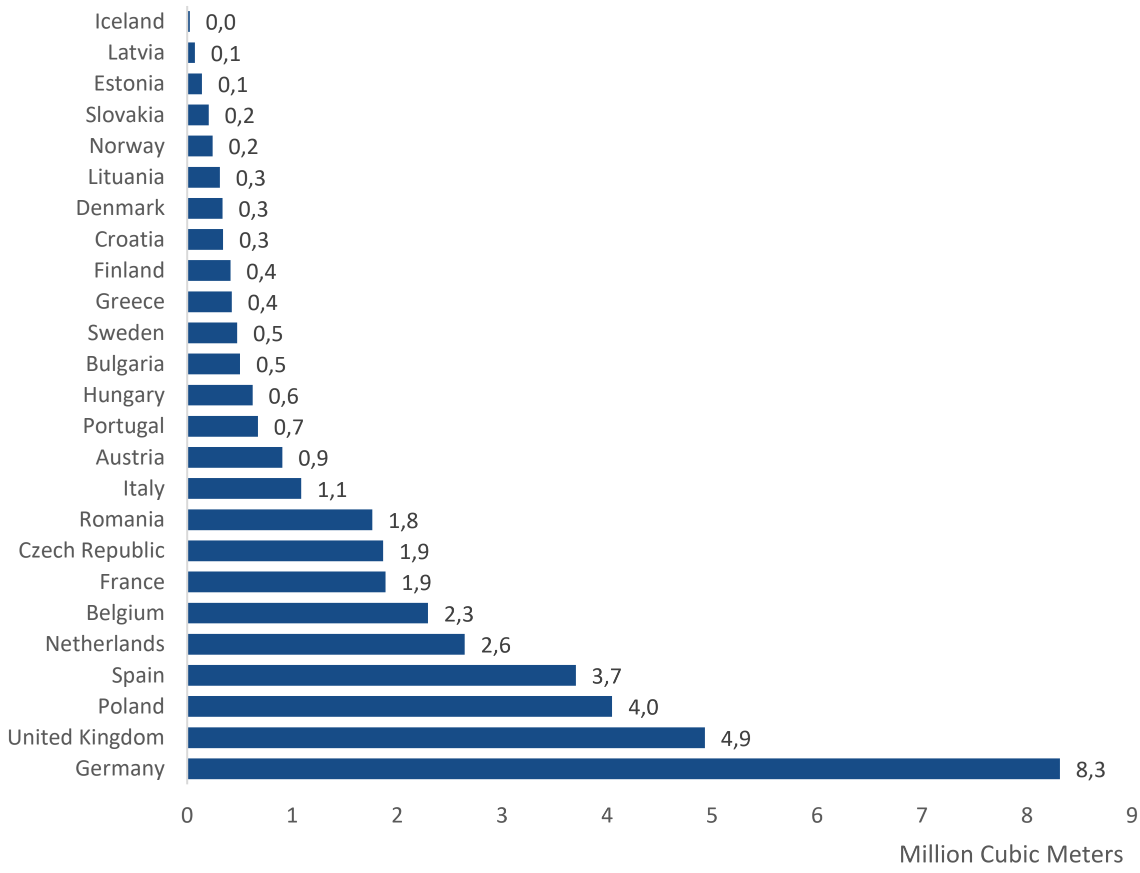
3.1 Background

3.1.1 Rationale

As a by-product from brewing, brewers' spent grains (BSG) have been identified as one of twenty food chain sideflows considered suitable for valorisation in a previous report (Moates et al 2016).

BSG is widely produced as a by-product from breweries across the EU. Figure 18 indicates two-thirds of the EU's 39 Million cubic beer production is concentrated in only six Member States, with Germany by far the largest producer (8 Million cubic meters), almost doubling that of the next largest producers – the UK, Poland, and Spain. Considering BSG production relative to land area as a crude indication of the likelihood for surpluses, Germany and the UK are of particular interest for finding evidence of valorisation approaches for BSG.

Figure 18 2016 beer production in European countries (Eurostat[11])



3.1.2 Information on potential and actual BSG quantities

Estimates of BSG produced can be related to the volume of beer brewed, however the exact yield relationship varies in relation to the different varieties of beer, respective brewing process (and related size structures). Over the last century estimates from UK breweries range between 120 -140 kg moist spent grain per cubic meter of beer brewed (Crawshaw 2001). The moisture content is unspecified but typically this is around 80% from Lautering systems and 70-75% from mash filter systems. Estimates from continental brewing range 210–220 kg brewers spent grains per cubic meter (Lynch et al 2014 citing an established German brewing reference text), where 100–130 kg of BSG containing 70–80% water is obtained per 100 kg of initial malt.

Older sources suggest a much lower yield of 60% wet weight BSG is produced relative to the weight of malt input, which on a dry basis is considered to be only 15% w/w of the malt input (Hough 1985). Industry sources from a medium-large

[11] Eurostat data: PRODCOM list annual data [DS-066341] includes imports, however the internal market for imported beer is marginal compared to EU production.

UK brewery indicates a typical ratio of 1:1 dry malt grist to wet spent grains[12]. Differing brewing methods such as brewing stronger beer, or subsequent processing to lower final product ABV, may explain these differences. Therefore, crudely estimated using these data, around 4 Million tonnes per year of *wet* BSG may be produced by the EU's brewing industry. Data on the actual surplus or discarded quantities of BSG across the EU are not available. This is discussed in the following section.

3.1.3 Limitations and uncertainties

Waste status

Contrasting perspectives can be found on BSG's surplus or waste status in research literature and anecdotal industry sources. Some researchers justify valorisation concepts by identifying BSG as a potential waste problem due to regulatory restrictions regarding organic waste disposal but also changes in feed demand from the livestock sector (Zanker et al 2007). Others indicate moisture content, impacting transport cost and susceptibility for microbial spoilage, has limited its further uses beyond its predominant use as a [moist] cattle feed restricted to local farms, (Lynch et al 2014). Other researchers indicate that supply can outweigh demand, indicating its waste status (Mussatto 2014). However, these researchers do not explicitly address how much surplus BSG is available in any context. Is there a seasonal misalignment in peak brewing or low feed demand or both for example, and is this widespread or in certain locations?

Industry sources indicate BSG can also be ensiled, stock piled and capped to remove contact with air to prevent spoilage, as is common practice for other forage feeds. Ensiling can extend BSG for use as a feed over 6 months, or considerably longer, if combined with other forages or where silage additives are used[13] Anecdotal evidence in the UK suggests that BSG may still be used to supplement beef and dairy cattle feed all year[14].

From one author's experience in the UK, contracts secured with feed merchants to remove wet spent grain with a small payment or rebate to the brewery are typical. Therefore, subsequent management of BSG is in most cases handled by the commercial feed industry all year round. Unfortunately, animal feed merchants are unlikely to share their commercial approaches in managing BSG feedstocks publicly[15]. However, published prices for BSG feed exist year-round in the UK[16], but

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[12] Personal Communication, Information supplied by Head brewer on a non-attributed basis.

[13] Heuzé V., Tran G., Sauvant D., Lebas F., 2017. Brewers grains. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. https://www.feedipedia.org/node/74 Last updated on August 17, 2017.

[14] It is generally accepted as a finishing feed and dairy feedstuff in various UK online farming forums for example.

[15] Personal Communication, Tim Elsome, ForFarmers feed merchants. Aug 2017.

[16] UK Agricultural and Horticultural Development Board BSG price data.

typically increase in spring, reflecting demands by farms to supplement their declining stocks of winter forage.

No documented evidence or records have been found to establish the extent of surplus BSG in EU Member States. The circumstances or factors across member states in which production of BSG as a feedstuff outweighs demand is also uncertain. For example, it may be that ensiling practices are limited in southern member states where warmer climates make conditions unsuitable.

Drying BSG

Transport costs of moving volumes of wet BSG from larger breweries located far from cattle farms may justify investment in dewatering and/or drying facilities in some parts of the EU. The existence of several established drying machinery fabricators that supply and install equipment at large breweries worldwide indicates there can be a market for drying spent grain[17] Anecdotal evidence from a supplier suggests that the investment in drying of spent grain is typically only economical where breweries' beer production exceeds 1.5 million HL per year[18], indicating a production threshold for investment equivalent to 20kt of moist BSG per year. However, this could change in relation to drying fuel costs and other market factors.

Other factors

It is notable that industry decision makers highlight the site-specific context when determining which valorisation option to take[19]. Transport costs and scale of production (increasing likelihood of grains being surplus to local animal feed demands) appear to be the key factors determining waste status, or whether spent grains are utilised for animal feed.

The potential for non-feed uses for BSG are more likely where large brewery sites produce enough feedstock to make on-site, or near site valorisation processes investable. However, there are also risks to such investments where market conditions or policy support can change, for example regarding the price of fuel or milk in relation to protein feed or changes to fixed subsidies which energy investments may attract.

3.1.4 Site volumes

Understanding the quantities of side flows available for valorisation is important for assessing whether potential revenues support the scale of investment in the processes required. This has relevance to subsequent REFRESH Tasks (T6.5).

For example, drying BSG may be key to prevent spoilage and extend its potential for transport and further use.

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[17] E.g. http://www.vettertec.de/downloads/vt_BreweryIndustries.pdf

[18] Personal Comm. Ralf Rinder, Vettertec Gmbh. (key suppliers of dryers to the global brewing industry)

[19] Ian Smith, Senior Corporate Relations Manager, Diageo, cited in WRAP (2012).

Except for Germany, (Table 9), good quality data on brewery size (volumes brewed) in each Member State have not been found. Applying UK BSG relationship to beer brewed (see Information on potential and actual BSG quantities) to the mid intervals of each of the production volume range bands in Table 9, gives conservative indications of the range of BSG produced at different sized breweries.

Using the production threshold for dryer investment mentioned in the previous section, this would apply to the top 15 largest breweries in Germany, but with the scope to dry almost 40% of the Germany's total BSG production. The potential for any co-operative or contractual business models for centralised drying of surpluses to valorise wet BSG from smaller 'satellite' brewery sites will likely be constrained by haulage costs.

Table 9 Brewery size structures, (Deutscher Brauer-Bund 2017) and estimated annual BSG arising in Germany

Brewery size		Number of breweries		Estimated moist BSG tonnes/year	
Production banding HL/year	Approx. Mid interval	2016	5-year Mean	Mid interval estimates per brewery	Scaled to total sites
up to 1,000	500	738	**696**	6.5	4,505
1,000 – 2,999	2000	186	**190**	26	4,925
3,000 – 4,999	4000	61	**61**	52	3,139
5,000 – 9,999	7500	97	**95**	97	9,266
10,000 – 49,999	30000	168	**165**	389	64,261
50,000 – 99,999	75000	54	**58**	971	56,141
100,000 – 199,999	150000	37	**35**	1943	68,768
200000 – 499,999	350000	21	**25**	4533	112,413
500,000 – 999,999	750000	20	**17**	9713	165,122
1,000,000 – 2,000,000	1500000	15	**16**	19426	310,819
>2,000,000	2000000	11	**11.4**		
	TOTALS	**1408**	**1370.4**		**799,359**

NB data on structure and size of single brewery sites are not reflected, therefore the mean average is only an indication and may not reflect actual site volumes.

3.2 Current valorisation options

Research publications highlight the uses of spent brewers and distillers' grains for numerous potential applications (e.g. see reviews by Mussato 2014 and Lynch et al 2016). However, limited evidence can be found to substantiate that any of these have been realised commercially (i.e. at a TRL of 9) and fall within the scope of this research. EU projects recently report activities with commercial partners planning to pilot the manufacture of food chain uses for BSG[20]. Commercial valorisation routes that have been identified are summarised in Table 10.

In the UK there appears to be little evidence available regarding commercial uses of BSG beyond its traditional use as an animal feed. Small UK breweries are also seen to keep with tradition, and supply BSG as moist feed directly to local farms or via feed merchants[21]. This typically results in payment benefitting the breweries or, at the very least, avoidance of waste status and/or associated removal costs.

Table 10 Valorisation options identified for spent grains (TRL 9)

Product	Current applications	Reference	Data availability/ Contacts
Moist spent grain	Ruminant feed	Various feed merchants	Commercially confidential
Dried distillers grain	Ruminant feed	Various feed merchants	Commercially confidential
Specialised Flour (niche)	Baked goods	Food industry ingredient supplier and biscuit products	Niche product examples found in Germany but No data
Heat and electricity	Anaerobic Digestion	Purpose Energy, Massachusetts USA Göss brewery, Austria	Eric Fitch, Purpose Energy Göss contacts via REFRESH partner BOKU
Heat and electricity	Co-firing with wood chips (not commissioned)	Wärtsilä Energy Solutions	Bent Iversen Business Development Manager

[20] AB Inbev, one of the largest Brewers in Europe have announced their involvement in exploring the use of BSG to produce new beverages as part of EU Life project Refreshment (LIFE15 ENV/BE/000267). Websites accessed August 2017.

[21] Surveys of 90 UK small and micro sized ('craft') breweries (in both urban and rural settings) shows that animal feed is still the dominant end use even at these much smaller quantities (Kerby & Vriesekoop 2017). The survey did provide some evidence that local composting and anaerobic digestion may be only a minor alternative (<5% of breweries). Older research by Ben-Hamed (2012) reports survey data suggesting that farmers are predominantly collecting BSG directly from small and medium sized breweries, though the quality of this data has does not appear to have been substantiated for publication through a peer review process.

Heat for Distillery	Draff combustion (Not in scope)	Biomass plants operating at Glenlossie and Roseisle distilleries.	Diageo (no data or direct contact)
Heat for Brewery	100% BSG fired steam boiler	BSG fired 2.9 MW boiler operating by the Alaskan Brewing Company USA.	Geoff Larson (CEO)

3.2.1 Moist animal feed

Due to their high moisture and high fibre content, BSG is typically used as a wet ruminant feed. Demand may be seasonal. Where cattle are grazed in summer, demand will fall, conversely, in winter months BSG may be in greater demand to supplement ensiled winter forage and other stored feed sources. The transport distance and type of vehicles used relate to the size of the brewery (and quantity of the wet BSG available).

Some breweries may employ filter press systems and mill their malt more finely from which the residue is filter referred to in the UK animal feed industry as mash filter grains. This differs from BSG from a more traditional Lauter tun brewing system by having a finer texture and a slightly lower moisture content leading to a relative increase in nutritive content, according to feed merchant literature[22]. However finer (more fluid) mash grains can lead to logistical difficulties in handling from feed merchants and prevent effective ensilage by farmers[23].

3.2.2 Dried animal feed

In the UK, there is little evidence that BSG is dried for use as a feedstuff. UK feed merchants advertise straight moist brewers' grains but no commercial literature has been found for dried brewers' grains.

Government statistics[24] for animal feed production does not report any quantities of BSG used in compound animal feed. In contrast, substantial quantities used from distillery by-products are reported, however. Large distilleries dry more finely mashed spirit grains, often combining with pot ale, essentially syrup like residues, from the distilling process. These are widely sold in the UK as a Dark Distillers' Grain and Solubles (DDGS) feed or Malt Distillers' Dark Grains (MDDG). These can

[22] For example, http://www.forfarmersfeedlibrary.co.uk/search.aspx?search=brewers%20grain

[23] Robin Crawshaw, Personal Communication Oct 2017.

[24] https://www.gov.uk/government/statistics/animal-feed-production

be pressed and dried in the UK using direct gas fired rotary dryers for the grain drying step [25].

It is likely that the difference between BSG (not being dried) and DDGS/MDDG is explained by the scale of production, geographical context (relative to local farms) and, by including pot ale, higher energy and palatability. This results in a more valued traditional dried feed compared to drying BSG.

Only anecdotal evidence suggests European companies may be processing dried BSG as a bulk feed component of dry compound feed products[26]. Other companies market BSG with yeast in feed additives rather than a bulk feed stuff[27]. Some feed manufacturers may also use dried BSG, but information to highlight the extent of this practice in compound feed is not published or accessible.

3.2.3 Dried food ingredient

In Germany there is a niche market for BSG flour used in traditional bread recipes and health food snacks[28]. Commercial examples can be found with <10% of the ingredient in bread sold by an established chain of retail bakeries, and also biscuit manufacturers. The low content may be due to its impact on product flavour, which reportedly limits consumer acceptance in baked products if substituting cereal flour ingredients by more than 10%. In addition, it may be that there are perceived or actual regulatory barriers restricting the wider adoption of BSG in products which has been a factor in valorisation of novel food ingredients elsewhere[29]. Novel food regulation could be one such barrier given BSG may be considered not to have been consumed to any *significant degree* in the EU[30].

The cost of investment in drying equipment contrasts with small fees, or rebates, paid (or even simply avoided disposal costs) by merchants for a developed and long-standing use of moist BSG for animal feed. Commercial product development ideas have been found only at exploratory stages[31], though this could be seen more as promoting processing equipment manufacturers processing capabilities than formulating new food products from BSG.

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[25] For example the Chivas Bros distillery in Glasgow, Scotland uses this technology for grain drying.

[26] This is unsubstantiated and anecdotal, from personal communication with both Frank Vriesekoop Harper Adams University and Ralf Rinder, Technical Sales Manager, VetterTec GmbH (Sept 2017)

[27] Dried BSG constitutes 60% of a feed supplement marketed by Lieber GmbH

[28] For example, health food biscuits, and specialist supplier to the food processing industry, White-Star GmbH, sells BSG flour, and also patent literature has been filed by German biscuit manufacturer Rudolf Sommer Gmbh.

[29] Pers Comm. Prof Keith Waldron, Biorefinery Centre, Institute of Food Research, Norwich, UK.

[30] https://ec.europa.eu/food/safety/novel_food/legislation_en

[31] e.g. *Wet* extrusion for snack and breakfast cereal applications explored by Bühler AG Schill & Munz (2013)

Drying BSG for a food ingredient therefore assumes: -

1) A surplus that cannot be used economically by a local demand for moist animal feed, for reasons of either geography or scale of production.

2) A potential growth market for a premium food grade product emerges with significantly greater revenue potential or avoided costs than is currently associated with either moist or dried spent grain feed.

Only the first assumption may currently be inferred (from the suppliers of BSG dryers) as a commercial reality for larger breweries where the relatively high cost of investment in drying facilities may be justified. Company representatives indicate that this is typically for breweries only producing more than 1.5 Million HL of beer per year[32] These companies are established suppliers of large (>2 tonnes per hour) dewatering and drying solutions for brewers spent grain[33]. No evidence of established products has been found to support the second assumption.

3.2.4 Biomass energy

In the UK, £35 million had been invested in combustion plants designed and constructed for co-firing spent grain with woodchips at two large urban brewery sites[34]. The system had been designed to generate heat and power for brewery operations.

Belt presses were used to reduce moisture content from approximately 80% to 60%, before co-firing on site with wood chips in an efficient water-tube boiler. Steam generated would supply a back-pressure steam turbine driving an alternator to generate electricity. Turbine exhaust steam would then be utilised in a district heating system for the brewery with condensate returning low grade heat to the boiler feed water. However, due to a combination of commercial and technical reasons the facilities were unsuccessful and have since been decommissioned.

In the US, geographical constraints have stimulated an innovative brewery to succeed in recovering energy from brewers spent grain for process steam generation. This was initially pursued to offset oil fired drying costs for spent grain (dried for shipment South to other US states as cattle feed). Therefore, this valorisation option may be more applicable where both fuel costs and BSG surpluses reflect more remote sites, making drying and haulage costs less favourable. The application has reportedly been proven in a 2.9MW boiler (nominal capacity) used to fully substitute fuel oil that had previously supplied the brewery's heat demands. Spent brewers grain is milled to a proprietary specification,

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[32] Personal communication Ralf Rinder, Technical Sales Manager, VetterTec GmbH Sept 2017

[33] e.g. http://www.vettertec.de/downloads/vt_BreweryIndustries.pdf

http://ponndorf-gmbh.de/resources/Server/2015-11-06-Brautechnik-PonndorfAB-Lay2-EN.pdf

websites accessed August 2017

[34] https://www.wartsila.com/media/news/03-03-2008-wartsila-delivers-worlds-first-biopower-plant-using-brewery-spent-grain-to-produce-electricity-and-heat

compatible with mash filter brewing systems, and dewatered to 65% moisture using an industry standard mash filter. The grain is then dried in a triple pass rotary dryer before being introduced into the boiler fire box in such a way as to prevent aggregation of protein fractions of the grain and improve combustion efficiency[35].

3.2.5 Anaerobic digestion

Unless some pre-treatment process is carried out[36] the ligno-cellulosic fractions of BSG are not generally thought to provide a substantive benefit to the biomethane yields but rather contributing to digestate mass. However, Göss brewery in Leoben, Austria commissioned an up-flow anaerobic sludge blanket reactor in 2015 which reports an infeed of 16,000 tonnes of spent grain and almost 1,500 tonnes of surplus yeast per year with a total substrate volume of over 20,500 tonnes per year[37]. The resulting biogas has the capacity to generate 0.45 MW heat and 0.47 MW electricity via CHP and additional 0.7 MW of steam generation capacity. In the US, there are reports of a commercial scale anaerobic digestion plant solely treating brewery liquid wastes, including spent grains[38]. However, this practice has since switched to selling moist grain to local farmers for feed due to a substantial reduction in US gas prices[39].

Whilst other brewery wastes may provide more productive feedstocks for AD, unless commercially viable pre-treatment processes are employed, BSG would contribute relatively low yields of biogas compared to other bulk vegetable sources, whilst incurring material handling and digestate management costs. For AD to reach an investable capacity for smaller producers, supplementary feedstock with 3rd party wastes may be required, with additional regulatory and operational demands making this less attractive (WRAP 2012).

3.3 Technical description of valorisation options modelled for brewers' spent grain

3.3.1 Moist animal feed

The dominant costs and GHG impacts in relation to BSG as an animal feed are related primarily to the transportation from brewery to farm.

The feed value in relation to transport costs typically restricts utilisation of wet BSG to farms located within a certain distance of the brewery sites. The total delivery

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35 *For detailed process descriptions see patents US20170190994A1 and US20170121619A1*

36 See IEA task 37 report: *Pre-treatment of feedstock for enhanced biogas production, for a general review.*

37 https://www.bdi-bioenergy.com/en-references-97.html

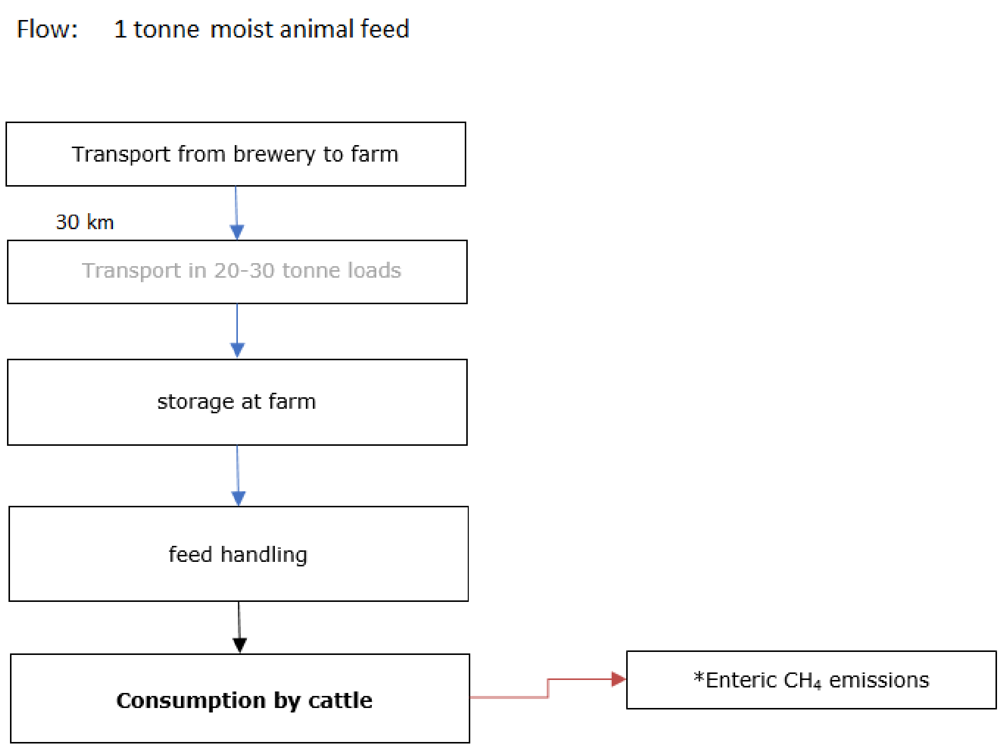
38 Magic Hat Brewing Company of Vermont in the United States claims to be the first brewer worldwide to install an anaerobic digestion system on site processing BSG, brewery waste water, spent hops and yeast. The installation uses an orbicular bioreactor (capacity 1,800 m^3.) installed and *patented* by Purpose Energy of Waltham, Massachusetts.

39 Personal communication Eric Fitch, Purpose Energy Sept 2017.

distance from brewery to farms will vary depending on quantities available. Past surveys in the UK suggest this is typically under 10km, (Ben-Hamed 2012) for weekly BSG production up to 10 tonnes. However, the data quality is uncertain and appears to include only responses from farmers collecting BSG from breweries. Much of the total UK BSG arising is managed by commercial animal feed merchants[40]. It is assumed that this is the case in other EU member states also, but no references or data sources were found to substantiate this.

Several leading UK feed merchants offer bulk delivery in tipper lorries in 20 - 30 tonne loads. Commercial sensitivity restricts access to information on feed merchants' logistical operations, but 20-30 tonne loads suggests BSG is largely collected from either single large brewery sites[41] or, probably less commonly, from several breweries before consolidation and supply to farms.

Figure 19 Model process flow for use of 1 tonne of BSG as a moist animal feed



**Some researchers have reported that rations incorporating BSG impact on enteric methane emissions from cattle compared to control rations (Moate et al. 2011, Duthie et al 2015).*

Rebate fees paid by feed merchants to breweries are commercially sensitive, however authors have obtained non-attributable information from an industry

[40] Personal communication Robin Crawshaw Oct 2017

[41] >20 tonnes per week would require brewery sites to produce >75,000 HL beer per year based on assumptions made in 3.1.4. BSG may be collected every 2-3 days depending on conditions.

source. This indicates fees can be around 50% of the average UK delivered sale price based on official surveys[42] of the same period. Net of fees and a profit margin of 15% based on discussions with a feed industry expert[43] a crude estimate of the value available for haulage indicates that 40km per tonne of wet BSG (albeit fixed in time) is a typical maximum transport limit[44]. The weakness of this approach is that it relies on unit transport costs derived from data reported by Ben-Hamed 2012 for UK breweries producing 10 tonnes of BSG per week[45]. However, this transport cost data is constrained to vehicles with a 6-tonne load capacity.

Further discussion with industry representatives suggests the actual maximum haulage distances for moist BSG will vary but a value of 80km was considered to be the maximum for transfer of larger quantities typical for the quantities (>20 tonne tipper truck loads) more widely delivered by feed merchants[46]. Therefore, 30 km is made for a conservative estimate of total haulage distance via 20-29 tonne tipper trucks. More robust anonymous surveys of both farmers and feed processors and merchants would need to be made to substantiate these assumptions across the wider EU. However, the tool will allow these default distances to be modified by users.

Table 11 Model inventory for 1 tonne of BSG used as a moist cattle feed

INVENTORY			
Input			
Brewers spent grain (fresh)	1	tonne	*Awaiting collection (1-3 days) at brewery, moisture 75-80%*
Transport			
DIRECT			UK industry sources suggest this is <10% of total volume*
1. Small brewery to farm	<20	km	*Typically, 10km or less. (Based on survey by Ben-Hamed 2010 of 150 small/medium UK Breweries)*
2. ensilage/direct feeding			*6 tonne cap lorries at 0.6-0.8 loading by farmers.*

[42] Farm Brief Feed Prices Report, UK Agricultural and Horticultural Development Board.

[43] Robin Crawshaw, RC feeds, expert adviser and member of the Brewers' Grains & Moist Co-products Committee of the Brewing Food and Beverage Industry Suppliers Association, personal communication Oct 2017.

[44] This will of course change for feed merchants' vehicle load capacity, in addition to fuel prices, inter-annual variability, and seasonality of feed markets.

[45] Based on survey of UK breweries by Ben-Hamed 2012

[46] Personal Communication, Ruth Evans on behalf of Brewers' Grains & Moist Co-products Committee of the Brewing Food and Beverage Industry Suppliers Association, Nov 2017.

VIA MERCHANT (larger)	30	km	*Haulage may be as far as 80km in the UK, but 30 km is a reasonable estimate for a typical distance.*
1. Brewery to farm			*Capped from air to prevent spoilage* *Assumed any further fermentation CO_2 emissions excluded*
2. Ensilage/direct feeding			*20 -29 tonne capacity tipper truck,* *Commercial feed merchant. (loading: 80-100% one-way, empty return).*

On farm processes	
feed storage and handling	*Assumed negligible change in operational emissions with BSG or other feed sources.*

*Personal Comm. Ruth Evans on behalf of Brewers' Grains & Moist Co-products Committee of the Brewing Food and Beverage Industry Suppliers Association
**Micro breweries waste survey (Kerby and Vrieskoop 2017)

Comparable products

Brewers spent grain is commonly used as a low-cost moderate protein supplement in forage-based diets for ruminants such as beef and dairy cattle. However, differences in digestibility, palatability and the absence or presence of essential amino acids and/or anti-nutritive factors makes it difficult to identify products that are functionally comparable.

The challenge in identifying feed products that are comparable to fresh or ensiled BSG is the many potential components and combinations that could be used. For example, Münger and Jans, (1997) report that 16 ingredients in total were adjusted to include or omit BSG in feed rations comparable to the original maize silage and oilseed protein meal.

Since there are no accepted standardised or average formulations for ruminant feed rations, nor statistically representative data sets to determine a consistent and reliable set of equivalent products used in beef and dairy systems, a simple average crude protein equivalent is indicated as a metric for identifying comparable products. BSG crude protein content on a dry basis can vary between 20% and 30% depending on the brewery product which is broadly similar to oilseed rape meal commonly used for dry straight or compound ruminant feed rations (Crawshaw 2001). This is considered more suitable, as the next nearest cost bulk protein feed commodity available, than premium priced protein feeds such as hi-pro soy meal[47].

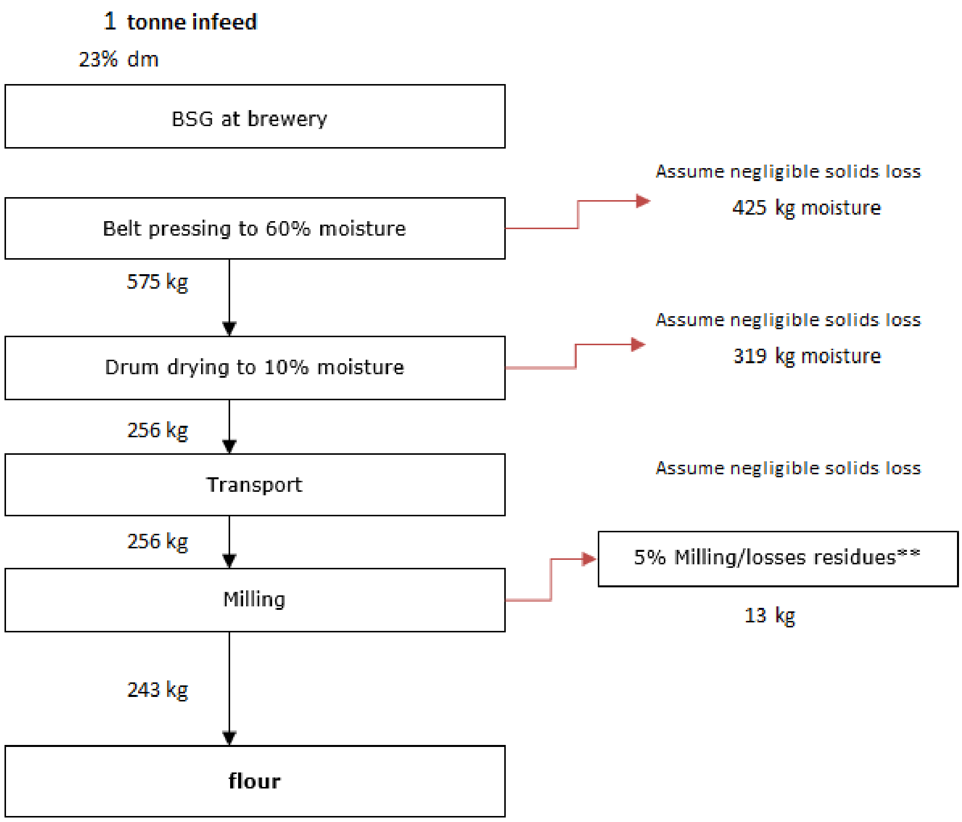
[47] Based on Personal Communication with Robin Crawshaw, Independent feed expert.

On crude protein basis[48], 1 tonne of moist BSG is assumed to be comparable to approximately 172 kg of rape meal or 136 kg soybean meal (Bertilsson et al 2014).

3.3.2 Dried brewers' spent grain flour as a food ingredient

BSG is sold as a flour for ingredients in baked goods. This is not widespread and sources of data on the scale of production and associated processing methods have not been found. Here a theoretical model is presented (Figure 20) with an inventory based on secondary data sources for applicable processes (Table 12).

Figure 20 Model process flow for drying 1 tonne of brewer's grain and offsite milling into wholegrain flour



[48] Assuming moist BSG at 23% dry matter contains 6% crude protein and rape meal containing 35 % crude protein (see Annex 11 for calculations). However, ignoring digestible protein qualities, and differences in other essential nutrients, the impact on other ingredients required to formulate truly equivalent feed rations must be acknowledged as a key limitation of this approach.

Dewatering

The first stage in drying BSG is to physically remove unbound moisture to reduce thermal drying costs. Belt presses[49] may be applied with smaller capacities (<2t/hr) but past evidence suggests larger breweries have employed screw presses for dewatering BSG[50]. Theoretically if the liquid expressate or press water is energy rich it could be used as a liquid animal feed, an AD feedstock, or may even be returned to improve the brewing extraction yield (Crawshaw 2001). Here it is assumed to be treated as an effluent with negligible processing impacts since there are no data to quantify BSG press water composition.

Drying

Specifications published for a BSG flour product indicates a 7% (maximum 11%) moisture for storage. Moisture gain/loss during milling, sifting, and blending is dependent on various conditions, including storage, and it is perhaps too simplistic to assume that a 7% moisture level is achieved entirely due to the drying process for BSG prior to milling. This also would accrue a greater drying energy cost penalty to BSG compared to any substituted food cereal grains, since these are typically stored prior to milling at moistures nearer to 14% (in the UK). Given limited information on the moisture content for food grade spent grains, specifications for stable storage of dry cereal feeds of 12% moisture has been assumed for dried BSG. A reference specific energy consumption has been used from a commercial supplier of tubular bundle indirect rotary driers specifically designed for drying BSG[51].

Milling

Specific energy consumption by the grain milling industry of 50-100 kWh per tonne of product reported as part of IPPC BREF reports (EC 2017). This is based on a survey of ten milling companies.

Smaller batch milling may attract a marginal decrease in energy efficiency assuming increased start up frequency per mass processed and possibly equipment efficiencies. Therefore, until empirical data on dried BSG milling properties is made available, the largest of the range of specific milling energy values reported (EC 2017) has been assumed to allow for efficiency losses by smaller processing runs or smaller flour mills appropriate to relatively smaller volumes of BSG flour compared to wheat flour.

Limitations and uncertainties

Processing capacities of the flour mills from which milling energy consumption has been derived in the BSG model are not reported; however, being subject to IPPC permits these are likely to represent larger industrial mills. Therefore, a much

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[49] e.g. https://www.flottweg.com/fileadmin/user_upload/data/pdf-downloads/Bandpresse-EN.pdf

[50] see http://www.vincentcorp.com/content/spent-grain and suppliers listed in footnote 33.

[51] Technical specification provided by Ponndorf Anlagenbau GmbH, Germany.

larger tonnage in each process run is likely compared to batch milling required for relatively smaller quantities of dried spent grains. This data uncertainty is a key limitation in this model.

The IPPC BAT draft report on milling also suggests that harder grains such as barley, with a tightly adhering husk, cannot simply be separated in a traditional wheat mill and are usually subjected to an abrasion process called pearling prior to milling. No data can be found to substantiate if pre-milling processes would be required for dried brewers spent grain. However, spent grain is likely to differ in this quality due to the steeping, biological processes, and drying and mashing actions of the malting, brewing and drying process. For these reasons it has been assumed that the need for pearling or additional pre-treatment is not required.

No information is available on milling performance (moisture, loss/gains, and extraction yields) for dried BSG to enable a more nuanced comparison. Actual losses in industrial flour milling (known as extraction losses) can vary considerably depending on production variables[52]; again, these are not known for dried BSG. Therefore, no net change in moisture due to milling has been assumed and a conservative default 5% milling loss has been based on laboratory scale milling whole BSG (no fractionation)[53]. This default value should be modifiable in the tool to allow for adjustment should further data become available.

Comparable products

BSG flour, without separation for higher protein fractions, may have a crude protein content of around 20%. This is a higher % than strong bread flour but only marginally so for some high gluten wheat flours.

The nearest comparable products, by end function, are most likely to be other ingredients used in baked goods for enhancing product protein content. This may be either higher protein wheat flours or semi-refined whey powders used in baked goods marketed as nutritional sports snacks or health foods.

For the purposes of the tool a high protein whole wheat bread flour is assumed to be a reasonable comparison product.

However, with no readily accessible formula or data sets the equivalency of food protein in identifying a comparison product is nuanced. This has been outlined by (Sonesson et al 2017) with a call for further research on the need to refine functional units of food products regarding nutritive factors such as digestible protein quality.

The specifications published for BSG flour indicates packaging of 30 x 25 kg food grade paper sacks per pallet (750kg) and storage life of 18 months. It is reasonable to assume differences between cereal grain flour bulk packaging and BSG flour for

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52 e.g.Sugden D. 1996: Article in trade press - www.world-grain.com on flour extraction yields

53 Unpublished, Personal Communication, Fatima Arrutia, Research Scientist, Biorefinery Centre, Quadram Insititute, Biosciences, UK.

a similar market, or blends thereof, are negligible. Therefore, packaging is excluded from the tool inventory.

Table 12 Model inventory for processing 1 tonne of BSG into flour

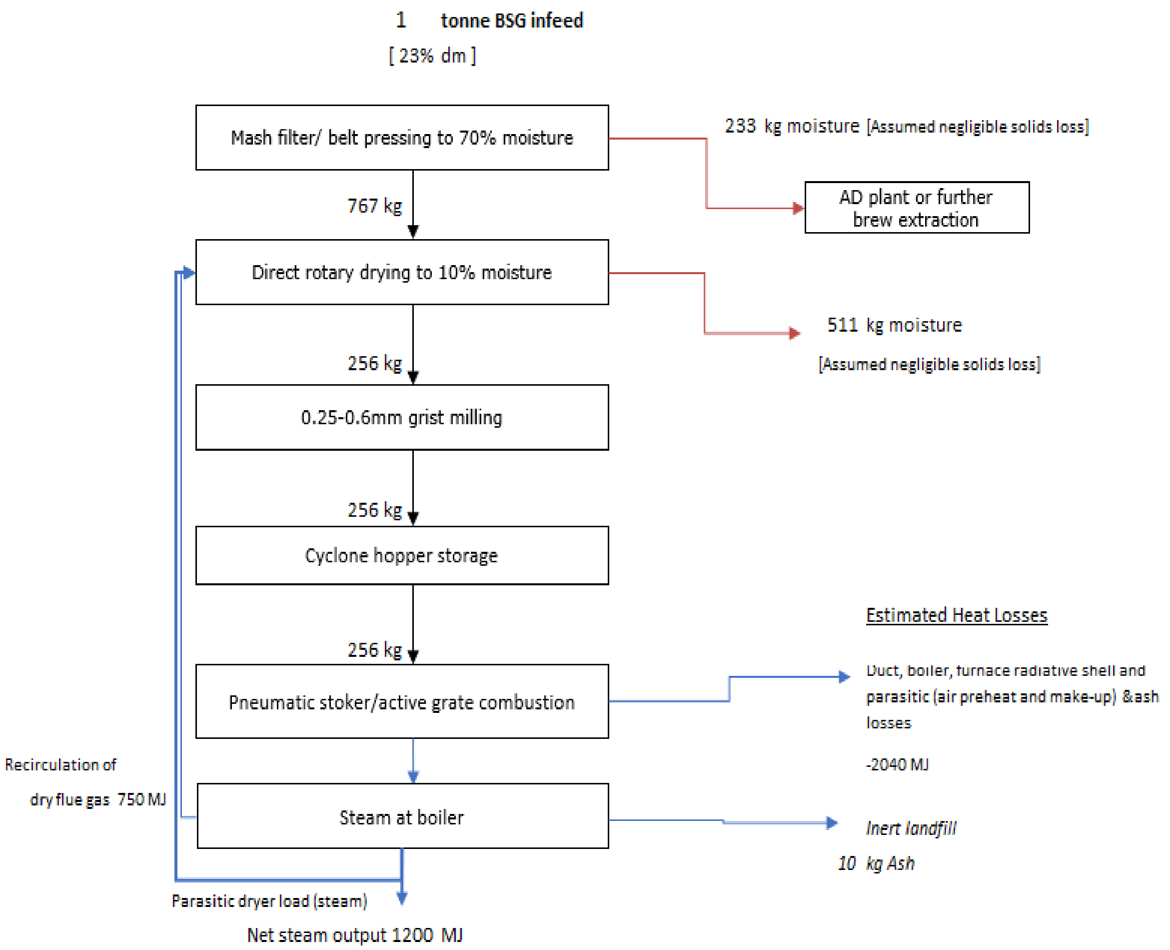
INVENTORY			
Belt/screw pressing			
Brewers spent grain	1000	kg	
Electricity	9	kWh	
Output			
Pressed spent grains	575	kg	(40% w/w dry matter)
liquor /expressate	425	kg	To effluent treatment (assumed minimal solids loss)
Drum dryer (tubular bundle)			
Pressed spent grains	575	kg	(40% w/w dm)
Heating fuel MJ	1280	to 1430	Based on Ponndorf GmbH nominal dryer performance and an assumed 75% steam efficiency, (Omitting losses from boiler gives a range of 960-1072 MJ for the dryer)
Electricity	4	kWh	
Output			
Grain 10% w/w moisture	255	kg	
Transport			
Bulk transport	30	km	*Assumption no data sources*
Output			
Flour milling			
Milling losses	*13*	*kg*	*Assumed 5% losses**
Electricity	*26*	*kWh*	*Caveat: based on IPPC data for larger cereal mills*
Output			
Brewers grain flour	240	kg	
** Observed in lab based milling of BSG in research at Biorefinery centre, Quadram Institute Research.*			
NB Values have been rounded			

3.3.3 Brewers' spent grain as a combustion fuel

A basic model of an existing biomass furnace and spent grain dryer using 100% spent grain as a feedstock in operation has been scaled to a 1 tonne of wet spent grain infeed (Figure 21). This has been based on information and measurements supplied by the Alaskan Brewing Company that have designed, patented[54] and operate an innovative and commercially successful system in the US.

54 For detailed process descriptions see patents US20170190994A1 and US20170121619A1

Figure 21 Model process flow for drying 1 tonne of BSG for onsite combustion energy



Operational electricity consumption

The operational electricity consumption of the whole system (mainly milling, mash filter belt press, dryer fan and pneumatic stoker duties) has been measured from distribution boards power loads during operation, rather than estimated or measured from individual unit processes (Table 13).

Milling

Milling of grists for brewing is standard practice. However, successful combustion of BSG in a commercial brewery has been found to require a finer milled BSG, prior to brewing and employing a mash filter system. For the more traditional Lauter filtration, finer milling may be conducted after drying BSG[55]. In this case, the energy consumption is assumed to be similar to an industry standard grist mill based on published nominal power specifications[56]. In the inventory presented in Table 13 the milling is conducted prior to brewing, with a mash filter employed. The electricity consumption has been included in the operational electrical load measurements. However, in Figure 21 the milling is shown after the drying process, demonstrating application in traditional brewing using a Lautering filter bed process.

Drying mass balance

The pressed grain is dried using fans to drive hot air through a three-pass rotary dryer. The air is indirectly heated by coils using parasitic steam consumption supplied from the boiler. The dryer steam consumption and BSG throughput have been based on actual measured data provided by the brewing company. The dried spent grain is pneumatically transferred to the furnace directly, with the furnace in-feed/burn rate working at a 1:1 ratio with the drier ex-feed/drying rate. This has allowed mass balance losses and net energy yields to be scaled to a reference value of 1 tonne of wet BSG. Furnace and drier losses have been estimated from both secondary data from suppliers and primary data supplied by brewery engineers. Specific estimates related to ash (heat loss and use) have been omitted since ash material significance is likely to be small (1% by mass), and heat loss is inherently included in the mass balance approach based on gross energy input minus known net useful energy.

Comparable products

After parasitic drying duty taken from the boiler, supplemented also by recirculated flue gases, the net energy yield per tonne of fresh BSG has been estimated to be approximately 1,200 MJ or 25% of the LHV of the BSG burnt. This is used for the breweries operation. Prior to this the brewery had been reliant on fossil heating oil as a combustion fuel. However, comparable heat production could be based on data sets for average fuel used for industrial heat supplies in Europe.

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[55] This patented process is commercially demonstrated by its originator the Alaskan Brewing Company.

[56] Specific energy consumption of 2kWh has been derived for a material flow (approx. 250kg dried BSG) relating to 1 tonne of original wet BSG. This is based on assumptions made for the mill motor duty, sized from established industry Mill suppliers Meura.

Table 13 Model inventory for combustion of 1tonne of BSG for energy

INVENTORY			
Input: Wet brewers spent grain at brewery site	1	tonne	23% dry matter
Belt/screw pressing			
Electricity		kWh	*Inc in total system measurement 'Operational electricity'*
Output			
pressed spent grains (40% w/w dm)	767	kg	
liquor /expressate	233	kg	*No data on solids loss - assumed negligible*
Direct drum dryer (3 pass)			
Heat input (delivered steam)	1590	MJ	*Steam heat supplied to dryer air steam coils*
Heat input from flue stack (gross)	750	MJ	*Gross input - no duct losses*
Losses	960	MJ	*Duct losses, infiltration and final exhaust*
Output			
Grain 10% w/w moisture	255	kg	
Milling (lauter system only)			
Hammer milling dried grain	*See total*	kWh	*Required particle size 0.25-0.6mm*
Combustion			
Electricity	*See total*	kWh	*Pneumatic stoker /Vibrating grate/conveyance/cyclone/dryer fans*
Heat value of dried BSG (LHV**)	4830	MJ	
Parasitic steam/heat to dryer	1590	MJ	Based in measurements made by brewery
Losses (including flue stack gases)	2040	MJ	*Duct, boiler, furnace radiative shell (air preheat and make-up) and flue losses*
Operational electricity	47	kWh	*Extrapolated from the quotient of measured total power draw of the processes and typical dryer ex-feed (BSG combustion rate)*
Surplus exportable steam	1200	MJ	*Approx. 25% of the BSG LHV is exported as surplus steam*
NB Values have been rounded			

**Latent and sensible heat absorbed by combustion product H_2O is already accounted for in LHV and is therefore excluded from loss estimates.*

3.3.4 Energy recovery

Energy recovery from brewers spent grain was modelled in accordance with the model used for all side flows in the spreadsheet tools (Östergren et al, 2018). The effect of co-digestion with other substrates is not taken into account and thus the value should be considered as conservative. This valorisation route leads to three specific utilities: electricity, heat and digestate (used as fertiliser). Table 3 and Table 4 provides an overview of the inventory used for BSG in the model.

Table 14 Biogas potential BSG, per tonne Fresh Matter (FM) with a Dry Matter content of 23%

Side-flows	Theoretical biogas yield in m3/t FM	Theoretical CH4 content in %	LHV in MJ/ MJ/t FM
BSG	93,00	60.0	21,50

Table 15 Emissions and energy recovery BSG, per tonne Fresh Matter (FM) with a Dry Matter content of 23%

Emissions AD kg $CO_{2\ eq}$/ t FM input	Net Electricity KWh/t FM input	Net Thermal energy KWh/t FM input	Digestate t FM/t FM input	Credit for digestate application kg $CO_{2\ eq}$/ t FM input
50,3	182	75	887	-8,62

Comparable products

The selected comparison products used in the model are:

- Electricity (country specific) and EU average heat production
- Electricity and EU average heat production
- Electricity and EU average heat production and production and application of mineral fertiliser (the digestate from the AD is spread on land, providing nitrogen, phosphorous and potassium to the soil)
- Hydropower electricity and wood chips

3.4 Description of the FORKLIFT spreadsheet model for brewers' spent grain

3.4.1 Generic information

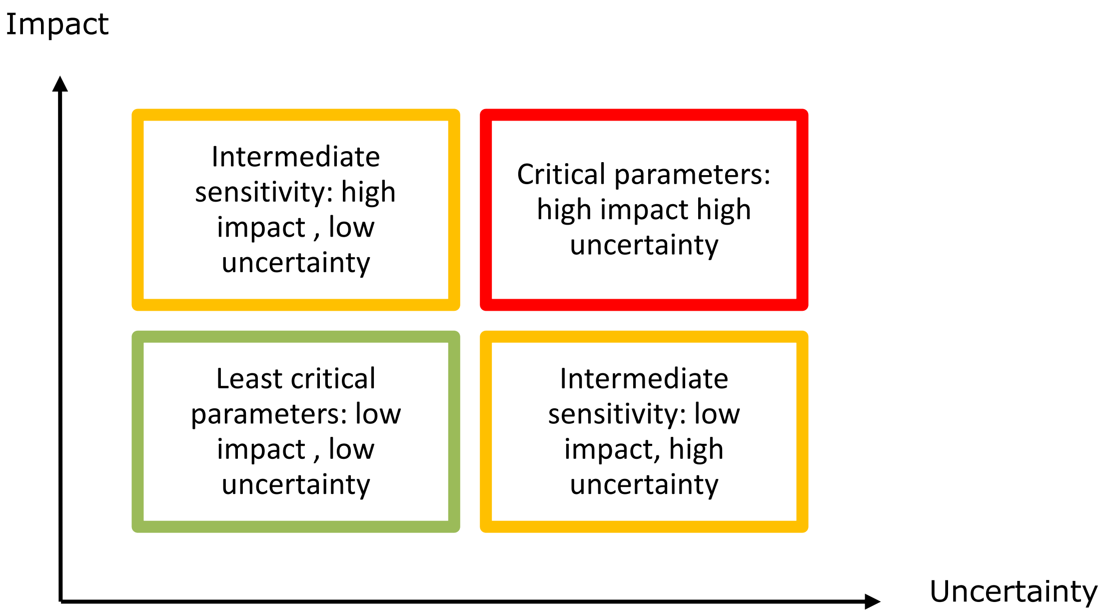
The model calculates the GHG emissions and costs associated with the handling of 1 tonne of BSG with a dry matter content of 23%. For the upstream burden from raw material production an average value of cultivation of barley (for malt produced for brewing) has been assumed (0.5 kg CO_{2eq} /kg dried barley). The process of malt production from barley and respective yields has been omitted from this upstream burden in line with other processes in the spreadsheet tool However, malt production from barley can incur in the region of 10% losses by weight when factoring rejections, screenings, culm removal and the malting process[57]. This is complicated given rejections, screenings, and culms can be subsequently sold to animal feed merchants (albeit at much lower cost than malting barley).

The upstream burden attributed to the valorised product is calculated through economic allocation according to the REFRESH report D5.4 Simplified LCA & LCC of food waste valorisation (Östergren et al 2018). It should be noted that generally the revenue from side-flows of food or drink producers compared to the main products have a much lower value. Therefore, the proportion of the upstream GHG burden allocated to the valorisation approach is also typically low relative to its processing impacts since economic allocation is applied. When the upstream burden increases, the accuracy of the model will decrease as upstream processing, such as malting, have been excluded from the tool inventory.

Critical parameters were qualitatively assessed using the model developed previously in D5.4 Simplified LCA & LCC of food waste valorisation (Figure 22). Description of standardised models (Östergren et al 2018). Note that the matrix in some cases also includes parameters that cannot be changed (Annex 11) as an information to the user. The reason for keeping them constant is that they are generic numbers used in several models to allow comparison between different side flows. The assessment is based on the *relative* impact of a parameter compared to the total impact of the valorisation process.

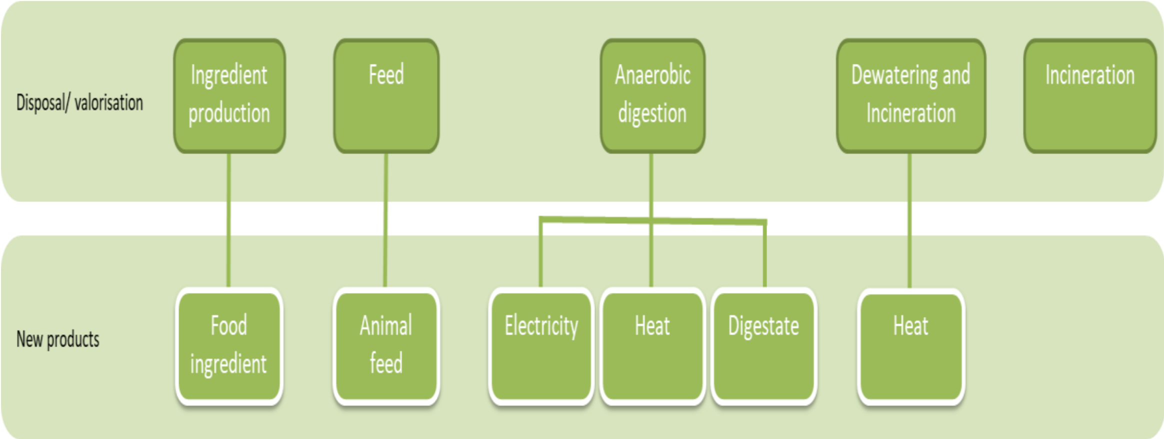
An overview of the spreadsheet tool and option included in the model is provided in Figure 23 and in the next section the sub-models are described. The full inventories are provided in Annex 11 as supplementary information

Figure 22 Assessment of critical parameters



[57] MAGB website

Figure 23 Overview of the BSG spreadsheet model in FORKLIFT



3.4.2 Brewers' spent grain as a moist animal feed

Figure 24 The moist feed option for BSG in FORKLIFT

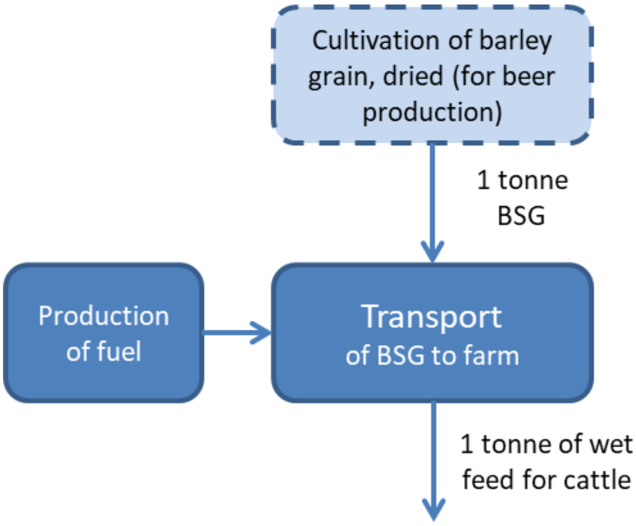


Figure 24 illustrates the processes that are considered in the calculation of GHG emissions and costs for using BSG as feed. The environmental impact and cost from the upstream (dotted line) processes are included if the BSG carries an economic value.

The model assumed BSG is transported to the farm by truck. Its GHG burden includes both fuel production and combustion. The cost inventory uses fuel price data only.

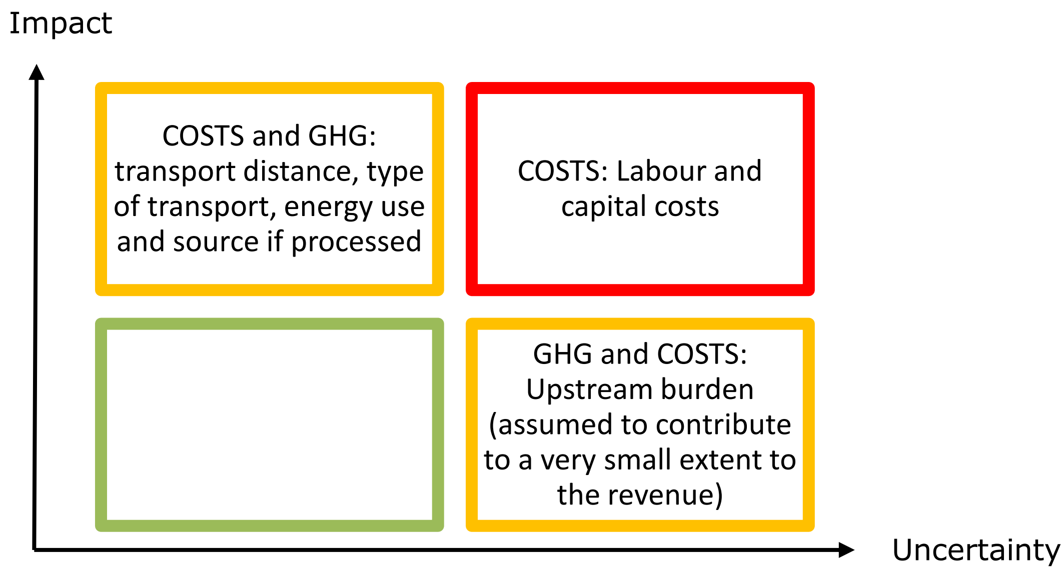
In this valorisation option, 1 tonne of feed is the product, which can be used as a moderate protein supplement in forage-based diets for ruminants. Although the BSG will most likely not substitute one single feed ingredient, but more likely a combination of feed components, comparisons have been provided for other protein feed components being rapeseed meal and soy meal. The amount of comparable rapeseed meal (172 kg) or soy meal (136 kg) are based on providing the same amount of crude protein as in 1 tonne of BSG (60 kg of crude protein).

Parameter being modelled are provided in Table 16 and the assessment of critical parameters are provided in Figure 25.

Table 16 Adjustable model parameters for moist feed option of BSG.

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transports tractor single trailer 50% Load Fraction (LF)	20	km	A pre-selection of transport options is provided, distances can be set freely for options see Table 11
Electricity use	0	kWh/tonne BSG	May be added if addition handling is required.
Heat use	0	kWh/tonne BSG	May be added if addition handling is required.
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 25 assessment of critical parameters for moist feed production



3.4.3 Dried brewers' spent grain flour as a food ingredient

Figure 26 The food ingredient (flour) option for BSG in FORKLIFT

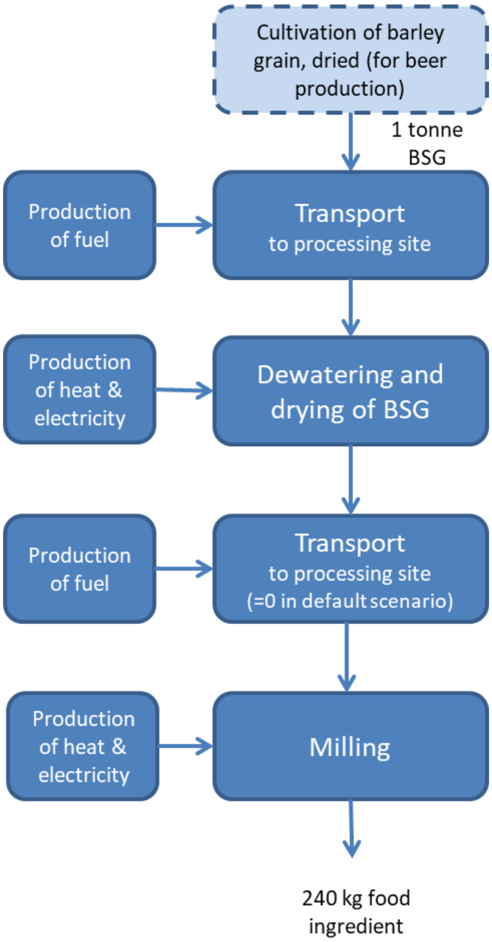


Figure 26 illustrates the processes that are considered in the calculation of GHG emissions and costs for using BSG as a food ingredient. The environmental impact and cost from the upstream (dotted line) processes are included if breweries receive payment for their BSG.

The BSG is first stabilised by dewatering and drying (so that it is not spoiled in further transport and storage) before being transported to the milling plant. In FORKLIFT's default setting however, the second transport is set to zero, i.e. it is assumed that the wet BSG is transported to a processing site, and the drying and milling takes place at the same site.

Regarding fuel for transport and heat and electricity, the calculations includes GHG emissions from their production and supply to their point of use. The costs considered are the costs of the electricity, and fuel for transport and heat.

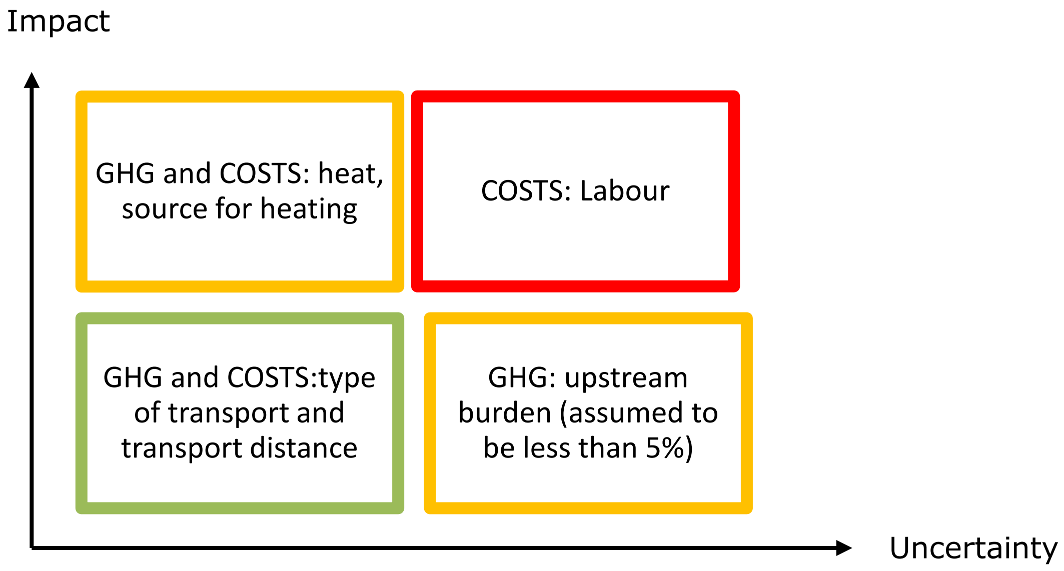
In this scenario, 240 kg of flour is produced with a crude protein content of 15-20%. For comparison we have included production of 240 kg wheat, even though wheat flour has a slightly lower content of protein than the BSG product.

Parameters being modelled are provided in Table 17 and the assessment of critical parameters is provided in Figure 27.

Table 17 Adjustable model parameters for food ingredient (flour) option using 1 tonne of BSG

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Heat use for drying BSG	282	kWh/tonne BSG	The actual heat delivered to the dryer (independently of fuel selected).
Transports BSG (Rigid truck, 20-26 t, Euro 4, 50% LF)	30	km	A pre-selection of transport options is provided, distances can be set freely.
Electricity use for processing BSG	39	kWh/tonne BSG	Dewatering, dryer operation (rotary motors) and milling stages
Fuel used for generating heat	Light fuel oil		A pre-selection of fuels is provided (biogas, natural gas, har coal, wood chips from forest, EU-average heat)
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 27 Assessment of critical parameters for ingredient production (BSG)



3.4.4 Energy recovery using anaerobic digestion (AD)

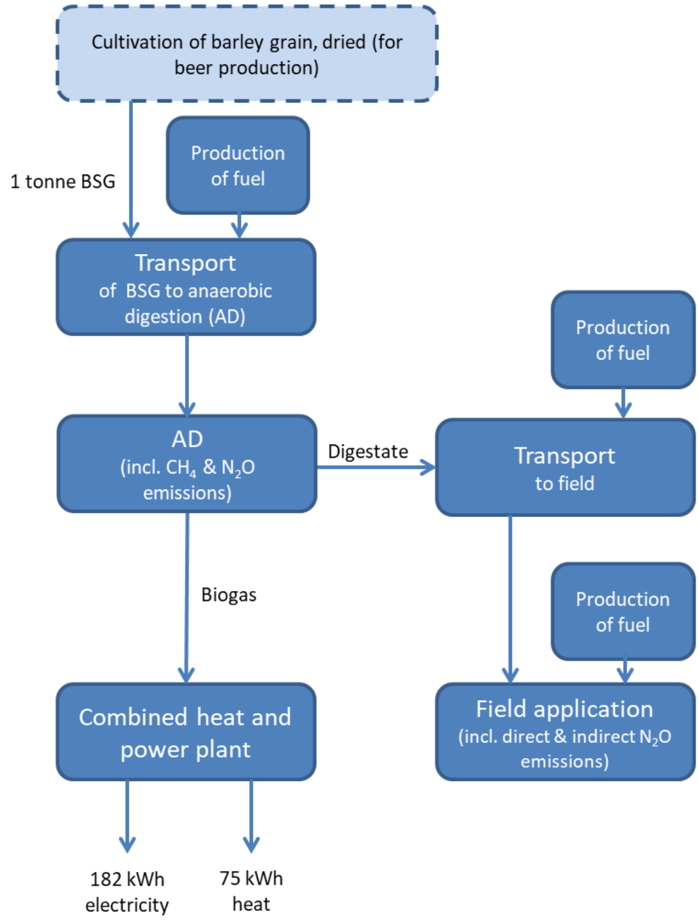
The calculations are based on the streamlined approached recommended in the REFRESH report "D5.4 Simplified LCA & LCC of food waste valorisation" (Östergren et all 2018).

Figure 28 illustrates the processes included in FORKLIFT's calculation of GHG emissions and costs for producing biogas from BSG and generating electricity and heat from it. The environmental impact and cost from the upstream processes (within the dotted line) are included if the brewery receives a direct economic benefit (revenue) from the side-flow. This is considered unlikely for AD where it is treated in Member states as a waste disposal service with disposal or gate fees applied.

The BSG is transported to the AD plant by truck.

Regarding the use of fuel, the GHG calculation covers the emissions of producing the fuel and combustion in the truck, as well as fugitive biogas emissions from its storage and during use in the biogas engine (slip) generating heat and electricity. The cost takes into account the price of fuel for transport.

Figure 28 Energy recovery from BSG



In this valorisation option, no energy requirements for pre-treatment processes have been assumed. The tool assumes that 182 kWh electricity and 75 kWh of heat are exported as products. The results are compared with

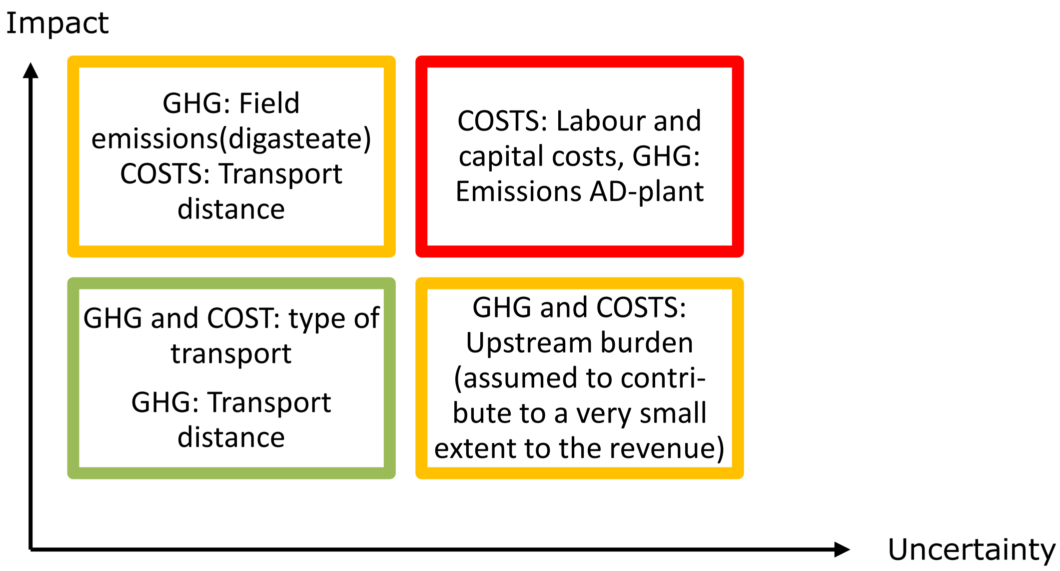
- Electricity (average for selected country in the model) combined with EU average Heat
- Hydropower and wood chips heat
- Electricity and heat EU average heat
- Electricity and heat EU average including production and application of mineral fertiliser since the digestate from the AD commonly is spread on land, and therefore provides nitrogen, phosphorous and potassium to the soil.

Parameters being modelled are provided in Table 18and the assessment of critical parameters is provided in Figure 29

Table 18 Adjustable model parameters for biogas and energy production (AD) from 1 tonne of BSG

Parameter	Defaul t value		Comments
Country	EU		Determines energy mix and cost
Transports of digestate to the filed (tractor single trailer 50% Load Fraction (LF))	20	km	A pre-selection of transport options is provided, distances can be set freely.
Transports of BSG to the AD plant (tractor single trailer 50% Load Fraction (LF))	20	km	A pre-selection of transport options is provided, distances can be set freely.
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 29 Assessment of critical parameters for biogas and energy production BSG (AD)



3.4.5 Combustion of brewers' spent grain for heat

Figure 30 Process considered for combustion of BSG with heat recovery

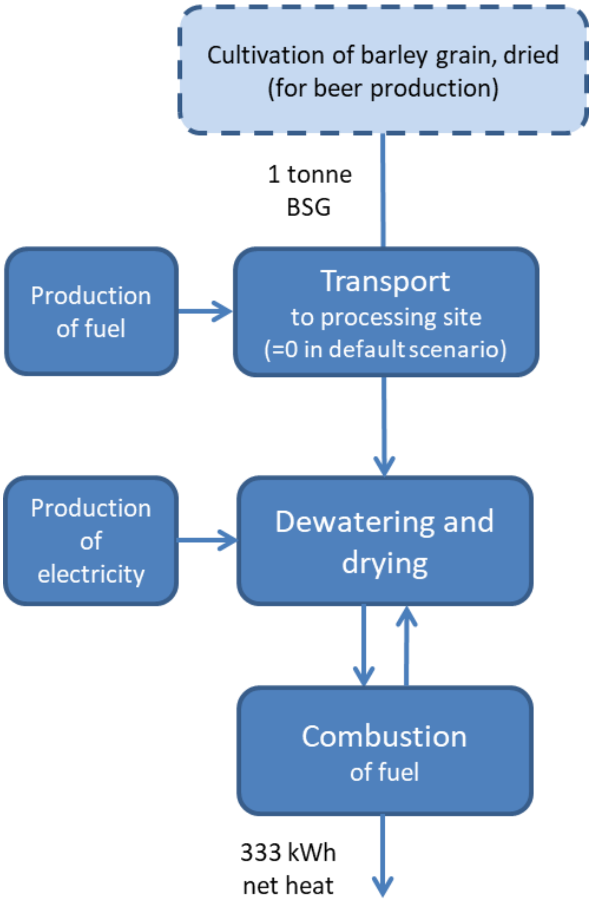


Figure 30 illustrates the processes that are considered in the calculation of GHG emissions and costs for producing heat energy from BSG, after dewatering. The environmental impact and cost from the upstream processes are included if the BSG carries an economic value (therefore in dotted line).

In the default scenario, it is assumed the dewatering and combustion occurs at the brewery, therefore the transport step is set to zero. The user can change this if applicable.

The BSG is dewatered to 65% moisture using an industry standard mash filter. The grain is then dried in a 3 pass rotary dryer before being introduced into the boiler fire box. The dryer uses heat from the combustion exhaust. This is supplemented with air heated via steam coils, as a parasitic load taken from the boiler. The dryer steam consumption and BSG throughput have been based on actual measured data (see 3.3.3)

Regarding the use of fuel, electricity and heat, the GHG calculation covers the emissions of producing the fuel (electricity) and combustion in the truck. The cost considers the price of electricity, and fuel for transport and heat.

In this valorisation option, 1/3rd of MWh net heat is produced. The results are compared with

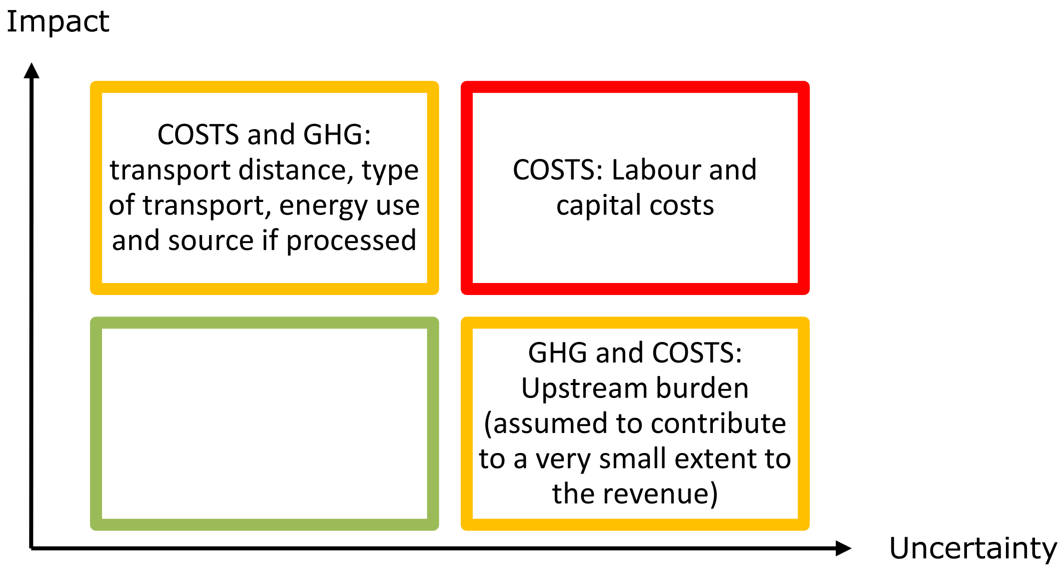
- Wood chips heat
- EU average heat

Parameters being modelled are provided in Table 19 and the assessment of critical parameters are provided in Figure 31

Table 19 Adjustable model parameters for use of 1 tonne of BSG as a biomass fuel through combustion with heat recovery.

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Electricity use	47	kWh/tonne BSG	Based on measured total system load in operation and feed rate. Load includes milling, dewatering, conveyors and rotary dryer operation (fans)
Transport of BSG to drying & combustion site (Truck with semi-trailer , Euro4, 28-34 tonne, 90% Load Fraction (LF))	0	km	A list of transport options is provided, distances can be set freely.
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 31 Assessment of critical parameters for fuel through combustion with heat recovery



3.4.6 Incineration of brewers' spent grain

Figure 32 Process considered for incineration of BSG (principally for disposal)

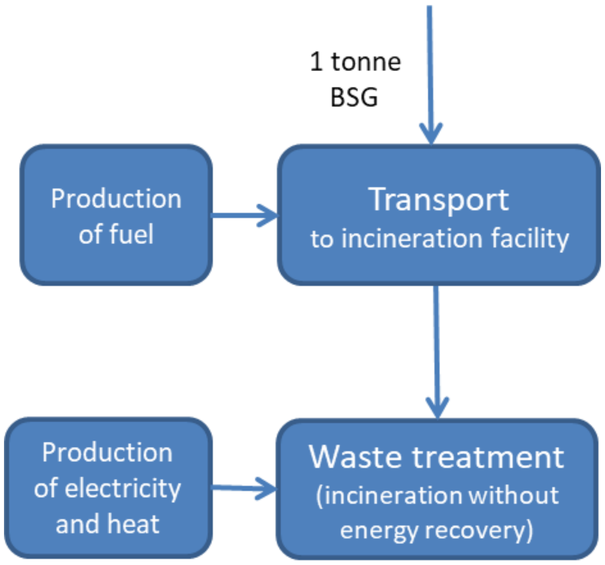


Figure 32 illustrates the processes that are taken into account in the calculation of GHG emissions and costs of this option for handling BSG. The BSG is sent to a waste treatment facility by truck, where it is incinerated together with other waste flows. In this scenario it is assumed that the BSG carries no economic value, and therefore the side flow does not carry any environmental impact or cost from the upstream processes (relating to crop husbandry, agronomic inputs harvesting, transport and grain drying and processing).

Regarding the use of fuel, electricity and heat, the GHG calculation covers the emissions of producing the fuel and combustion in the truck, as well as emissions from generating the auxilliary energy demand for the incineration. The cost takes into account the cost of the fuel for transport and heat.

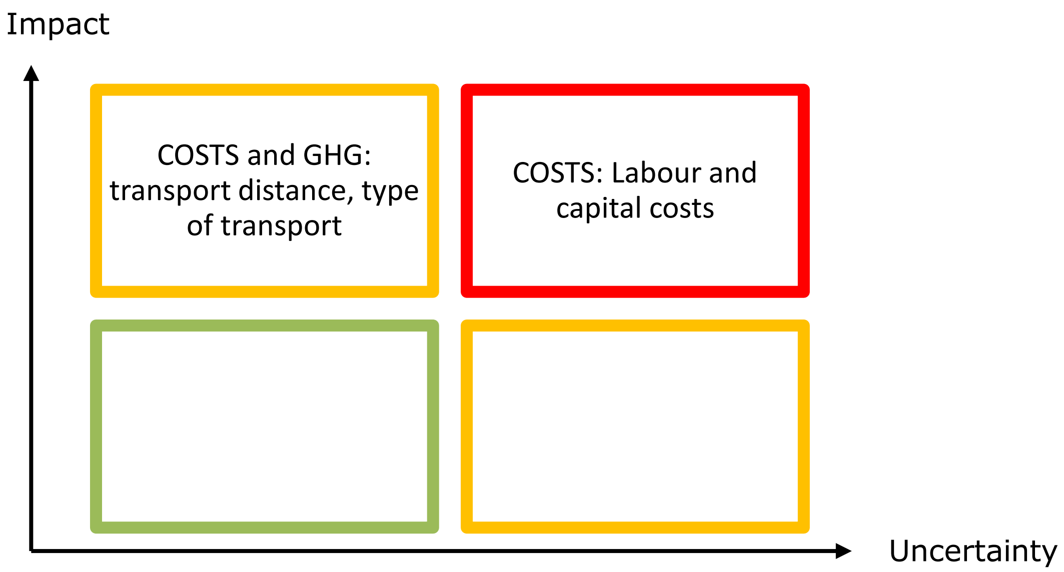
Since BSG with moisture content of more than 80% has a low net calorific value (3 MJ/kg) it is not considered to contribute any net energy to the incineration process. Therefore, in this disposal option, no product is produced, and hence no comparison products are shown in the result figures.

Parameters being modelled are provided in Table 20 and the assessment of critical parameters are provided in Figure 33

Table 20 Adjustable model parameters for waste incineration of 1 tonne of BSG

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transport of BSG to incineration plant (Truck 50% Load Fraction (LF))	20	km	A list of transport options is provided, distances can be set freely.
Labour and capital costs	0	EURO	Set by the user

Figure 33 Assessment of critical parameters for incineration of BSG



4 Annex 4: Abattoir by-products spreadsheet model: Pigs blood

List of abbreviations

ABP	Animal by-products
Cat 3 ABP	Category 3 animal by-products from slaughterhouses or abattoirs are fit for human consumption at the point of slaughter but are not intended for human consumption for commercial reasons.
Cat 2 ABP	Category 2 animal by-products from slaughterhouses or abattoirs are materials which are considered high risk requiring approved treatment and then are limited for use as combustion fuels or approved disposal.
Cat 1 ABP	Category 1 animal by-products from slaughterhouses or abattoirs include specified risk materials (partly dependent on country's disease control status), body parts that pose a disease risk, parts of infected animals or animals suspected of being infected of diseases transmissible to humans or animals. Cat 1 ABP's are considered of the highest risk requiring approved tightly controlled treatment and disposal.
PAP	Processed animal protein restricted to materials classed as Cat 3 ABP
UF	Ultrafiltration is membrane filtration that uses high pressures or concentration gradients to retain (higher molecular weight) solids but allows (lower molecular weight) fluids (water) and some dissolved solids to flux across semi-permeable membrane.
SEC	Specific energy consumption e.g. kWh/tonne of processed product.

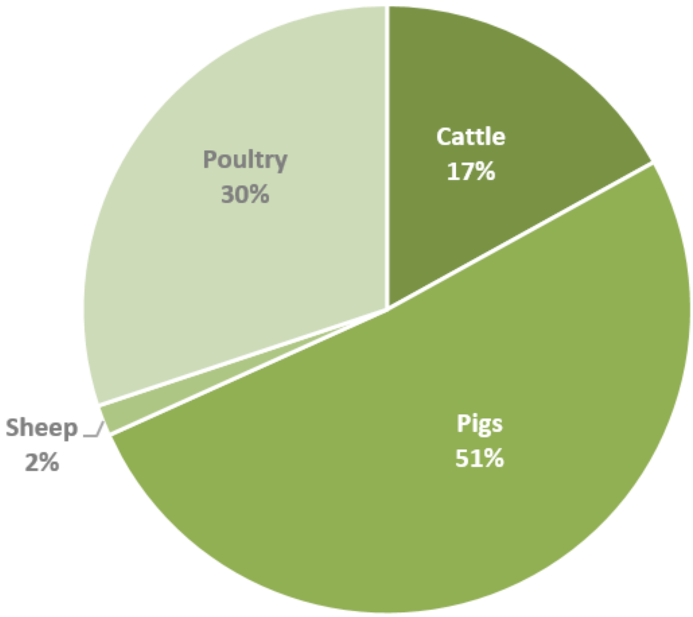
4.1 Background

4.1.1 Rationale

As a by-product from abattoirs, blood has been identified as one of twenty food chain side flows considered suitable for valorisation by Refresh deliverable 6.1 and 6.9.

For the purposes of producing high level valorisation models, we have focussed on pigs blood only since there are restrictions on valorisation of blood from ruminant animals such as beef cattle and sheep or blood has a risk of being mixed with these animals, at abattoirs that slaughter both pigs and cattle (further information in 4.1.4). In addition, pig meat is the main type of meat produced in the EU-28 (Figure 34) resulting in the largest potential source for blood derived products, (blood typically constituting 3-4% of an animal's live weight). Pig meat also represents 9.0 % of the total EU agricultural output.

Figure 34 Proportion of animals slaughtered, by weight, in the EU-28 in 2014 (Eurostat 2017)



4.1.2 Blood products and blood meals

For the different uses of blood there is a distinction between separated *blood products* and whole *blood meals*:

Blood products are derived from blood by processing whole blood and, under certain conditions, separating it, into key constituents of plasma and cellular material for various end uses.

This distinction has also been made for the regulation of animal by-products not intended for, but fit for, human consumption. The EU defines 'blood products'[58] as derived products from blood or fractions of blood fit for human consumption, *excluding blood meal*; but including dried/frozen/liquid plasma, dried whole blood, dried/frozen/liquid red cells or fractions thereof and mixtures.

Blood meals are classified as a processed animal protein derived from the heat treatment of blood or fractions of blood in accordance with regulations. This involves a specific duration of temperature and pressure treatments for heating whole blood or haemoglobin, depending on its animal source. Typically, it is milled into a powder form for further use as a pet food ingredient, nitrogenous fertiliser or an animal feed ingredient restricted to aquaculture or fur animals.

4.1.3 Information on potential and actual quantities

Roughly estimated, 2 million tonnes of blood per year is the maximum theoretical quantity produced from the number of slaughtered cattle, sheep, pigs, and poultry across the EU-28 (Table 21).

This approximates to, in crude protein content (dry matter equivalent), 1.6 million tonnes of lean meat or 1 million tonnes of soy meal animal feed.

Industry surveys suggest whole fresh blood dried to a meal reduces the mass to 15-20%, though figures of 140 kg of blood meal per tonne of raw blood are also reported (EC 2005). Applied to the blood yield estimated from slaughtering records across the EU this indicates the potential for bloodmeal production of approximately 350,000 tonnes ±25% (Table 21).

Eurostat and other official information sources provide limited detail on the fate of animal blood removed from slaughterhouses across the whole of the EU. However, a recent industry survey of companies across 21 European Member States reports a figure of less than 50,000 tonnes of blood from slaughterhouses ends up as **blood products** for food, feed, and pet food, and a further 100,000 tonnes ends up as **blood meal** mostly used in pet foods, but also fish feed and fertiliser (Figure 35).

Whilst the survey does not represent industry across the whole of Europe[59], it covers the main producing countries, indicating that there is potential for greater utilisation of blood for higher value blood products in the food and feed chain in the EU based on estimates in Table 21

A more accurate picture of blood utilisation would require broader access to information on both the slaughtering and rendering industries activities to capture a representative sample of commercial enterprises. It is likely that obtaining this information will be restricted by companies exercising their rights to withhold

58Annex 1 point 4 of Commission Regulation (EU) 142/2011

59The survey is carried out by European Fat Processors and Renderers Association (EFPRA), a trade body with industry members representing 300 companies (with over 500 plants) from 21 EU Member States. Details of the survey respondents, including their countries were confidential.

commercially sensitive information from interested parties[60], but also the accuracy with which industry record material flows (EBLEX 2014)

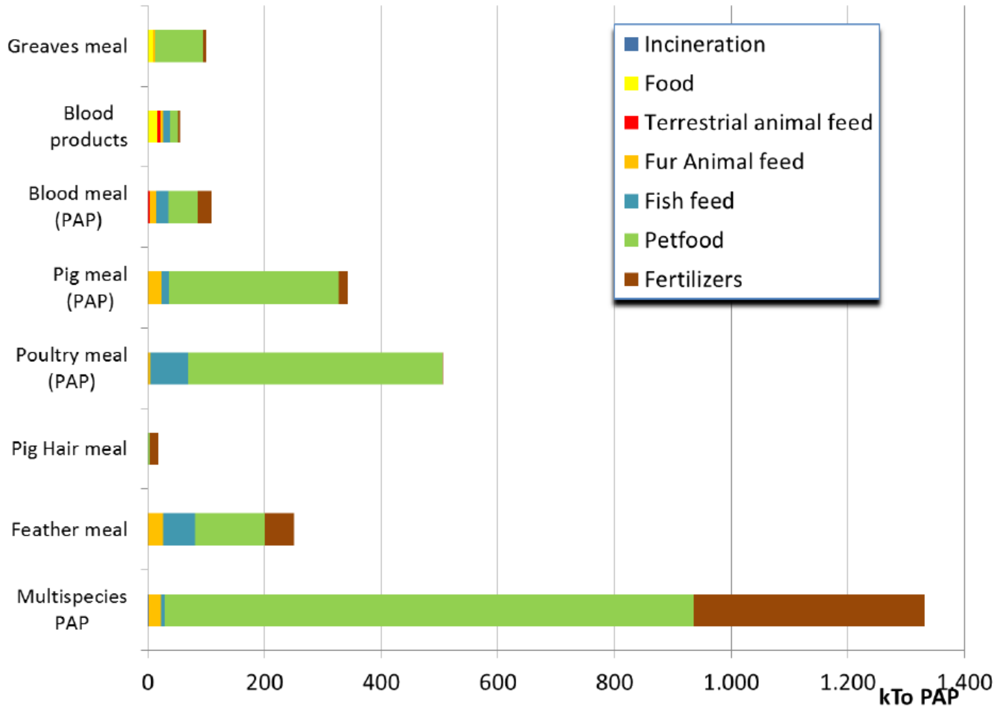
Table 21 Crude estimation of the *potential maximum* quantity of harvestable blood from animals slaughtered for meat

	Cattle	Pigs	Sheep	Poultry
	(‘000 tonnes)	**(‘000 tonnes)**	**(‘000 tonnes)**	**(‘000 tonnes)**
EU-28 (carcass weight) †	*7,326*	22,136	*707*	*13,000*
Carcass weight/live weight	***50%****	**78%**	***50%****	***82%*****
%w/w blood / live weight high estimate	*4.0%*	*3.5%*	*4.0%*	*3.0%*
%w/w blood / live weight low estimate	*3.5%*	*3.0%*	*3.4%*	*2.2%*
Low blood estimate	*513*	*849*	*48*	*350*
High blood estimate	586	991	57	477
			Total range (Million tonnes)	*1.8 – 2.1*
			Dried meal equivalent to 15-20% w/w of fresh blood (‘000 tonnes)	*265 - 440*

†EU-28 data *source:* Eurostat (online data code: apro_mt_pann)
* Sheep and Cattle kill out % from AHDB EBLEX
**Poultry kill out % from poultry slaughterhouse survey, average 82%, ranges from 77% to 86% Pers. Comm. Julie Rumsey, Livestock Commodities Statistics, DEFRA, UK Government. June 2017.

60 The industry survey data and further details of the actual survey coverage and blood product descriptions (dried/liquid) are confidential, even amongst EFPRA members. Personal Communication from Dirk Dobbelaere Secretary General of the European Fat Processors and Renderers Association (EFPRA) July 2017.

Figure 35 The end use of animal by-products from an industry survey of representatives in 21 Member States taken from Dobbelaere (2017)



PAP = Processed animal protein from category 3 animal by-products (by-products edible at the point of production, but not intended for human consumption).

4.1.4 Animal feed restrictions

There are regulatory restrictions[61,62] in the EU prohibiting any animal protein being fed to ruminants and preventing the use of ruminant blood or any kind of processed animal proteins, of which blood meal is one, in feeds for farmed animals including horses and goats and pigs kept as pets[61]. There are exceptions for certain (dog and cat) pet foods and animals bred only for producing fur.

Only low risk[63] blood from non-ruminant animals, having all satisfied inspection and processing conditions[64] can be used to make *blood products* for use in feed for non-ruminant farmed animals such as pigs and poultry[65]. Any processing and

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[61] (EC) 999/2001 (as amended) Laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies. (OJ L 147, 31.5.2001), Herein 'The European 2001 TSE regulations'.

[62] (EC) 1069/2009 (as amended). Laying down health rules as regards animal by-products and derived products not intended for human consumption

[63] Under the EU Animal By-product (ABP) regulations low risk is defined as (Category 3) animal by-products not intended but fit for human consumption at the point of slaughter.

[64] (as amended 2015) specific conditions separating non-ruminant blood products from ruminants to mitigate disease risk are set out under the European 2001 TSE regulations (Annex IV, Chapter IV, section C).

[65] From 1st September 2005, the European 2001 TSE regulations were relaxed by amendments (EC 1292/2005) to allow non-ruminant blood products to be used as an intraspecies feed source for poultry and pigs.

transporting blood derived proteins also require strict separation from feed products intended for ruminants.

Regulatory restrictions prevent the maximum potential viable blood collected from slaughtered animals from being used for blood products. This is due to measures put in place to reject blood that may be stored with blood collected from an animal failing precautionary anti and post mortem veterinary inspections. Therefore, whole batch collections of health animals blood can be required to be rejected due to one animal failing inspection.

Contaminated porcine plasma in pig feed has been associated with the global viral porcine epidemic diarrhoea (PEDv) due to infection of pigs with the alpha coronavirus, and swine delta coronavirus (SDCv), (EFSA 2016). The EU has instigated regulatory controls for imports of spray dried porcine plasma into European Union countries which require heat treatment and storage[66]. However, representatives of some member states farming communities oppose the use of pig feed containing any plasma protein, even shunning suppliers that may use it in other feed ration formulations[67]. Plasma protein is banned by the UK's Red Tractor assurance scheme, which covers 90 percent of this Member State's domestic pig supply.

Blood meals differ from blood products and are classed as processed animal protein (PAP). Due to TSE regulations feed restrictions in the EU only allow PAP to be used as a feed in aquaculture for farmed fish and invertebrates. Blood meal PAP's largest market, however, is for pet food.

4.1.5 Techno-economic barriers

Blood as a food or feed protein source is subject to technical challenges relating to its potential for rapid spoilage, processing requirements and traceability.

The sophisticated technologies required for efficient, hygienic, and traceable blood collection systems means that this maximum potential may not be realised, particularly for onsite processing by smaller abattoirs where the additional cost of investment may not be viable. In this case processors using blood from smaller independent abattoirs will be burdened by costs of refrigerated transport and processing risk controls and traceability necessitated by modern meat and feed hygiene standards[68].

4.1.6 Potential cultural barriers

Apart from technical challenges, the use of blood for various applications is prohibited by some religions. The extent to which blood products and subsequent

66 Section 10 of the Annex to EU 142/2011 pertaining to Points 17 to 21 of the Commission Regulation (EU) 2015/9

67http://www.thepigsite.com/swinenews/36027/uk-pig-industry-moves-to-red-alert-over-ped/ Website accessed July 2017.

68 (EC) 183/2005 laying down requirements for feed hygiene

derivatives such as hydrolysed proteins, or peptides, will also be prohibited is not yet fully understood.

Blood derived ingredients for use in consumer goods such as food, cosmetics, and pharmaceuticals may also face cultural sensitivities. Vegan and vegetarian citizens have called to attention their concerns when manufacturers have failed to communicate in a transparent way that their products contain animal derived ingredients[69].

Its use may also run into issues of wider public acceptance resulting from cultural and political barriers (see Ofori & Hseie 2013 or the reported reaction of Sweden's Agricultural Minister[70]).

4.1.7 Site volumes

The volume of blood available to a processor will be related to individual abattoir capacity, but also their regional density. Larger premises may slaughter a mix of cattle, sheep, and pigs. The TSE regulations' strict requirement for prevention of ruminant protein in feed would require investment in facilities to prevent any risk of intraspecies contamination. Though this is possible, it is considered more likely that blood for feed purposes will be sourced from specialist, single species slaughtering sites.

Data on the total annual pigs killed and the number of sites in some EU Member States have been published in the EU's IPPC BAT reference notes (EC 2005, Table 22). This is an older source of data. However, industry representatives updating BREF notes in 2017[71] suggest site sizes vary widely across the EU and so the 2005 data are still within the representative range. Data on the size of individual sites throughput are not published, therefore the estimates are based on mean averages. It is important to note that this data may not reflect the actual site size structure of the industry.

Table 22 Estimates of annual quantities of pig blood per site from several EU member states

Annual pig slaughtering statistics			Average kills per site '000's	Carcass weight average kg	Live weight kg	blood (~3% w/w) tonnes/site/ year	m^3 blood per site
Country	Total pigs killed '000's	Sites					@1.055 kg/litre
Belgium*	11,531	120	96	93	120	**346**	328
Denmark*	21,000	24	875	77	100	**2,625**	2,488
Finland*	756	3	252	82	100	**756**	717

69 E.g. https://www.bbc.co.uk/news/business-38144598
70 http://www.thepigsite.com/swinenews/24136/sweden-condemns-eu-pig-feeding-rules/
71 Adrian Kesterson, UK Technical Advisor, UK Foodchain and Biomass Renderers Association (FABRA), Personal Communication July 2017. www.fabrauk.co.uk

Sweden*	3,900	16	244	84	110	**804**	762
UK†	6,356	9	706	82	*105*	**2,220**	2,100

All figures have been rounded
*IPPC BAT Slaughtering & animal by-products - 2005
† UK Agricultural and Horticultural Development Board: Pig Pocket Book 2017

4.2 Current valorisation options

Valorisation routes for blood from slaughtered livestock are already established commercially in Europe (i.e. at a TRL of 9). Examples of these are summarised in Table 34.

Table 23 Current valorisation options (TRL 9)

Product	Current applications	Reference	Data availability/ Contacts	Refresh contact point
Blood meal	Pet food	E.g. Leo Group[73] SARVAL[72]	Processing equipment suppliers	,,
Blood meal	Organic nitrogenous fertiliser	Dobbelaere (2017), EC (2005), Leo Group[73]	EC (2005), Processing equipment suppliers	E.g. Mavitec, Haarslev etc.
Blood meal	Aquaculture feed	Dobbelaere (2017) Heuzé & Tran (2016).	EC (2005), Processing equipment suppliers	,,
Blood derived functional proteins	Food (meat) extender/ functional proteins	SONAC BV[74]	Ramirez (2012)	Marel (Butina) Alfa Laval, SONAC
Blood products: Albumin	Pet food	Ramirez (2012), SARVAL[72]	Equipment suppliers	Marel (Butina) APC Alfa Laval

[72] http://www.saria.co.uk/pet_food_ingredients/joint_venture_operations.html
[73] http://www.omegaproteins.co.uk/processed-animal-proteins
[74] https://www.sonac.biz/markets/food-ingredient-supplier/protein-in-meat-supplier/

Product	Current applications	Reference	Data availability/ Contacts	Refresh contact point
Blood products	Animal feed	Dobbelaere (2017), EC	Ramirez (2012)	SONAC
Energy	Anaerobic Digestion	Rudolf Großfurtner GmbH	Markus Ortner, BOKU.	

4.2.1 Pet food

Blood collected from abattoirs is also processed by the rendering industry into a blood meal sold to pet food manufacturers (Figure 35, Dobbelaere 2017).

Blood products from plasma, as a liquid, after fractionation of blood from its cellular constituents contains only 6% to 8% of total blood proteins, consisting primarily of albumin, globulins, and fibrinogen (Bah et al 2013). This can be dewatered and dried to produce a powder or flour meal with a much higher crude protein content for use in both dried or moist pet foods. Blood albumin, separated from plasma is also used as a pet food additive[81].

4.2.2 Organic fertiliser

Blood meal as a fertiliser with an organic approved status in the EU[75] is mainly used as a nitrogenous input. After regulated animal by-product processing requirements to prevent disease risks, blood can be applied as an agricultural fertiliser as a dried meal but also land injected.[76]

It has not been possible to obtain data to quantify blood based liquid fertiliser that is currently land spread, injected or dried and sold as a blood meal fertiliser. However, industry surveys suggest that blood is commonly rendered into a blood meal for retail as an organic nitrogenous fertiliser, a use which is second only to its use by the pet food industry (Dobbelaere 2017, EC 2005).

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[75] Blood meal is named in Annex I of Reg (EC) No 889/2008 (EC, 2008), (as amended), as an authorised fertiliser by article 3(1) for use in growing organic labelled products '*under Regulation (EC) No 2092/91 and carried over by Article 16(3)(c) of Regulation (EC) No 834/2007'*

[76] Proposals made to invest in facilities by one of the four major companies in England and Wales processing animal by-products indicates also that processed liquid blood is used for land injection as an agricultural fertiliser. The supporting technical summary for the IPPC permitting application documents a liquid fertiliser production line sterilising blood in a batch cooker (processing 6 tonnes per hour) in addition to blood meal production for feed.UK Environment Agency website Accessed June 2017.

4.2.3 Aquaculture feed

Blood meal and blood products are used for aquaculture feeds, but this is a comparatively small market compared to those of pet foods and fertiliser[77]

However, since the derogation of the EU ban on non-ruminant blood as a protein feed source for aquaculture in 2013, this market has been growing. A 2016 industry survey reports that blood meal use increased by 76% from the previous year to approximately 20,000 tonnes (Dobbelaere 2017). In addition, the survey suggests a further 10,000 tonnes (approx.) of blood products, most likely the cellular fraction for haemoglobin, were used for aquaculture feed in 2016[78].

4.2.4 Blood products as food ingredients

Blood has been traditionally used as a primary ingredient in blood sausages, puddings, and soups amongst other traditional foods. A relatively old publication suggests that up to 30% of *blood products* produced were used by the food industry (Gatnau et al 2001)[79]. A more detailed review of the current state of the art for blood collection, processing, and downstream purification and modification techniques to generate functional blood proteins for use in food applications has been presented by Lynch et al 2017. The authors suggest this is an underutilised resource, though indicate contemporary data on current use is unavailable.

Recent surveys by industry bodies suggest around a quarter of the blood that is processed supplies the food industry, but the total quantity of blood processed is relatively small (Figure 35). Markets for blood derived functional proteins appear to be emerging in Europe; technical food manufacturing applications for enhancing flavour, colour, protein content, consistency and binding of meat products are being marketed commercially[80].

4.2.5 Pharmaceutical uses

The therapeutic or nutraceutical potential for certain bioactive peptides from blood have been reported, but *in vivo* evidence for their actual bioavailability and clinical efficacy is less well established (Bah et al 2013).

Information on the extent to which bioactives from animal blood are being commercially processed in Europe for these uses is unclear. Key UK blood processors produce immunoglobin which is sold to pharmaceutical companies globally[81]. Public data to quantify the extent to which immunoglobin and other

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[77] An industry survey across 21 EU Member States (Dobbelaere 2017) suggests approx. 70% of the 2.7 million tonnes/year of processed animal protein from meat industry by-products is used in pet food and around 20% is used for producing organic fertilisers.

[78] In the UK key processers of blood from livestock produce haemoglobin for use in the aquaculture industry Pers comm. Jane Brindle, Group Technical Manager, Leo Group Limited.

[79] No source is provided by Gatnau et al, however, so the data on which this is predicated cannot be substantiated. Contact via e-mail with the joint author has been pursued with no response.

[80] e.g. https://www.sonac.biz/markets/food-ingredient-supplier/protein-in-meat-supplier/

[81] LGI Group, APC GB and SARIA partnership operation for collection and processing of animal blood through fractionation to produce immunoglobin which is sold to pharmaceutical companies around the world. SARIA UK website accessed July 2017.

bioactive components are extracted from abattoir blood across the EU for commercial purposes have not been found.

4.2.6 Plastics

A thermoplastic called *Novatein Thermoplastic Protein* has been developed from blood meal[82]. However, this does not yet appear to be manufactured at commercial scale and is not clear that this application meets the EU technology readiness level scope TRL 9 set out for this task.

4.2.7 Blood products: pig and poultry feed protein

Spray dried porcine plasma (SDPP) is used as a feed for weaning piglets, which typically substitutes whey protein used in cheaper milk replacer products. Antimicrobial, dietary, and related growth rate benefits have been reported when feeding plasma to weaning piglets which is purported to allow a reduction in synthetic antibiotics use (Pierce et al 2005; cited in Bah et al 2013). Though legal in the EU some member states have effectively placed a voluntary ban on SDPP use in feed due to concerns regarding the recent spread of Porcine Epidemic Diarrhoea that has been associated with contaminated plasma in pig feed[83]. For example, SDPP is banned by the UK's Red Tractor assurance scheme, which covers 90 percent of the nation's domestic pig supply.

4.2.8 Anaerobic digestion

Whilst anaerobic digestion (AD) plants that are approved to handle animal by-products should be listed by Member States[84], there are no details to determine the proportion, if any, that digest large volumes of blood from slaughterhouses. Third party AD gate fees may be a disincentive for abattoirs to dispose of blood, where it can be sold or taken by renderers at no or low cost. AD plants owned and operated by abattoirs as a dedicated abattoir facility exist that process blood exclusively with abattoir waste[85]. Blood may also be co-digested with other feedstocks (IEA 2003). There are limitations, however, on the use of blood in AD plants. Though research applying modifications of Buswell formula's etc indicates blood has a potentially high methane yield, in higher concentrations the relatively nitrogen rich blood can increase ammonia which can inhibit methane production (Hejnfelt and Angelidaki 2009, IEA 2009).

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[82] http://adurobiopolymers.com/Novatein. A theoretical production eco-profile has been published for Novatein

[83] http://www.thepigsite.com/swinenews/36027/uk-pig-industry-moves-to-red-alert-over-ped/ Website accessed July 2017

[84] According to the EU: *EU countries' competent authorities approve and register establishments that handle animal by-products and derived products. They also draw up and make public up-to-date lists of these establishments. Every national website should show the regrouping of ABP activities that require approval. The links to these websites are here:* https://ec.europa.eu/food/safety/animal-by-products/approved-establishments_en *(accessed July 2017)*

[85] An example of this can be found in Innkreuze, Austria.

4.3 Technical description of valorisation options modelled for abattoir blood

4.3.1 Blood meal as fertiliser

IPPC best practice reference notes for slaughterhouse operations documents 14% w/w overall yields for dried blood meal from raw blood with a final moisture content of 5% (EC 2005). There are different processes that can be used to produce blood meal using various methods of coagulation, concentration, drying technologies, and comminution. Here direct steam coagulation and modern disc drying technology is modelled from mass balance process estimates from industry. Yields of 18.5%, by weight, from original liquid infeed with a final moisture of 8-9% are assumed. The energy consumption and yields presented, (Figure 36,Table 24), are not based in monitoring data from operational site processes, but are mass balance estimates provided for current industry processing equipment by suppliers.

Collection

For fertiliser blood meal the collection process at the point of slaughter is likely to be a non-sterile open system, typically capturing blood in a long stainless-steel trough. Inevitably some fugitive and residual losses will occur. The proportion/efficiency of blood collected for blood meal fertiliser – i.e. how the actual volume captured compared to the total available from animals varies for the different sideflow product systems - is not known.

Continuous stirring of the collected blood requires electricity. This is to prevent fibrin forming which binds blood clots together. Blood cooling is required for further processing or fractionation into plasma for pet foods, but for the inventory model blood meal fertiliser is assumed to be coagulated before any spoilage can occur and so would not require any chilling or storage.

Coagulation

To reduce the drying energy burden, a proportion of the aqueous content can be physically separated from blood after it is coagulated by heat, although some soluble constituents may be lost during this process. Approximately 90 °C is reported to be the optimum temperature for coagulation. Commercial continuous 'blood coagulator' units inject steam directly[86]. The actual energy demand of steam injection will vary depending on blood properties and its initial feed temperature. Estimates received from industry sources vary. One source suggests 150kg directly injected steam per tonne of raw blood and another 170kg per tonne, with system steam pressures of 8 and 4 bar gauge, respectively[87]. The range in direct heat energy required for coagulation approximates to 300-350 MJ per tonne of blood processed. No infeed rate was supplied for assumptions on the higher energy demand estimate. The lower reported value assumes the blood infeed temperature

[86] Sources: http://mavitecrendering.com/rendering-equipment/processing-section/blood-coagulator/
https://www.haarslev.com/products/blood-coagulator/
accessed June 2017.

is 20°C. This would seem acceptable for fertiliser blood meal production since there is no need to preserve important blood fractions by chilling immediately. 20°C is assumed to be a realistic temperature for blood passively cooling to air temperature from a live animal body temperature.

Estimates of typical steam raising and system efficiencies adds a level of uncertainty in estimating the respective fuel requirements. Nevertheless, assuming steam raising and distribution efficiency of around 75%, the estimated equivalent demand for steam coagulation is assumed to be around 400 MJ fuel energy per tonne of raw blood. Physical decanting

The resulting coagulum is then either pressed or decanted by centrifuge to remove residual unbound moisture. Estimates from industry suggest 95% of the solids are recovered from decanting with the resulting coagulum centrate for drying containing around 55% moisture. Other older sources suggest this kind of process leaves the coagulum with around 60% moisture for the drying process[88]. 5% of solids lost in the liquid removed are assumed to end up as waste effluent in a treatment plant or land injected, with negligible fertiliser benefit.

Drying

Specific energy requirements for disc dryers depends on the degree of physical dewatering achieved from the coagulated blood. Here coagulation and separation are assumed to achieve a moisture of 55%, compared to the original of 80% moisture of raw blood.

Batch drying of blood may be associated with smaller processing volumes, whereas continuous processing systems are more likely to be used in larger throughput facilities. However, there are no data sources describing the size of blood rendering operations across Europe to characterise the typical scale of this side flow at site level. In addition, there are a variety of processing routes for drying blood meal such as spray drying or disc drying, continuous ring drying or rotary drum drying (Heuze and Tran 2016).

EU industry surveys report the use of a direct contact ring dryer in its blood meal processing description (EC 2005). However, a subsequent enquiry with an industry supplier[89] indicates that indirect disk dryers may now be more appropriate for the specialist application of drying viscous, blood coagulum. Disc drying also is proposed for blood meal production in a recent IPPC permit application by renderers in the UK. Therefore, the scenario here assumes a disc dryer is the contemporary technology chosen for drying blood.

Electrical energy is required for motorised parts for conveyance of congealed blood through the disc dryer and extraction of both final product, and vapour. The installed power of 15-20 kW is indicated for these processes by one industrial

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[88] Steve Baldwin, Haarslev UK Ltd. Personal communication Aug 2017, also T. Fernando, Protech Ltd, Grey literature source.

[89] Pullen, W.- APC Food OSI, GEA Process Engineering Ltd. Personal Communication July 2017.

supplier. Since the process flow relates to 1 tonne per hour infeed of raw blood the crude energy estimated per tonne of raw blood treated is 15-20 kWh.

Milling

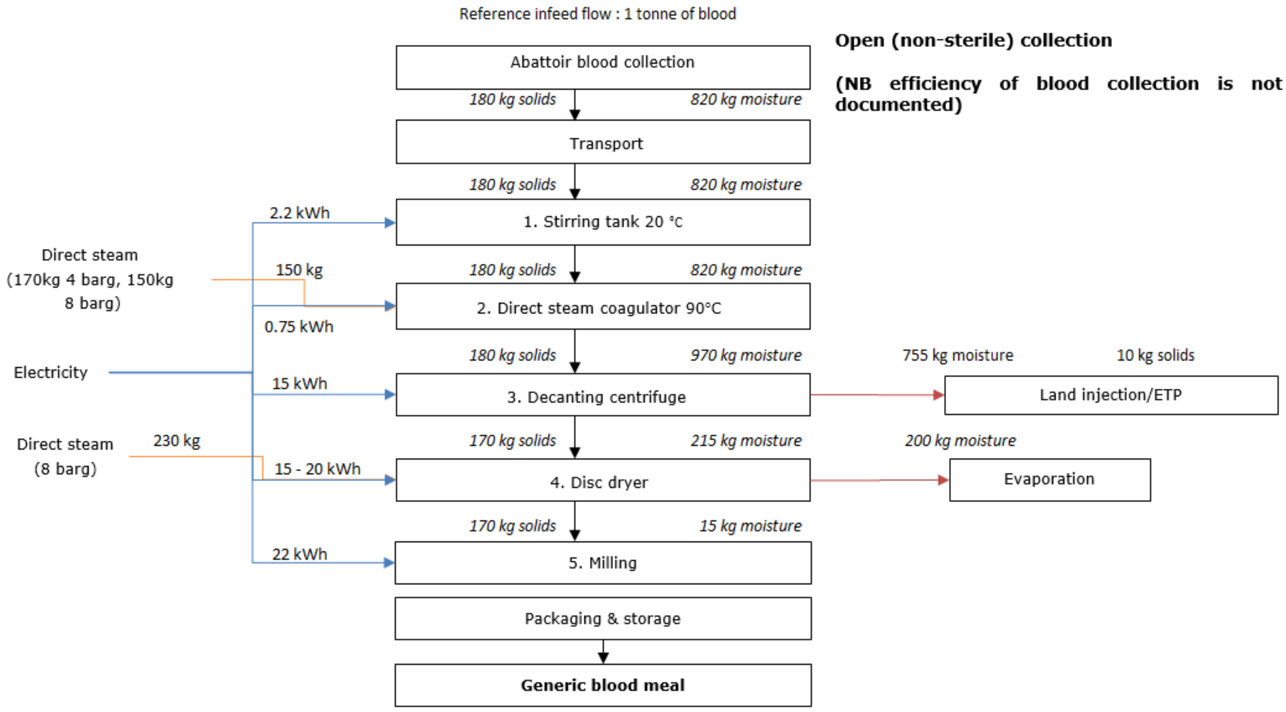
The milling process is largely comminution of flakes from the disc dryer into a homogenous meal for ease of handling (conveyance, packing and end use). Milling requires the majority of processing electricity demand. Typically, the meal is then blown into storage hoppers for packing into bulk bags which requires an additional, but relatively smaller, duty for fan motors which is included in the installed power estimate. Hammer milling machinery with capacity of 1-3 tonnes per hour for dried animal by-products may be driven by electrical motor sized >30kW (shaft power).

Uncertainties and limitations

The specific power data has been queried, being somewhat larger than expected for some of the processes scaled to 1 tonne throughputs. However, this was reconfirmed by the suppliers to represent installed energy reflecting a 1 tonne in line throughput. The quality of the electricity consumption data is therefore uncertain since this is based on only one supplier’s estimates and it has not been verified due to a lack of information from requests to other independent sources. The steam consumption data for coagulation has been checked against calculations and appears to be based on heat capacity of blood of 4 MJ/kg/C which is a reasonable assumption accounting for an approx. 10% heat loss. The steam consumption estimates for co-agulation (direct steam injection and consumption) by suppliers however, appears to be based on heat from indirect (latent) heat of steam. However the process heat, which is required for the inventory, is assumed to reflect the total heat demanded for coagulation. The background LCA data is fixed average heat supply and does not distinguish between different efficiencies for direct and indirect steam consumption, which is a limitation of the forklift model, when considering the impact of condensate recovery may have on net boiler efficiency.

Process flows related to sanitation operations have not been included in the model. It has been assumed for the purposes of the model that these are attributed to (and dominated by) the open processes of meat production/abattoir operations that are outside of the system boundary. Within the system boundary starting at blood stirring, the water supply, heating, and pumping energy demands dedicated to process sanitation have been considered negligible per tonne processed. The reasoning is that these are largely continuous and closed (steam based) processes for blood meal production. This may be an oversite but there are no data available to estimate this.

Figure 36 Indicative data for processing 1 tonne per hour of whole blood into dried blood meal



Open (non-sterile) collection

(NB efficiency of blood collection is not documented)

Nominal installed electrical power demand provided by plant manufacturer[90]

1. Agitator for stirring tank 2.2kw
2. Blood Coagulator 0.75kw
3. Decanter 15kw*
4. Dryer 15kw to 20kw
5. Milling with blowing fan 22kw

Comparable products

Blood meal nitrogen content is reported by retailers of commercial and domestic horticultural supplies at a range of 12-15%, sometimes with a minor contribution of elemental phosphorous (<1%). Storage to prevent spoilage requires moisture contents of 10% or less. 1kg of blood meal has equivalent of less than half of the 33 and 35% elemental nitrogen found in a typical synthetic ammonium nitrate fertiliser. In addition to this, the relative plant bioavailability of blood meal nitrogen may be considered. Typically, its function, as a nitrogen fertiliser available for

[90] Haarslev UK Ltd. Steve Baldwin, Personal communication Jul 2017. It is important to state that the 'installed electrical power' can only be an indicative reference and may not represent actual average power demand of motors, which can vary with load, sizing and reactive loads. However, these estimates, (even after subsequent confirmation Aug 2017 from Haarslev that these relate to the actual in-line process step throughputs provided of 1 tonne/hour), appear to *overestimate electrical energy consumption for decanter duty for the throughput rate so should be used with caution. Other sources most efficient indicates a nominal SEC of around 2-3kWh/tonne infeed for 25t/hr decanters at maximum capacity, dewatering decanters range of 0.7-1.2 kWh/m3 is an indicative reference in GEA literature for water/sewage applications.

plants, is assumed only for the initial growing season. Allowing for this Gutser et al 2005 approximate this to 60-80% of total nitrogen is bioavailable from blood, meat and bone based organic fertilisers compared to the mineral fertiliser equivalent (MFE). So 1kg of blood meal has been assumed to be comparable to the nitrogen available from 0.2-0.4 kg of ammonium nitrate in the year of application.

During use, differences in direct and indirect N_2O emissions related global warming impacts between blood meal and synthetic fertilisers have not been established. Basic IPCC tier 1 methods for N_2O emission estimates are related to total nitrogen applied so for the purposes of the model are not considered to differ between blood meal and mineral fertilisers on a total nitrogen basis[91]. Tier 2 or 3 type estimates modelled across a range of soils and conditions reflective of a ranger of European countries are not accessible for any derivation of average emissions in use

Table 24 Model inventory for processing 1 tonne of pigs' blood into bloodmeal (energy figures have been rounded)

INVENTORY				
Raw blood collection				
	Sanitation hot water use	-		*No process specific data, assumed negligible and use is attributed to dominant meat production processes.*
	Transport (rigid tanker)	200	tkm	*Assumption - varies depending on geographical context*
	Output			
	1 tonne to rendering plant			
Storage				
	electricity	2	kWh	*Continuously stirred tank to prevent coagulation*
Coagulation & decanting				
	Duty (steam) heat energy	150	kg	*Steam injected, based on manufacturers estimates*
	Heat losses	25	MJ	*Assumed 10%*
	Heat energy demand	300	MJ	
	Coagulation electricity	1	kWh	
	Centrifuge electricity	2[i]	kWh	
	Output			
	Coagulated dewatered blood	385	kg	
	Centrifugate effluent	765	kg	*Assumed ~6% solids and nearly 80 % moisture removed (land injected)*
Disc dryer				
	Electrical	<20	kWh	Motor duty
	Drying duty (steam) energy	470	MJ	
	Dryer Losses (assumed ~10%)	50	MJ	*(Could be more depending on time taken for falling rate drying period)*

[91] In Chapter 11 N_2O emissions from managed Soils, and CO_2 emissions from Lime and urea application, Volume 4: Agriculture, Forestry and Other Land Use, 2006 IPCC Guidelines for National Greenhouse Gas Inventories. . It is important to note that field studies on which EF1 has been based determined N_2O emission factors for applied N (not adjusted for volatilisation) when they were estimated. So the emission factor has been determined from fertiliser-induced N_2O–N emitted / total amount of N applied

INVENTORY		
System losses (assumed ~25%)	175	MJ
Total fuel energy demand	520	MJ
Output		
Dried flaked blood	185	kg
Milling		
Electricity	20	kWh
Output		
Dried powdered blood meal	185	kg

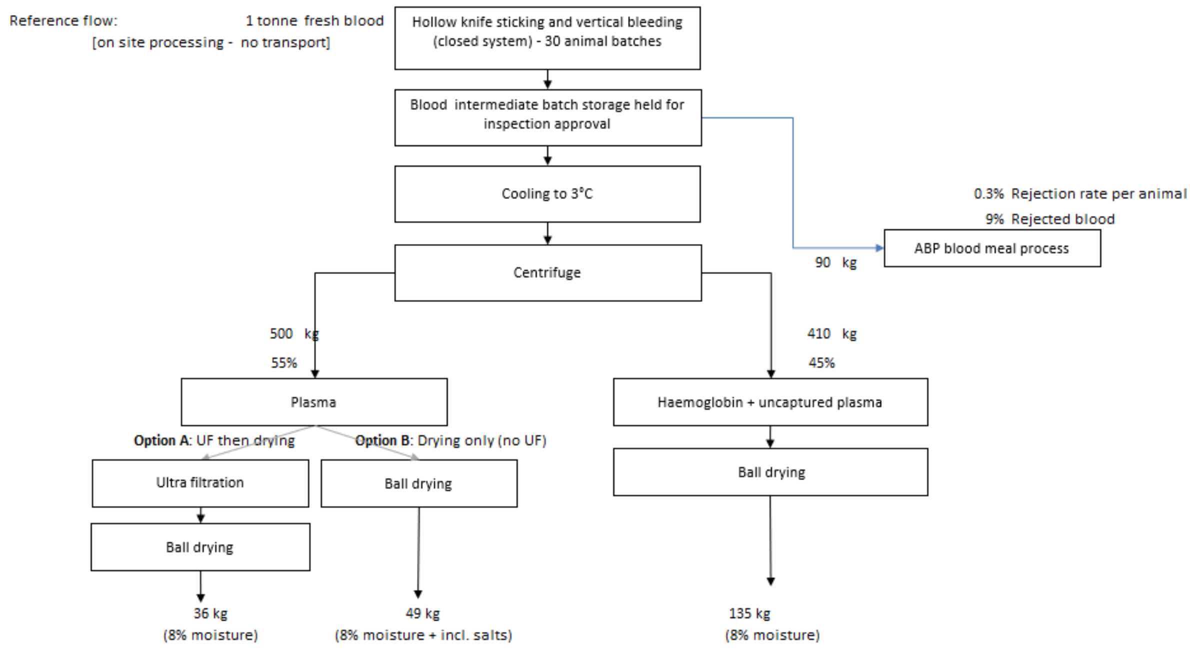
[i] Estimate received from machinery supplier give 15 kWh, other sources indicate a more conservative estimate of 1-2 kWh/m³ infeed, the conservative number has been used

4.3.2 Blood product: Food protein additive

In some large modern abattoirs in Europe blood is processed into fractions[92], which are used in food products either as a liquid, (which can be concentrated and frozen) or from a dried powder. There are various processes for fractionation of blood products to obtain various potential functional uses in food processing applications, (see Lynch et al 2017 for a contemporary review). Here the main production process that has been modelled is centrifugation, membrane concentration and ball drying for dried plasma protein powder. A further sideflow of this process the cellular fraction consisting mainly of haemoglobin.

[92] Danish Crown's Edidan plant in Denmark is an example.

Figure 37 Model process flow for 1 tonne fresh blood products (dried plasma and cells), sources: EC 2005, Marel 2017, Alfa-laval[96]



Blood collection systems

Specialist companies operating in Europe already supply engineering solutions for closed sterile blood collection for pig slaughtering lines. System capacities can be up to 1,000 pigs per hour with collecting efficiencies around 85% of blood available[93]. Hollow knife systems are used to collect batches of blood and 85° C water consumption for knife sterilisation is applied to prevent cross contamination. The hot water energy demand is estimated based on inventory water consumption provided by suppliers assuming 60% heat recovery (Table 25).

Rejection rates

Modular containment allows isolation and rejection of batches of blood taken where any animal is deemed unfit by routine post mortem veterinary inspection. Suppliers of commercial systems for this kind of blood collection system report through experience that rejection rates per animal range from 0.1% to 0.4%.

Any animal rejections would require all blood in the associated batch to be removed from the feed chain by either being consigned for disposal or further treatment for use subject to, and restricted by, animal by-product regulations. A sideflow of 1000 kg blood would require over 300 pigs to be slaughtered. For this quantity, assuming a conservative 0.3% rejection rate per animal, means approximately one animal fails inspection in just over 300, and therefore one batch, on average, will be

[93] Marel website accessed July 2017

rejected as unfit. Inventory data has been received relating to a system processing 30 pigs per batch[94]. This has been assumed for the blood processing model. Therefore, of 1000 kg of blood collected, one batch of 30 pigs blood collected is assumed to be rejected prior to processing. This approximates to 90 kg of the blood sideflow, leaving a gross yield of just over 900kg before processing. The rejected blood will be processed according to animal by-product regulations and rendered appropriately. The blood meal scenario outlined in 2.3.1 is assumed for processing the rejected blood.

Cooling loads

Once collected, whole blood is held for a short period in intermediate storage whilst pending veterinary approval. Once approved, it is immediately cooled to 3°C. Processing is assumed to be at the abattoir site with no additional refrigerated transport to other processing sites. Estimates for electricity demand of glycol chillers were reported for blood processing on a per animal basis[94] and is based on processing a batch size of 30 animals. This equates to roughly 0.06 kWh per litre of blood processed. GHG emissions from fugitive refrigerant leakage has been excluded. This is assumed to be negligible for modern systems.

Centrifugation

Plasma is separated from the cellular fraction of blood by centrifuge technology that is well developed and used primarily in the dairy processing industry. Plasma typically constitutes 55–65% of porcine blood by weight. For the model, based on industry guidance, a separation efficiency is assumed to capture 55% of the blood weight as plasma.

Concentration - ultrafiltration

Previously, older falling film technology was employed, which doesn't remove residual solids and salts (around 2 % w/w of blood). Now larger modern abattoirs can employ ultrafiltration (UF) for concentrating the fractionated plasma protein content prior to drying. This option may only be economic at larger processing plants. Typically, from a starting protein content of 7 % (around 9% total solids) applicatons can more than halve the water content and concentrate the plasma protein before drying[95]. The electricity consumption for UF here has been based on a system designed to process 3,500 litres blood plasma per hour concentrating to 30% plasma protein (for installation at a bovine blood processing plant) with a reported 40kW nominal installed capacity[96]. Data for a range of processing

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[94] Literature received from René Poulsen, Butina A/S, Personal Communication June 2017.

[95] For example Danish Crown's Edidan plant in Denmark uses two stages Spiral and Plate & Frame membrane ultrafiltration to dewater plasma from 7% to 14% and even 18% before a drying stage.

[96] Based on an industry specified system, Personal Communication John Forrester Alfa Laval, August 2017.

capacities could not be obtained, therefore scaling from the specific energy consumption per litre infeed or kg outfeed is a limitation.

Drying

Operating at lower temperatures than some alternative drying processes ball drying is considered to preserve a higher proportion of functional proteins (lysine). It is also purported to be around 30% more energy efficient alternative to spray drying by commercial suppliers of this technology (Marel 2017). The ball dryer capacity depends on the concentration of animal blood plasma but commercial suppliers indicate a range of 240-500 litres of evaporated water per hour requiring between 1.4 and 1.6 kg of steam per litre (Marel 2017). Similar assumptions are made for drying duty in the model for the separated cellular fraction, consisting mainly of haemoglobin.

For plasma assumed to have been concentrated by membrane filtration the delivered energy demands for drying approximate to around 8 to 10 MJ of supplied fuel energy (LHV) per kg plasma protein (92% dm), or 45 to 55 MJ per kg plasma (92% dm) that does not undergo any concentration process before drying. A 75% system efficiency has been assumed for steam supplied for indicative fuel energy estimates.

Table 25 Model inventory for processing 1 tonne of pigs' blood into plasma protein and haemoglobin

	INVENTORY			Description	*Source*
Blood collection & separation				*[Inventory based on 30 pigs processed per batch]*	*Butina A/S*
Input	Sodium citrate	81	kg	*Anti-coagulant, used at a rate of 8.5 g per litre blood*	*Butina A/S*
	Cold water	3,460	kg	Sanitation (excluded, assumed negligible)	*Butina A/S*
	Warm water 55 °C	127	kg	Sanitation	*Butina A/S*
	Hot water (85 °C)	698	kg	Hollow knife sterilisation	*Butina A/S*
	Compressed air 7 bar	95	Nm^3		*Butina A/S*
	Water heating MJ	145	MJ	Assuming 60% heat recovery	Estimated
	Refrigeration	50	kWh	*Electricity (chiller load estimate for cooling from supplier)*	*Butina A/S*
	Centrifuge electricity	<1	kWh	*Based on Alfa Laval product data (16 kW and 25m³/hr max capacity Clara 250)*	*Alfa Laval*
Output	Blood plasma	500	kg		
	Blood cells	410	kg		
	Rejected blood	90	kg	*Based on 0.3% animal rejection rate (see text).*	
Haemoglobin drying					
Input	Fuel energy	772 MJ	to 930 MJ		
	Dryer electricity	22	kWh	Approximated from quotient of nominal installed power and specific maximum evaporation 500 litres/hr	

	INVENTORY			Description	*Source*
Output	Dried haemoglobin	135	kg	8% moisture	
Plasma concentration (Option A)					
	Electricity	6	kWh	*Ultra-filtration (Spiral and plate scaled from a larger blood plasma processing unit (3.5 m³/hr)*	*Alfa Laval*
Output	Concentrated blood plasma	112	kg	*From 6.7% solids to 30% food grade plasma protein solids*	*Alfa Laval*
	Permeate (removed)	388	kg	*Water with residual solids and salts*	*Alfa Laval*
Plasma drying after concentration and salts removal (Option A)					
Input	Fuel energy	210 MJ	to 255 MJ	*Ball dryer* (using indirect steam, 75% fuel energy converted to steam)	*Butina A/S*
	Dryer electricity	6	kWh	Approximated as quotient of nominal installed power and max evaporation 500 litres/ hr	*Butina A/S*
Output	Dry plasma protein	34	kg	Dry protein basis only	
	Product plasma dried	36	kg	*Dried to moisture content of 8% - food grade assumes solids and salts removal by UF*	
Plasma drying without concentration (Option B)					
Input	Fuel energy	1,260 MJ	to 1515MJ	*Ball dryer* (using indirect steam, 75% fuel energy converted to steam)	*Butina A/S*
	Dryer electricity	6	kWh	Approximated as quotient of nominal installed power and max evaporation 500 litres/ hr	*Butina A/S*
Output	Dried plasma with salts	49	kg	8% moisture	
Products					
(**Option A**)	Dry UF plasma protein	36	kg	With UF step - dry protein basis only, salts removed. 8% moisture	
(**Option B**)	Dried plasma with salts	49	kg	No UF step – solids/salts retained and 8% moisture. 8% moisture	

Comparable products

Industry sources claim that blood plasma can replace a certain proportion of meat in force meat products (sausages, salami, cooked meat products etc) on a 100% weight basis, though given plasma's water binding capacity, this results in a slightly reduced protein content. For its use in food products mineral salts and other solids are assumed to be removed by the UF stage. So 1kg dried plasma previously concentrated by ultrafiltration and dried to 7-8% moisture is just over 7% by weight, of its raw liquid form[97]. On a protein equivalent basis 3kg of liquid plasma

[97] Though this will vary, industry sources indicate separated porcine plasma is 6.7% by weight is plasma protein alone, with 8% moisture its 7.3% of the original liquid mass. 2.4% are mineral salts and solids, with water making up the remaining 90.9% (Literature received from René Poulsen, Butina A/S, Personal Communication June 2017.)

in its raw proportion (approx. 7% plasma protein) is reportedly able to replace 1kg of meat and 2 kg of water in forcemeat products[97]. So 1kg meat equates to 0.22 kg dried plasma (8% moisture). Therefore 1 kg of dried plasma protein (8% moisture) is considered roughly comparable (substitutable) to approx. 4.6 kg of meat cuts that are used in force products such as sausages or salami etc. Product system GHG credits for substitution for meat production are proposed on this basis in the model.

The plasma dried without pre-concentration retains salts and solids, so this may need further refining or may be used in lower concentrations in certain animal feed formulations. It may be comparable to whey or fishmeal in some animal feed applications.

The primary constituent of the blood's cellular fraction, the retentate from the plasma centrifugation process, is haemoglobin. This co-product is assumed to be dried as powder in the same way as plasma and can be used as a natural ingredient to enhance flavour and colour in meat products or used in aquaculture feed formulations as a constituent protein source. In this context we are looking at blood products as food ingredients and thus the feed options has not been considered.

4.3.1 Anaerobic digestion of blood with energy recovery

Energy recovery from pigs' blood was modelled in accordance with the model used for all side flows in the spreadsheet tools (Östergren et al, 2018). The effect of co-digestion with other substrates is not considered and thus the value should be considered as conservative. This valorisation route leads to three specific utilities: electricity, heat and digestate (used as fertiliser). Table 26 and Table 27 provides an overview of the inventory used for pigs' blood in the model. For comparison (not used in the model) Figure 38 and Table 28 provides estimates for co-digestion of blood with other side flows from a slaughter house (Ortner, 2015).

Table 26 Biogas potential pigs blood, per tonne Fresh Matter (FM) with a Dry Matter content of 20%

Side-flows	Theoretical biogas yield in m3/t FM	Theoretical CH4 content in %	LHV in MJ/ MJ/t FM
Blood fresh	62,00	72.00	25,80

Table 27 Emissions and energy recovery Fresh blood, per tonne Fresh Matter (FM) with a Dry Matter content of 20%

Emissions AD kg $CO_{2\ eq}$/ t FM input	Net Electricity KWh/t FM input	Net Thermal energy KWh/t FM input	Digestate t FM/t FM input	Credit for digestate application kg $CO_{2\ eq}$/ t FM input
34,16	145	50	934	-3,18

Comparable products

The selected comparison products used in the model are:

- Electricity (country specific) and EU average heat production
- Electricity and EU average heat production
- Electricity and EU average heat production and production and application of mineral fertiliser (the digestate from the AD is spread on land, providing nitrogen, phosphorous and potassium to the soil)
- Hydropower electricity and wood chips

Figure 38 Anaerobic digestion of slaughterhouse wastes, including blood, normalising inputs to a flow of 1 tonne of blood infeed[98]

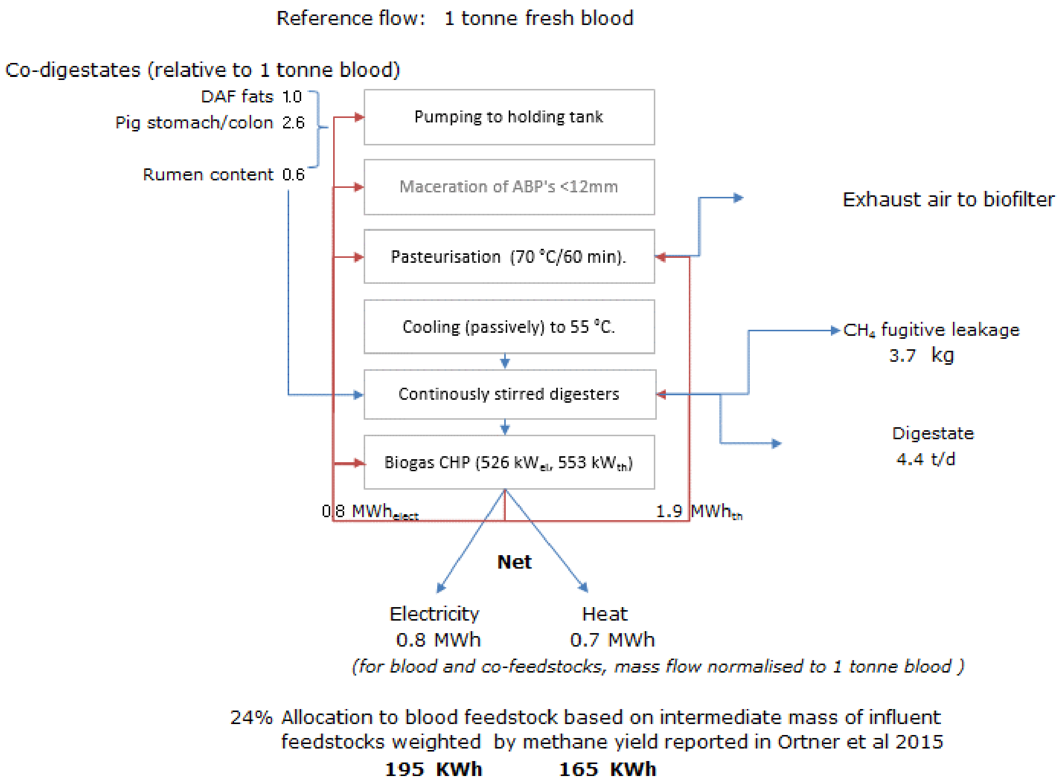


Table 28 Attributing energy yields to blood based on CH_4 yield potential and proportion of feedstock reported in Ortner et al (2015)

input flows	t	%VS	t_{VS}	$Nm3_{CH4}/t_{VS}$	Nm^3CH_4	Allocation
Blood	**1**	**20%**	**0.20**	**460**	**92**	**24%**
Pig stomach colon	2.6	15%	0.38	555	210	55%
Grease trap	1.0	11%	0.11	465	49	13%

[98] The yields and proportions of the other co-digested materials are based on those reported by Ortner et al 2015 regarding an existing AD plant processing slaughterhouse wastes.

Rumen content	0.6	13%	0.08	350	28	7%

4.3.2 Waste water treatment and of life

Waste water treatment from abattoir (blood) without energy recovery has been considered only as a reference point for a Refresh Situation 4. It should be noted that in EU the handling of animal by products is strictly regulated by the Animal By-Products Regulation (Regulation No 1069/2009)

4.4 Description of the FORKLIFT spreadsheet model for abattoir blood

4.4.1 Generic information

The model calculates the GHG emissions and costs associated with the handling of 1 tonne of blood (dry matter content of 20%).

An average value of production of feed and rearing of animals has been assumed as 5.8 kg CO_2eq/ kg carcass weight (Cederberg & Flysjö 2004)

The upstream burden attributed to the valorised product is calculated through economic allocation according to the REFRESH report D5.4 Simplified LCA & LCC of food waste valorisation (Östergren et al 2018).

The low monetary value of sideflows allocates a small fraction of the upstream burden which, generally, contributes a small impact to the valorisation process. When the upstream burden increases the accuracy of the model will decreases, since upstream processing, such as abattoir processes and site services, have been excluded from inventories in FORKLIFT. *For animal-based products the upstream burden may be very significant*

Critical parameters were qualitatively assessed using the model developed previously in D5.4 Simplified LCA & LCC of food waste valorisation (Figure 39). Description of standardised models (Östergren et al 2018). Note that the matrix in some cases also includes parameters that cannot be changed (Annex 11) as an information to the user. The reason for keeping them constant is that they are generic numbers used in several models to allow comparison between different side flows. The assessment is based on the relative impact of a parameter compared to the total impact of the valorisation process.

An overview of the spreadsheet tool and options included in the model is provided in Figure 40 and in the next section the sub- models are described. The full inventories are provided in Annex 11 as supplementary information

Figure 39 Assessment of critical parameters

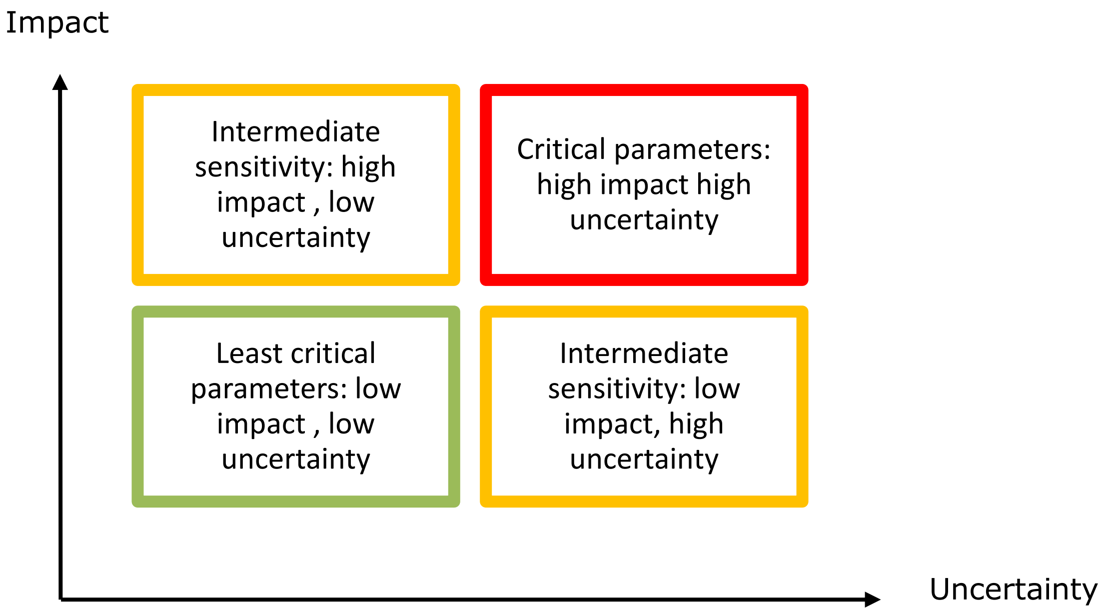
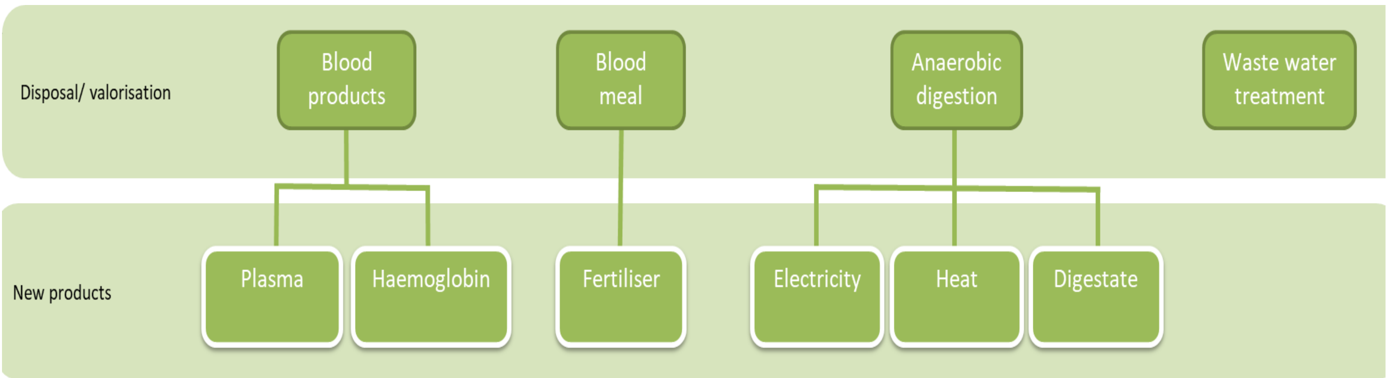


Figure 40 Overview of the spreadsheet model for abattoir by-products



4.4.2 Blood meal as fertiliser

Figure 41 The blood meal as fertiliser option in FORKLIFT

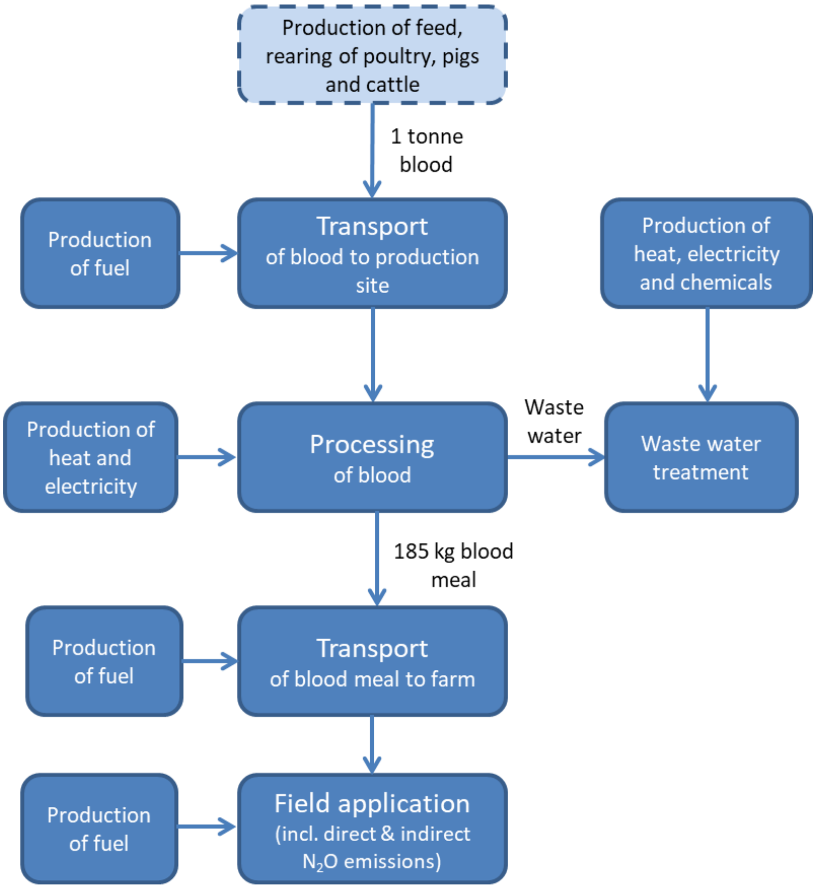


Figure 41 illustrates the processes that are considered in the calculation of GHG emissions and costs for making blood meal and applying it to the field as an organic nitrogenous fertiliser. Parameters used in the default Forklift model are provided in Table 29 and the assessment of critical parameters are provided in Figure 42. The GHGs and cost from the upstream processes (dotted line) are included if the blood provides a revenue to the abattoir. It should be noted that

The blood is collected and sent to a processing plant by truck. There, the blood is stirred, coagulated, decanted, dried and milled, then transported by truck to the farm. Electricity consumption for the decanter centrifuge are based on conservative the conservative value provided in Table 24.

The blood meal is spread by tractor onto the field. The climate impact of direct and indirect emissions of nitrous oxide (N_2O) is considered in the calculations.

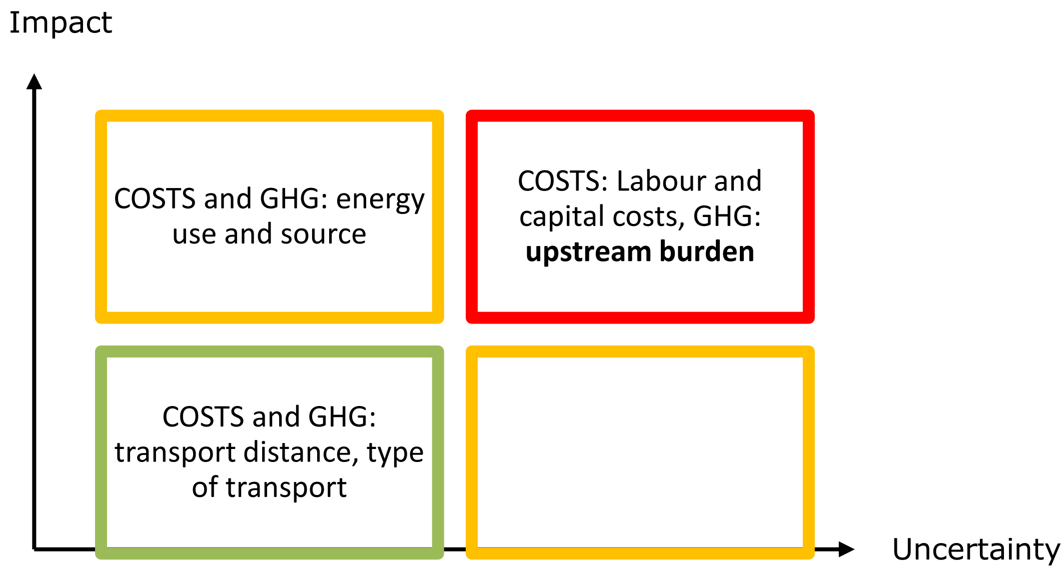
Regarding the use of truck and tractor, the GHG calculation covers the emissions of producing the fuel and combustion in the truck. The cost inventory takes into account the price of fuels only.

In this valorisation option, 185 kg of blood meal is the product, containing 25 kg of nitrogen (the mid-interval of the 12-15% w/w estimate for total nitrogen). Other examples of fertilisers are dried poultry manure and mineral fertiliser. Therefore, GHGs and cost of production and application of 463 kg poultry manure and 73 kg ammonium nitrate corresponding to 25 kg nitrogen are also provided as a comparison. For simplicity the lower bioavailability of nitrogen from organic fertilisers has not been factored into the Forklift model.

Table 29 Adjustable model parameters for blood meal as fertiliser.

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transport to blood meal production (Rigid truck, 20-26 t, Euro 4, 50% LF, cooling)	200	km	A list of transport options is provided, distances can be set freely.
Transport of blood meal to farm (tractor single trailer 50% Load Fraction (LF))	20	km	See above
Electricity use in processing	45	kWh/tonne blood	Lower estimate due to a more conservative power demand for the decanter centrifuge (2kWh/tonne infeed) is used based on alternative sources.
Heat used in processing	228	kWh/tonne blood	
Fuel for heat generation	Light fuel oil		A pre-selection of fuels is provided (biogas, natural gas, hard coal, wood chips from forest, EU-average heat)
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 42 Assessment of critical parameters for blood meal



4.4.3 Plasma and haemoglobin food ingredient

Figure 43 illustrates the processes that are considered in the calculation of GHG emissions and costs for making plasma and haemoglobin of the blood. The GHGs and cost from the upstream processes (dotted line) are included if the blood provides a revenue to the abattoir.

Parameters used in the default Forklift model are provided in

and the assessment of critical parameters are provided in Figure 44

The default parameters in the model are based upon the assumptions that the plasma is partly desalted and concentrated before drying according. Internal losses for heat generation (e.g the steam efficiency) has not been included since it is site and situation specific)

In the default scenario, the blood is assumed to transported to the processing unit by chilled transport.

Before further processing, the FORKLIFT model assumes losses based on typical rejection rates due to animals failing health inspections (see details in the technical description). This is factored into the model yield according to Figure 43. The blood is separated into plasma and haemoglobin and the fractions are dried. The rejected blood is assumed to be further processed into blood meal and used as fertiliser, i.e. spread onto fields.

Regarding the use of fuel for transports, electricity and heat, the GHG calculation covers the emissions from fuel and heat production and also combustion in the truck, as well as emissions from production of heat and energy used in the process. The cost takes into account a reference price for electricity, and fuel for transport and heat.

In this valorisation, 36 kg plasma, 135 kg haemoglobin and 17 kg blood meal are produced. No comparable product has been identified for the haemoglobin, but the plasma can substitute meat in forced meat products like sausages. 1 kg of dried plasma is assumed to be equivalent to 4.6 kg meat based on its protein content. It should be noted that under the conditions that no comparable products can be identified it implies that the net GHG emissions and costs in the wider perspective will increase with production volume for this application as long as the product will not take any other products place on the market. However this perspective is beyond the scope of the approach applied here, and is more related to consequential approaches outlined in other REFRESH reports (see Davies et al 2016).

Figure 43 The food ingredient (plasma and haemoglobin) option in FORKLIFT

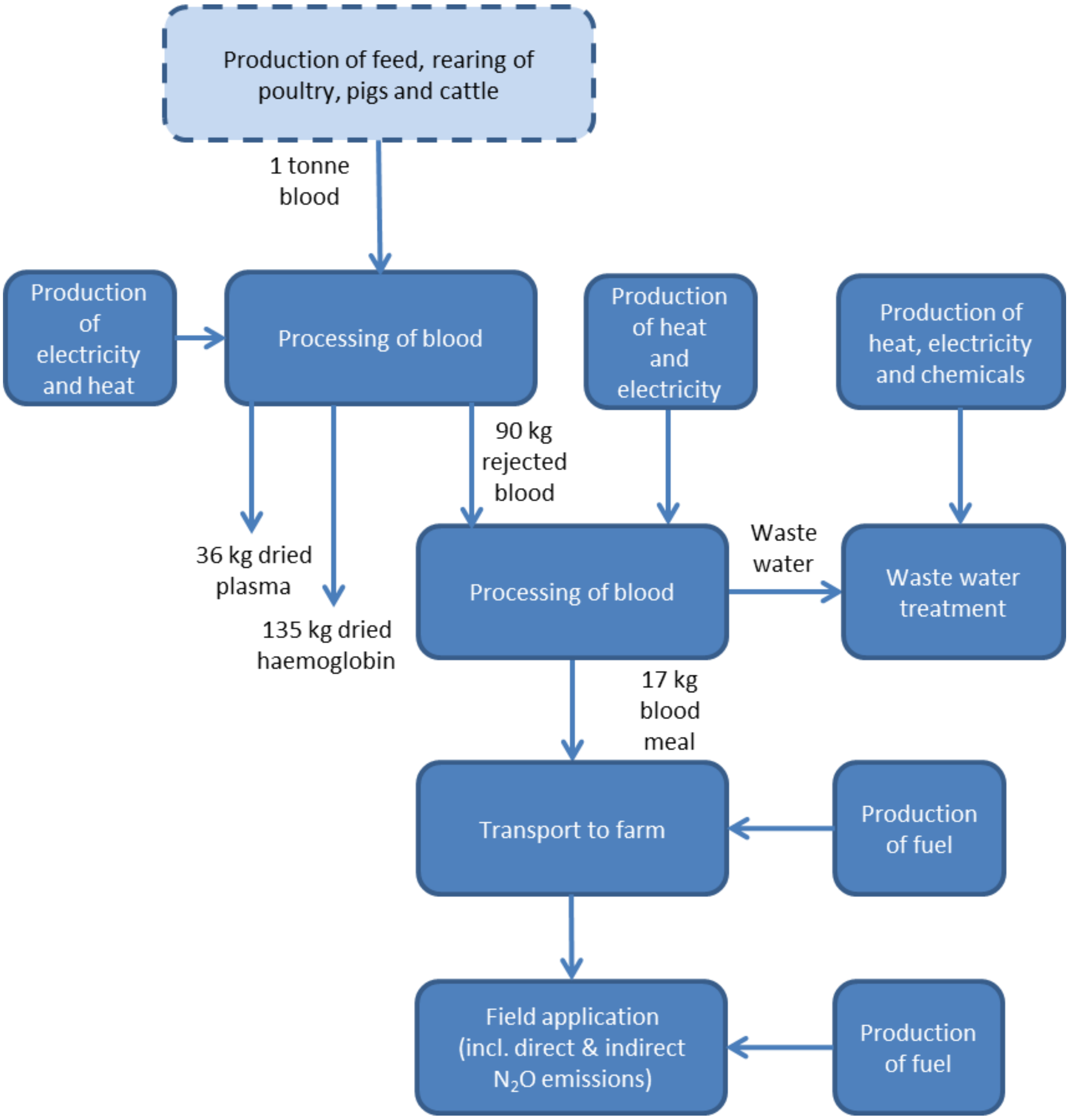
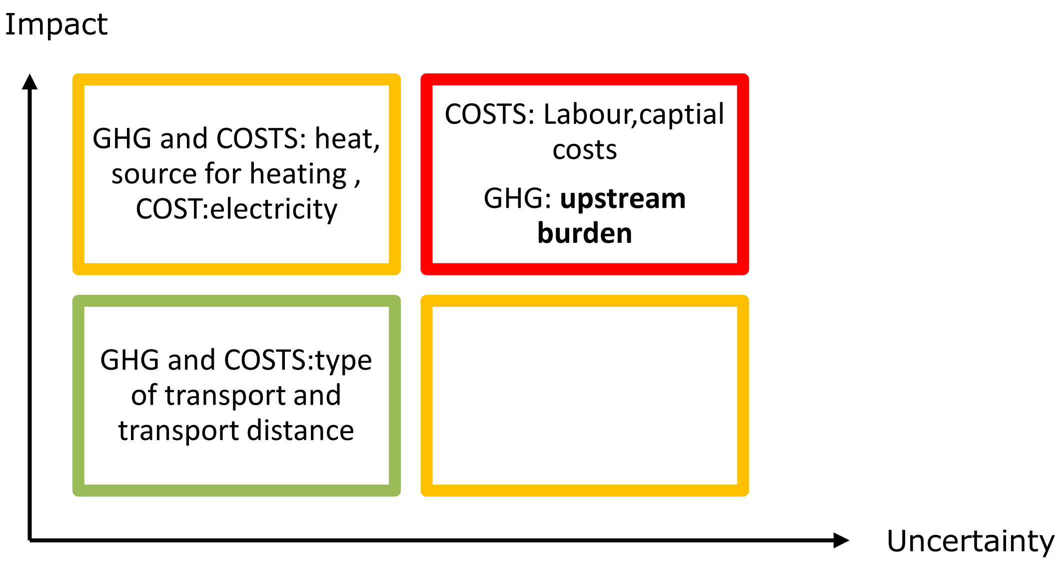


Table 30 Adjustable model parameters for food ingredient (plasma and haemoglobin) using 1 tonne of abattoir blood

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transports of blood to processing plant (Rigid truck, 20-26 t, Euro 4, 50% LF, cooling)	200	km	Selected transport options are provided, distances can be set freely.
Transport of blood meal to farm (rejected blood)	20	km	See above
Electricity use for processing	84	kWh/tonne blood	
Heat use for processing	341	kWh/tonne blood	This includes drying of haemoglobin in addition to hot water for knife sterilisation and also plasma drying energy
Fuel used for generating heat	Light fuel oil		Selected fuels are provided (biogas, natural gas, hard coal, wood chips from forest, EU-average heat)
Electricity use for processing of rejected blood (17kg)	4	kWh/tonne blood	
Heat use for processing rejected blood (17 kg)	20	kWh/tonne blood	
Fuel used for generating heat	Light fuel oil		See above
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 44 Assessment of critical parameters for food ingredients (plasma and haemoglobin)



4.4.4 Energy recovery using anaerobic digestion (AD)

The calculations are based on the streamlined approaches recommended in the REFRESH report "D5.4 Simplified LCA & LCC of food waste valorisation" (Östergren et all 2018).

Figure 45 illustrates the processes that are considered in the calculation of GHG emissions and costs for using the blood to produce biogas. The GHGs and cost from the upstream processes are included (dotted line) where the blood returns a direct revenue to the processor.

Parameters used in the default Forklift model are provided in Table 31 and the assessment of critical parameters are provided in Figure 46.
The blood is transported to the AD plant by truck.

Regarding the use of fuel, the GHG calculation covers the emissions of producing the fuel and combustion in the truck, as well as fugitive biogas emissions from the storage, biogas engine (slip) generating heat and electricity. The cost takes into account the price of fuel for transport.

In this valorisation option, 145 kWh electricity and 50 kWh of heat are the products. The results are compared with:

- Electricity (average for selected country in the model) combined with EU average Heat
- Hydropower and wood chips heat
- Electricity and heat EU average heat
- Electricity and heat EU average including production and application of mineral fertiliser since the digestate from the AD commonly is spread on

land, and therefore provides nitrogen, phosphorous and potassium to the soil.

Figure 45 Energy recovery from abattoir blood

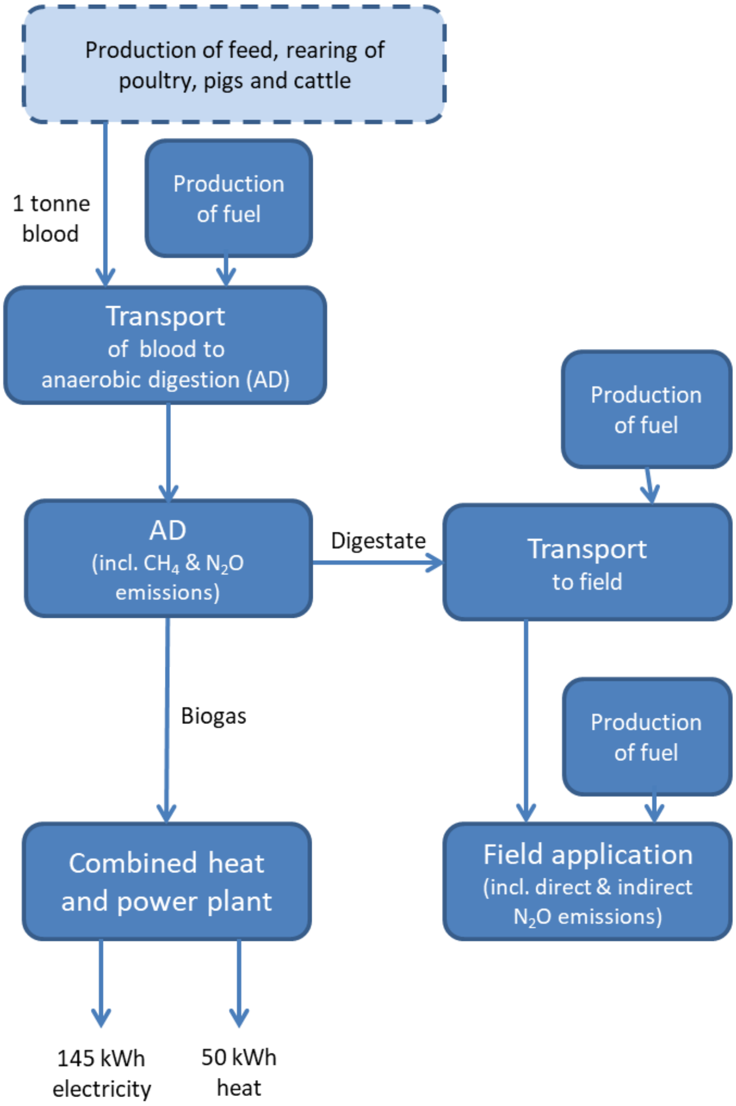
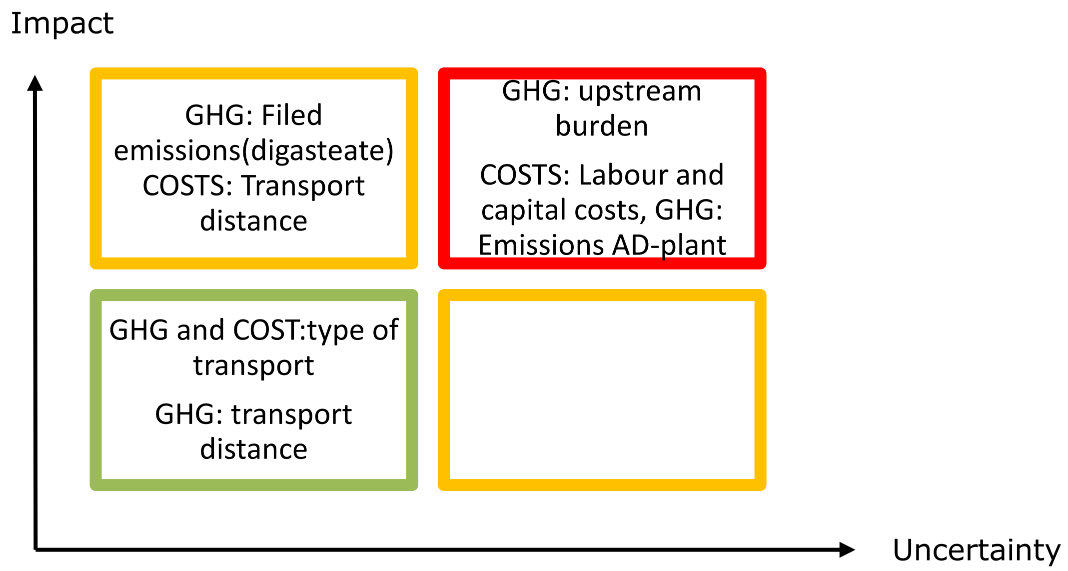


Table 31 Adjustable model parameters for biogas and energy production (AD) from 1 tonne of blood

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transports of digestate to the filed (tractor single trailer 50% Load Fraction (LF))	20	km	A pre-selection of transport options is provided, distances can be set freely.
Transports of blood to AD plant (tractor single trailer 50% Load Fraction (LF))	20	km	A pre-selection of transport options is provided, distances can be set freely.
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 46 Assessment of critical parameters for biogas and energy production (AD) ingredient (plasma and haemoglobin)



4.4.5 Waste water treatment

Figure 47 illustrates the processes that are considered in the calculation of GHG emissions and costs of wastewater treatment of abattoir blood. The system starts with the blood being discharged to a waste water treatment facility. In this scenario it is assumed that the blood carries no economic value, and therefore the side flow does not carry any environmental impact or cost from the upstream processes (production of feed, animal rearing and transport of animals to the slaughterhouse).

In this valorisation option, no product is produced, and hence no comparison products are shown in the result figures.

Parameters used in the default Forklift model are provided in Table 32 and the assessment of critical parameters are provided in

Figure 47 Waste water treatment of blood.

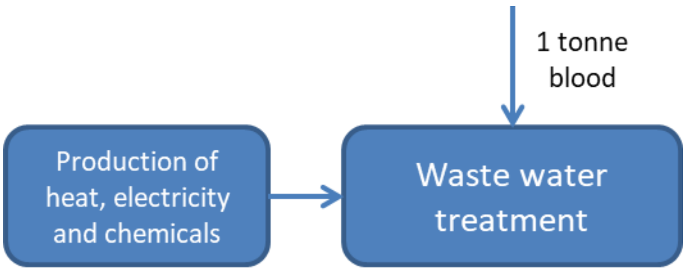
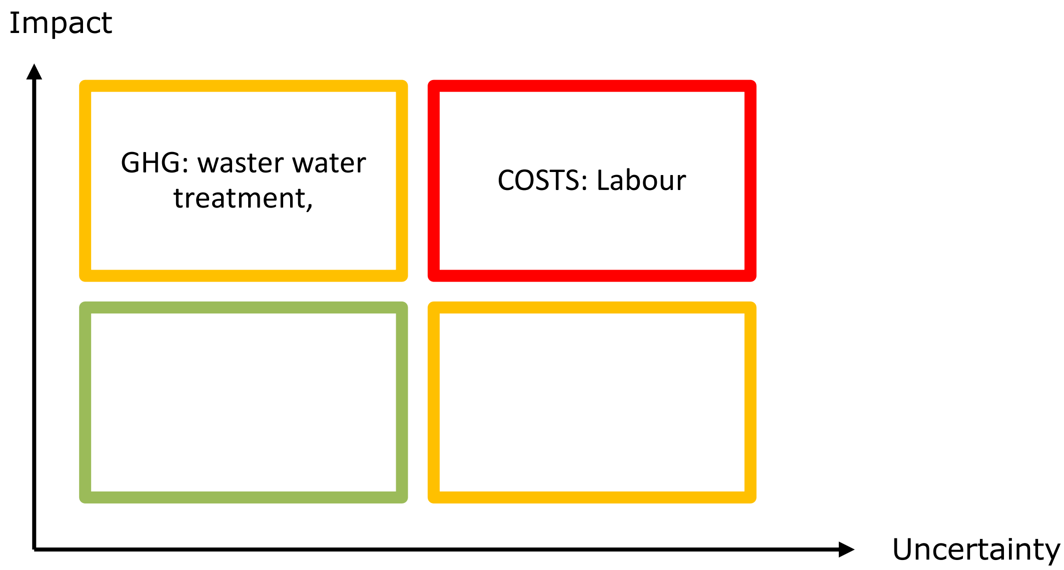


Table 32 Adjustable model parameters for waste water treatment from 1 tonne of fresh blood at site

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Labour and capital costs	0	EURO	Set by the user

Figure 48 Assessment of critical parameters for waste water treatment without energy recovery



5 Annex 5 Whey permeate spreadsheet model

List of abbreviations

ABP	Animal by-product
EWPA	European Whey Processers Association
IMF	Infant milk formula
ME	Metabolisable energy (animal feed)
MSNF	Milk solids, non-fat
PHE	Plate heat exchanger
RO	Reverse osmosis
TMR's	Total mixed rations (animal feed)
TVC	Thermal vapour compression
UF	Ultrafiltration
WPC	Whey protein concentrate
WPI	Whey protein isolate
WPP	Whey permeate powder

5.1 Background

5.1.1 Rationale

As a by-product of cheese production, sweet whey and its derivatives have been identified as one of twenty food chain side flows considered suitable for valorisation by Refresh deliverable 6.9 (Moates et al 2016).

Although, in the past, whole cheese whey may have been largely considered a by-product of limited value, key markets for concentrated and dried whey protein powder have emerged in the last ten years. Whey is now recognised as a valuable raw commodity alongside major dairy products such as milk, cheese, and butter (EC 2016) and its processors are equally represented in EU dairy sector trade organisations[99].

In a recent report for the European Commission on agricultural commodities an assumption has been made that all raw whey is being collected across the EU for further use (EC 2016). In the UK also, <3% of raw whey has been estimated to become waste (AHDB 2017).

Cheese whey makes up about 85% of the total whey[99] in the EU. Other sources of whey are by-products of caseinate production or acid whey from certain types of yoghurt products. Casein whey may be sweet ('rennet' casein, from enzymatic process), or an acid whey using mineral or lactic acids to separate casein. This typically uses skimmed milk as the feedstock (Tetrapak 2017). As a driving product, caseinates are not produced exclusively for food products, so are excluded from the scope here.

An increase in acid whey has also been reported due to the rise in demand for Greek style yoghurts, (mainly in the US), and there are current EU funded projects[100] and industry solutions[101] focussed on acid whey valorisation. However, though the trend for yogurt related acid whey production may have increased awareness and concern for this sideflow in the US, it is not considered to be as significant a sideflow as cheese sweet whey in the EU[102].

The major markets for whey are the manufacturing of whole whey powder (WWP) or various whey protein concentrates (WPC's). The highest protein concentrates achieved (>92% dm) are marketed as whey protein isolates (WPI). These products are used for specialist animal feeds (milk replacers), food, confectionary and drink ingredients alongside a growing market for lifestyle/sport protein supplements.

[99] For example European Whey Processors Association reports within the European Diary Association Economic Report 2017

[100] http://lifeforacidwhey.arhel.si/en

[101] Arla foods have published R&D findings for processing acid whey into new food products using their ingredients

[102] Personal communication Lee Hartley, Head of R&D, Volac International Ltd.

5.1.2 Scope

Concentrated whey protein products are still dependent on cheese production as the main driving product and are seen to remain so in future projections for food commodities (EC 2016). However, from the previous sections we can see that processing whey from medium to large cheese producers in Europe into further derivatives can be considered normal industrial practice with cheese producers receiving revenue from selling whey to processors[103]. Therefore, WWP and WPC's are not wholly consistent with the REFRESH definition of a sideflow indicated by *the less the better, (Davis et al 2017)* given their revenue value to cheese processors[104]*.*

Therefore, the liquid whey fraction, specifically after whey proteins have been recovered by filtration, has been chosen as an appropriate focus for valorisation. This is called whey permeate, (also referred to as deproteinated whey). Whey permeate is also distinguished from milk permeate[105], and since the latter has not been selected as a top 20 sideflow in the previous refresh report (Moates et al 2016) it is not considered here.Whey permeate contains solids consisting mostly of the milk sugar, lactose, but may also contain residual protein, fats, minerals, and salts depending on the WPC filtration process applied.

5.1.3 Information on potential and actual quantities

The EWPA have estimated total potential cheese whey solids availability of 4 million tonnes per year in 2016, (EWPA 2017) equating to 65 million tonnes of raw cheese whey, assuming 6% typical solids average. EU sources indicates around 50 million tonnes of raw liquid whey (Figure 49) is manufactured into whey products across the EU in 2015[106]. Whether the discrepancy of 15 million tonnes, indicate raw whey is not captured for manufacturing, or whether assumptions used to make these estimates are less accurate is uncertain[107]. The EU figure broadly aligns with a reporting of generic *whey powder* production, of 2 million tonnes solids per year[108].

However, since the fraction of lactose and proteins is not given in these figures, estimating a mass balance of potential EU production of whey permeate sideflow, has not been possible. This will require detailed production data on particular driving products, and processing methods for whey protein concentrates, to estimate permeate yields. This commercial data is not freely published or accessible. The only other published data relating to whey processing in the EU is lactose production of approximately 500,000 tonnes[108]. Estimating surplus

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[103] Personal communication Lee Hartley, Head of R&D, Volac International Ltd.

[104] For example whey products contributions to UK cheese processors income has grown from 10% to 15% AHDB website Accessed November 2017.

[105] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016R0534

[106] A production figure of 2 million tonnes of whey powder is reported, which is 4% by mass of the EU estimate of 49.7 tonnes of liquid whey. This is 2/3rds of the 6% total solids content assumed typical for raw whey (4.5% lactose, 0.5% protein, non-protein nitrogen 0.5% with minerals and ash making up the rest, Tetra Pak 2017) but some allowance may be given for partial removal of mineral and lactose fractions in this figure.

[107] Requested details of these estimates were unavailable so it is unclear what assumptions have been made.

[108] Production figures published on the EWPA website, accessed Nov 2017.

available for further valorisation by accounting for the existing uses of whey is also difficult because the whey processing value chain is too complex (Figure 50).

5.1.4 Site volumes

The volume of cheese whey potentially available for valorisation is directly related to the cheese processors production capacity. In cheese manufacturing, around 80-90 % of the milk ends up as whey by volume (JRC 2017, Tetra Pak 2017). The whole whey processing market is well established for food and feed ingredients (EC 2016). Where membrane filtration is used to concentrate the increasingly valued whey protein, the filtrate is a comparatively small fraction of the resulting volume of whey permeate sideflow. Therefore, estimates of whole whey volume can be used as a very approximate indication of the maximum volumes of whey permeate potentially exploitable in relation to processor size (i.e. if processors were to dedicate all of their whey for the filtration of whey protein concentrates). Table 33 shows these estimates in relation to UK cheese producers in 2015.

Table 33 Example size structure of UK cheese producers in 2015[109]

Cheese production	Companies Processing Milk		Volume of milk intake ('000's/yr.)		*Whey estimates from mid-intervals average*		
Processor size (tonnes per year)	**Number**	**% of Total**	**tonnes**	**m^3**	*'000 m^3/yr.*	*% of total*	*m^3 per day average. per processor**
100 and under	61	64%	3	3	*3*	*1%*	***0.2***
Over 100 - 1,000	10	10%	2	2	*1*	*1%*	***0.5***
Over 1,000 - 4,000	10	10%	19	18	*16*	*6%*	***6.1***
Over 4,000 - 10,000	9	9%	109	105	*90*	*37%*	***39***
Over 10,000	5	5%	162	157	*134*	*55%*	***105***
Total	**95**	**100**	**295**	**286**	***243***	***100***	

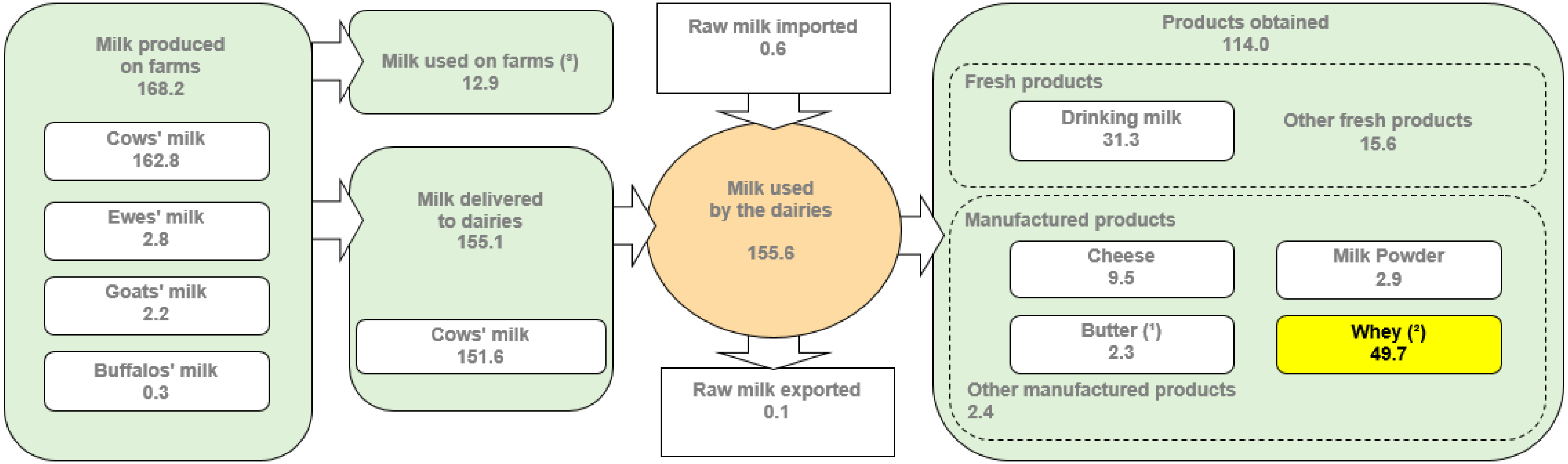
**Assumes 5 production days per week*

As a crude estimate, the UK cheese processor milk intake (Table 33) indicates just under ¼ million cubic metres of raw liquid whey was produced in the UK in 2015. Industry membrane process technology suppliers in the UK[110] have suggested the investment costs for whey permeate concentration is typically viable for processors

[109] UK DEFRA statistics taken from UK Agriculture and Horticulture Development Board Website, Accessed Nov 2017

[110] Personal comm. Tony Williams, Sales Director, ALPMA GB Ltd.

Figure 49 Production and use of milk EU-28, 2015, millions of tonnes (Eurostat 2016)[111]

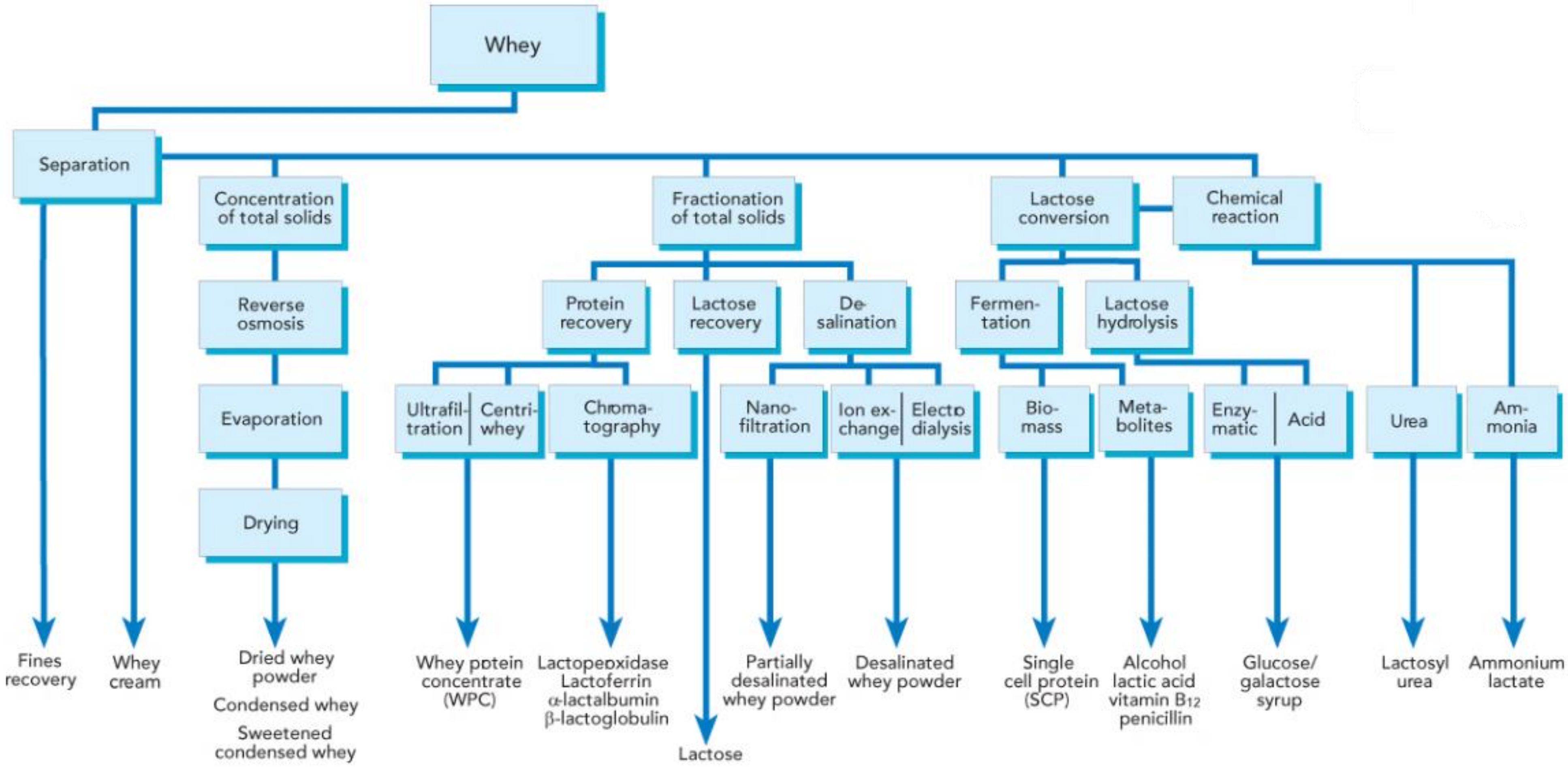


(¹) Includes other yellow fat dairy products; expressed in butter equivalent.
(²) In liquid whey equivalent.
(³) in whole milk equivalent
(⁴) Inconsistency with the sum of milk by species are due especially to inconsistency in NL data

Source: Eurostat (online data codes: apro_mk_pobta and apro_mk_farm)

[111] Adapted from the schematic originally published by Eurostat for EU Milk and milk products statistics

Figure 50 Examples of current whey products and derivatives processes.



(Source: The Dairy Processing Handbook Tetrapak©)[112].

[112] Published Online handbook, accessed November 2017

producing more than 50 cubic metres per day, which indicates a size threshold for processors producing around 5,000 tonnes cheese per year or more. *Using the whole whey volume estimates in Table 33,* as a proxy, this threshold is met by 14 out of 95 cheese processors in the UK. However, collectively these are responsible for almost 90% of the UK's whey production, with the largest 5 of these accounting for more than half of the UK whey output. In this UK example the capacity for further processing whey and/or whey permeate is considered to cover the majority of this sideflow. In this case there may be less potential for considerable volumes of surplus whey as a true waste. In absence of research evidence, even smaller creameries may provide raw or permeate whey feed for local farms. This has been confirmed anecdotally with a key UK industry representative[113] and also an independent animal feed consultant (Crawshaw 2001).

5.2 Current whey permeate valorisation options

Valorisation routes for whey permeate or deproteinised whey - are already established commercially in Europe (i.e. at a TRL of 9). Examples of these are summarised in Table 34.

Table 34 Current valorisation options (TRL 9)

Product	Current applications	Reference	Data availability/ Contacts
Lactose	Food, Infant milk formula and pharmaceutical carrier, base for prebiotics		
Whey permeate powder	Food ingredient Feed supplement	Arla Volac	Confidential data[114]
Liquid whey permeate concentrate	Feed ingredient	Trident feeds UK KW alternative feeds	
Ethanol (from whey permeate)	Potable Alcohol, Fuel	Carbery Group Muller Group Daensk Gaerings Anchor Dairy Farmers of America	Carbery Group Michael McCarthy Katzen Int'l (Engineering consultancy) Fonterra (Hamilton)
Heat and electricity	Anaerobic digestion	Clearflow ltd (e.g. The Lake District Cheese Company)	

[113] Pers. comm Lee Hartley, Head of R&D, Volac International Ltd. Jan 2018.
[114] Pers. comm. Uffe Stephanson. Arla Foods Ingredients Group.Nov 2017.

5.2.1 Whey permeate liquid animal feed

Whey permeate is a by-product of processing whey into whey protein concentrates for the human nutrition and animal feed markets. With much of the protein removed it consists mainly of the milk sugar lactose in addition to some mineral solids/salts. Some smaller UK cheese processors may have had arrangements with milk suppliers where raw unconcentrated permeate is returned to supplier's farms (Crawshaw 2001) and there are also rural creameries supplying raw permeate to local farms to cut haulage and disposal costs of using a more remote AD plant[115]. It may be concentrated by dairies for sale in liquid form for regional animal feed markets.

Whey permeate products are also processed for sale into the UK feed market by companies[116] that are owned by Associated British Agriculture, AB agri, itself part of Associated British Foods PLC., a much larger food manufacturing group operating globally. Therefore, clear links are established between larger companies' food and drink processing divisions valorising this sideflow for animal feed markets. As outlined before, smaller processors (whey equivalent <5000 tonnes of cheese per year) may not be able to justify the investment cost for membrane concentration technology. It is also notable that changes in valorisation routes of this sideflow do occur. One interviewed feed merchant[117] reported that an advertised whey permeate feed product with 30% solids concentration was no longer available due to the cheese processor investing in onsite anaerobic digestion to generate energy from this sideflow instead.

5.2.2 Whey permeate dried animal feed

The whole whey animal feed market is well established. For example, commodity reports for the European Commission suggests that animal feed currently accounts for over 50% of the market for whole dried whey powder (EC 2016). Though whole whey powder is commonly used as a '*milk replacer*' and also '*fat replacer*' in western European livestock production systems (Crawshaw 2001), whey permeate powders are also marketed to fulfil this function, in addition to production of compound feeds for livestock husbandry and as pet food ingredients[118].

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[115] UK farming press article: Feeding waste whey helps Scottish dairies on milk cost18 Oct 2016 farmers weekly, 2016: supplied free as part of a trial, but commercial cost for supply of £24/tonne were assumed.

[116] E.g Trident feed and KW Alternative feed

[117] Pers.comm non-attributable basis

[118] For example see Dutch company Van Lee BV

5.2.3 Food grade whey permeate powder

In July 2017 the standardisation of whey permeate as a food ingredient was approved via the Codex Alimentarius Commission and is expected to increase its wider use in the European food industry. Whey permeate is produced and marketed by a large European dairy processing company as 'an alternative to whey powder, demineralised whey powder, lactose, and other, more expensive milk solids in food products without altering the taste or texture or requiring any changes to processing parameters'[119]. The company is not able to share any information on its production process[120].

5.2.4 Food and pharmaceutical grade lactose

Lactose is an established commodity used in the manufacture of confectionary, dairy beverages, soft drinks, and baked goods. Having a low sweetness relative to other sugars it also functions to increase storage life of products. Lactose has been a key product refined from deproteinated whey permeate (Tetra Pak 2017). Investment costs into drying are likely to restrict lactose production to large processing sites, accessing large volumes of whey.

European lactose production is increasing to over half a million tonnes per year with over a third being exported for non-European markets[121]. Large investments have been made recently by European dairy processors to exploit a growing global baby food market[122]. Lactose is also important for the pharmaceutical industry as an excipient; a benign carrier material for drugs or active ingredients in pills and tablets. More recently lactose has become a source for a small but emerging high value prebiotics market which is predicted to grow significantly (Illanes et al 2016).

5.2.5 Ethanol products

Whey permeate has been fermented and distilled into potable alcohol since the late 1970's using the Carbery process (Pesta et al 2007). This has been further developed by the Carbery Group, which is still operating its alcohol production plant in Ireland. It is one of the first companies to supply potable whey alcohol for the drinks market. The company have since added further steps to diversify products, supplying the bioethanol fuel and chemical markets. Other commercial whey to ethanol plants exist in the EU, Denmark and more recently Germany[123], but also in the US and New Zealand, (Table 35) producing a variety of products (Table 36).

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[119] Arla foods website, Accessed Nov 2017.
[120] Uffe Stephansen, Arla Foods, Personal Communication Oct/Nov 2017.
[121] Figures published on the EWPA website, accessed Nov 2017
[122] E.g In 2014 Arla expanded lactose production in view of increasing supply to the infant milk formula market. 2016 Muller commissioned a 200 million Euro whey processing facility 'Molke V' in Leppersdorf, Germany for their subsidiary Sachsenmilch Milk & Whey Ingredient to target babyfood markets. Sources: Muller website and Sachsenmilch website accessed November 2017.
[123] In 2007, Muller group invested €22 million at the Leppersdorf site to produce 10 million litres ethanol a year from '*whey by-product, molasses*'. Website accessed No 2017

It is highlighted elsewhere (Ling 2008, Pesta et al 2007) that the low sugar content and lower ethanol fermentation product means that larger capacity and distillation energy inputs in turn requires greater capital investment for ethanol production compared to more sugar rich feedstocks. This means that an economy of scale can be a critical factor and co-operative models (Fonterra New Zealand) or agreements with several smaller whey processors to process their permeate (Carbery) may be necessary.

In the case of the plant in Leppersdorf, Germany, the owner Muller Group's control very large co-located processing operations, guaranteeing consistent low-cost supplies of permeate[124]. Finally, the commercial viability of producing bioethanol as a transport fuel may be dependent on legislative support and tax related subsidies in member states to buffer against unfavourable competition from global markets[125]

This may be a distinct competitive disadvantage for valorisation solely for ethanol as a fuel if no policy related subsidies are included. However, subsidies in combination with products for other markets such as potable ethanol for alcoholic beverages and food products, to ethanol production exists as an economically feasible valorisation process for some producers of whey permeate. These aspects should be covered in later tasks in REFRESH with regard to policy and demand-oriented assessments.

5.2.6 Anaerobic digestion

Some commercial cheese processors have installed onsite anaerobic digestion (AD) plants to generate energy from whey as a biogas production feedstock. These are co-digested with wash waters and other organic wastes[126]. AD plants have also been installed at the Carbery Group's ethanol plant in Ireland, making use of the surplus beer wash, stripped from the whey permeate fermentation process, as a feedstock.

Table 35 Example of reported current and past commercial whey to ethanol processes and associated plant capacities

Operator, country	Process name	Products	Annual ethanol production
Carbery group, Ireland	Carbery process	Ethanol	11,000 m^3
Sachsenmilch Leppersdorf, (Muller group), Germany	Not reported	Ethanol	10,000 m^3

124 Sachsenmilch's site in Leppensdorf claims to be one of the largest and most modern dairy locations in Europe and has a leading position in international competition with an annual intake capacity of 1.8 billion kilograms of milk.

125 At the time of writing Vivergo, a large commercial wheat based fuel ethanol plant has closed stating legislative uncertainty and falling bioethanol prices as the key cause of the plant closure, accessed Dec 2017.

126 Examples in the UK include the Lake District Cheese Company and Blackmore Vale Dairy in Dorset.

Operator, country	Process name	Products	Annual ethanol production
Dansk Gaerings-industri, Copenhagen	Dansk Gaerings	[Unknown]	[Unknown]
Fonterra (Anchor), Tirau and Reporoa, New Zealand	Originated from the Carbery process using milk solids and acid whey from casein manufacture	Ethanol	11,000 m^3 (two plants combined cap)
Golden Cheese Facility, Dairy Farmers of America, Corona, California, USA Land O'Lakes Melrose, Minnesota, USA.	Milbrew whey fermentation (Corona).	Ethanol & Single Cell Proteins (Corona)	Corona ceased dairy operation 2007/8 due to shrinking milk supply

Table 36 Example of ethanol products derived from Fonterra's whey to ethanol plant (source: New Zealand Institute of Chemistry[127])

Ethanol v/v	Ethanol products	
96%	Industrial ethyl alcohol (IEA)	Industrial solvent and coloured methylated spirits (Denatured)
96%	Standard ethyl alcohol (SEA)	Industrial solvent; white vinegar; medicines; surgical spirit; food colourings; food flavourings
96%	Neutral spirit (NS)	Higher quality deodorants, perfumes, and cosmetics; food colourings; food flavourings; alcoholic beverages
96%	Extra neutral spirit (XNS)	Alcoholic beverages; top quality deodorants and perfumes
99.8%	Industrial anhydrous alcohol (IAA)	Fuel grade uses, also industrial solvents for paint, printing ink and packaging industries.
99.8%	Neutral anhydrous alcohol (NAA)	Some aerosol products; hospital and pharmaceutical applications.
99.85%	High grade aerosol alcohol (HGAA)	Aerosols, especially hair care products; pharmaceutical cosmetics

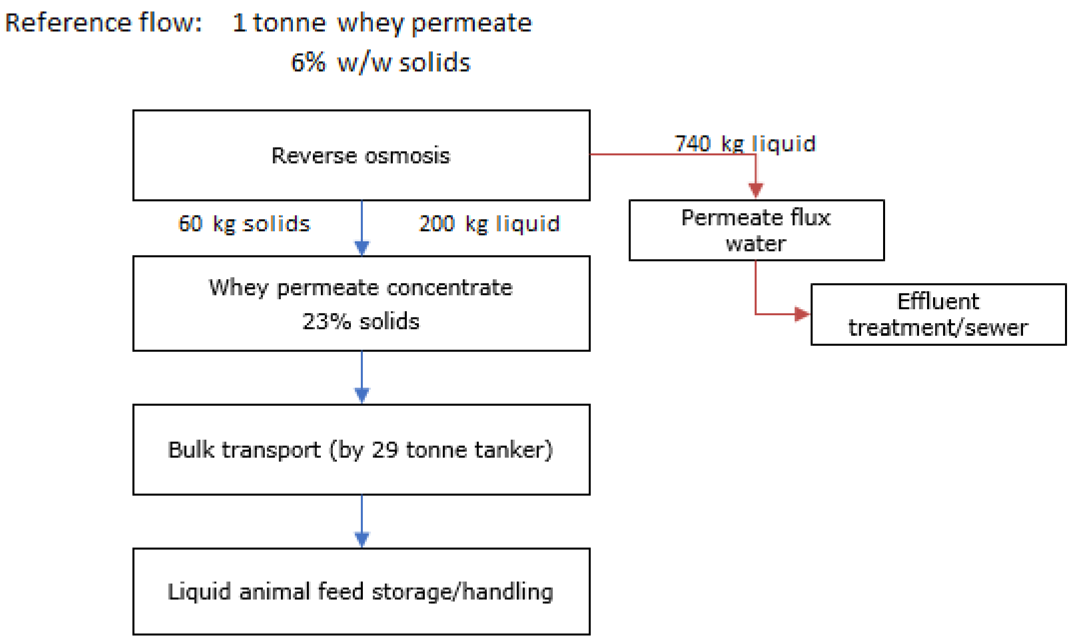
[127] http://www.nzic.org.nz/ChemProcesses/dairy/3H.pdf accessed Nov 2017.

5.3 Technical description of options modelled for whey permeate

5.3.1 Concentrated liquid animal feed

Due to the low content of its valued solids fraction, whey permeate is concentrated to allow transport to farms as a liquid animal feed product. UK feed merchants have supplied whey permeate with solids concentration between 18 to 45% (Crawshaw 2001). The solids concentration available from feed merchants at the time of this report was 23% which has also been chosen for the valorisation model here.[128] It is more stable at this concentration, with slower development of unwanted levels of lactic acid, but also less risk of lactose solids crystallising out than in higher concentrations, which can restrict handling (Crawshaw 2001).

Figure 51 Model process flow of 1 tonne of whey permeate concentrated for liquid animal feed (transport distance is an input variable)



Dairy plants can use reverse osmosis to concentrate whey solids. Here the energy demand is mainly consumed by the pump maintaining a pressure gradient required across filtration media. Estimates of specific energy demand 12 kJ per litre of flux for RO systems of have been taken from literature sources (Peters 2005, Meyer et al 2007).

[128] Personal communication, feed merchant representative, provided on a non-attributable basis.

Transport in 29 tonne liquid tankers is based on that advertised by commercial UK feed merchants. It is assumed that full loads are transported to farms with an empty return. The emissions are scaled to the proportion mass of product flow in the inventory (Table 37).

Table 37 Model inventory for concentrating 1 tonne of whey permeate for animal feed (transport step excluded)

INVENTORY			*By-product from the ultrafiltration of whey for whey protein concentrate*
Concentration			
Input			
Ultrafiltration whey permeate at dairy	1	tonne	*6% solids*
Electricity at dairy	3.1	kWh	*Reverse osmosis incl. 20% cleaning allocation (20 h/day 4h day cleaning)*
Output			*(based crude RO energy estimates from Peters 2005)*
Whey permeate concentrate	260	kg	*23% solids*
Water permeate	740	kg	*To effluent plant/sewerage treatment*
Transport			
29 tonne articulated tanker to farms	60	km	*(UK feed merchant indicates 30-40 miles (as an estimated typical average)*
Liquid whey permeate concentrate delivered	260	kg	*Assume an (0.26/29) attribution of emissions of a full load tanker in or approx. 16 t.km, (negligible losses), with the addition of a 0% load return (no back loading)*
Storage and use			
Liquid animal feed storage/handling	Negligible		*Agitation recommended over its 3-4 weeks (storage life) to prevent solids settlement, tank stirring assumed negligible energy contribution*

Comparable products

It is difficult to identify comparable products for whey permeate since there are no functionally similar products. Rather, feeding whey permeate can require an adjustment of several or more components of the existing ration to accommodate a similar or improved nutritive value. For example, a trial[129] incorporating 6 litres of raw whey permeate per day of a dairy cow's forage based total mixed rations (TMR's) reduced their use of 1 kg molasses/urea blend and 1kg soda wheat but increased their fresh weight silage intake by 3-4kg. Overall this was reported to reduce the farmer's feed costs and prevented the usual winter drop in milk quality. This makes any simple modelled outcome too complex, especially when the more likely comparable products (molasses etc) are also derived from food chain sideflows.

In this respect an alternative is to identify the quantity of a comparable feed product on the basis of functional equivalence using a simple common characteristic of the feed, such as protein or energy content. This crude approach is a limitation of the model.

In the case of whey permeate, the equivalent metabolisable energy (ME) would be the most obvious choice of parameter, given its key constituent is the milk sugar, lactose, 80% on a dry matter (dm) basis, indicating 12.5 MJ ME/kg dm, with 5% crude protein dm)[130].

With these limitations highlighted, a comparable energy feed product on a dry matter basis for the purpose of this model, can be assumed to be rolled or pelleted feed barley. 1 kg of whey permeate at 23% dry matter supplies 2.9 MJ ME, which is equivalent to ME[131] of 0.27 kg of barley grain at a typical storage moisture content of 14%.

5.3.2 Food grade lactose (not implemented)

This process was not implemented in FORKLIFT, the Whey permeate powder was selected as an example of dried ingredient. The inventory was however kept as a resource for future models and as for a comparison to whey permeate powder (next section).

The processing steps for lactose production are shown in Figure 52. Only food grade lactose is considered here. Additional steps are required for manufacturing a purer pharmaceutical grade lactose, which is not considered here.

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[129] UK farming press article: Feeding waste whey helps Scottish dairies on milk cost 18 Oct 2016 farmers weekly, 2016.

[130] Taken from KWW alternative feeds specification for 35% solids whey permeate.

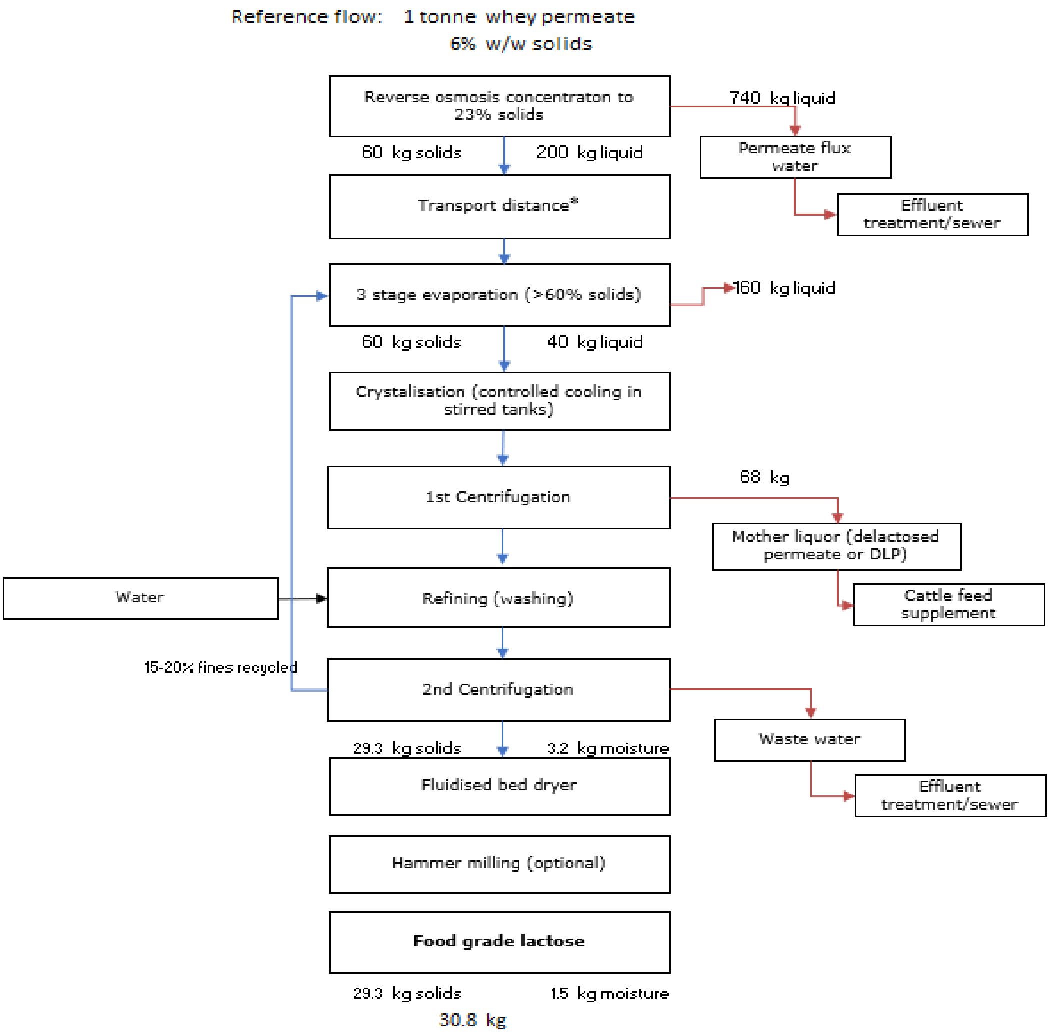
[131] On a dm basis Barley has a ME of 12.4 MJ, but a crude protein content of 10-11% (Heuzé et al 2016) which is double that specified[130] for whey permeate.

Reverse osmosis

The first stage of concentration by reverse osmosis is assumed to be from 6% solids to 23% solids with the same energy requirement assumed for liquid animal feed whey permeate.

Processors may use various evaporator technologies without RO, to concentrate from 5% to >60% solids. Here a RO concentration step is assumed to allow economic transportation of whey permeate to existing processors rather than construction of new capacity for lactose production at the cheese processing site.

Figure 52 Model process flow of 1 tonne of whey permeate used to produce food grade lactose (*transport distance is an input variable)



Evaporation

For the purposes of the model, three falling film vacuum evaporation towers with thermal recompression has been assumed for concentrating the permeate to 60% solids. This is based on generic process data outlined from an industry produced publication, (Tetra Pak 2017) from which an indication of the steam and electricity requirements have also been taken.

Limitations and uncertainties

The applications of commercial technology may differ depending on circumstances[132], but this information is proprietary with respect to valorisation, therefore information defining a modal or average technology choice from companies across the EU is difficult to establish. This is a key limitation in assuming representative commercial (TRL9) processes in any general valorisation models.

Comparable products

It is difficult to find a directly comparable product to food grade Lactose. In the food industry, its uses as a milk solids filler product are based on its relative sweetness. However, it is not directly comparable sucrose, since purely as a sweetener though its glycaemic index is considerably lower than sucrose, 3.3 times the concentration of lactose is required to give the same level of sweetness as sucrose (Paterson 2009).

For the growing market for infant milk formula (IMF) there is not a comparable product since the demand for lactose is necessitated by the reduced lactose content in bovine milk compared to human milk. Demineralised whole whey or whole whey powders are probably the nearest comparable products to refined lactose, sharing the same source material and composition, but differing process steps.

Lactose is also produced directly from milk UF permeate, as well as from whey processing permeate, (Tetra Pak 2017). Therefore, the whey processing route could be compared to average market lactose production, including milk UF permeate. However, data regarding the market share, cost and GHG emissions have not been identified for derivation of a market 'average lactose'.

Lactose is also added to baked goods to enable the Maillard reaction for flavour and browning. Where products follow a trend for reduced fat in ingredient labelling the nearest equivalents may be other milk solid non-fat (MSNF) dairy fillers such as demineralised whey powder. With relative costs as a driver, lactose may be used to substitute more expensive commodities such as low fat skimmed milk powders (SMP). Based on current market information the more likely candidate considered as comparable to lactose is

[132] Factors such as proximity to dairy processing operation, processing scale, age, capacity and relative costs of site utilities will affect technology choices. It is assumed existing lactose production conducted at larger sites able to invest in multistage evaporators (>1000 kg per hour evaporation).

SMP, primarily due to its use in confectionary[133]. This can be assumed on a 1:1 dry matter basis.

Table 38 Model inventory for processing 1 tonne of whey permeate into food grade lactose (transport steps excluded)

INVENTORY			*By-product from the ultrafiltration of whey for whey protein concentrate*
Concentration			
Input			
Ultrafiltration whey permeate at dairy	1	tonne	*6% solids*
Electricity at dairy	3.1	kWh	Reverse osmosis includes a 20% cleaning allocation (20 h/day 4h day cleaning)
Output			(based crude RO energy estimates from Peters 2005)
Whey permeate concentrate	260	kg	*23% solids*
Water permeate	740	kg	To effluent plant/sewerage treatment
Evaporation			
Input			
Whey permeate concentrate	260	kg	*23% solids*
Natural gas (for steam)	1.9	m3	*Assumes 0.14 kg steam kg^{-1}evaporated reported for 3 effects (Tetra Pak 2017), 70% steam supply efficiency & gas LHV 35.7 MJ m^{-3}*
Output	100	kg	*60% solids*
Crystallisation & centrifuging			
Input	100	kg	*60% solids*
Controlled cooling/stirring in jacketed tanks	-	kWh	*Typically, 65-70 C from evaporators to 20-25 C - temp control duty assumed to be negligible*
1st stage centrifuge	0.06	kWh	*approximated based on 0.7 kWh/m3 infeed (density assumed 1)*
2nd stage centrifuge	0.42	kWh	*approximated as above but assuming washing dilution to 10% solids before decanting*
Output			
Lactose cake	33	kg	*< 10% moisture including <1% impurities*
Mother liquor	67	kg	*By-product (soluble lactose, fines, proteins, and dissolved salts) can be used as a cattle supplement*
Drying			
Input			
	33	kg	*(10% approximated for purposes of calculations)*
Natural gas (for steam)	*0.30**	m3	*Fluidised bed dryer 92 °C for approx. 20 minutes, (Tetra Pak 2017)As above*
Electricity	No data	kWh	**Based on indicative data only (Mujumdar 2007)*
Output	31	kg	*Refined food grade lactose assumed max 5% moisture*

[133] For example in chocolate, where costs at the time of this report indicate an SMP price more than double that of lactose lactose may increasingly substitute up to 80% skimmed milk powder (SMP). Pers Comm Lee Hartley, Head of R&D, Volac International Ltd. Jan 2018.

5.3.3 Food grade whey permeate powder

Reverse osmosis

The process for refining food grade lactose from whey permeate is shown in Figure 53. The first stage of concentration by reverse osmosis is assumed to be from 6% solids to 23% solids with the same energy requirement assumed for liquid animal feed whey permeate and lactose.

As for other valorisation routes the RO concentration step is assumed to allow economic transportation of whey permeate to existing processors rather than construction of new capacity at the cheese processing site.

Evaporation

Specific energy consumption of the evaporation process is indicative of vacuum evaporation with thermal vapour recompression. This is based on generalised process descriptions and efficiencies reported in an industry handbook (Tetra Pak 2018), albeit here steam consumption reported for a single effect is in fact that of a 2-effect evaporator. Again, the commercial technology can differ depending on circumstances[134]. The process heat estimated in the inventory assumes hot condensate is recovered for steam generation. The concentrated permeate at 60% solids may be held for several hours or more in stirred tanks with a controlled cooling rate for crystallisation to improve permeate product qualities (low caking etc). This process has been omitted from the inventory since the energy consumption is not considered to make a significant material contribution (minor temperature control duties and small motors for stirring). Energy for flash cooling from evaporators to promote lactose crystallisation can be employed but has not been included here.

Drying

Two stage spray drying and belt crystallisation has been assumed based on data and descriptions from Peters (2005). This technology is being manufactured for contemporary processing with similar unit energy demands[135]. The cooling processes are assumed minor energy requirements relative to the steam heat demand from drying and have been excluded.

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[134] Factors such as proximity to dairy processing operation, processing scale, age, capacity and relative costs of site utilities will affect technology choices. Tetra Pak (2017) indicates the use of mechanical vapour compression (MVR) with pre-heating to reduce evaporation heat demand. However due to capital costs evaporation with a thermal recompressor is assumed here as a default, though less energy efficient, even single effect evaporation is considered more appropriate for duties <1000kg/hr of evaporation (Evaporator hand book 2008).

[135] E.g. See TetraPak large scale permeate dryers, website accessed Dec 2017.

Figure 53 Model process flow of 1 tonne of whey permeate to whey permeate powder (*transport steps excluded) based on Tetrapak 2017 & Peters (2005).

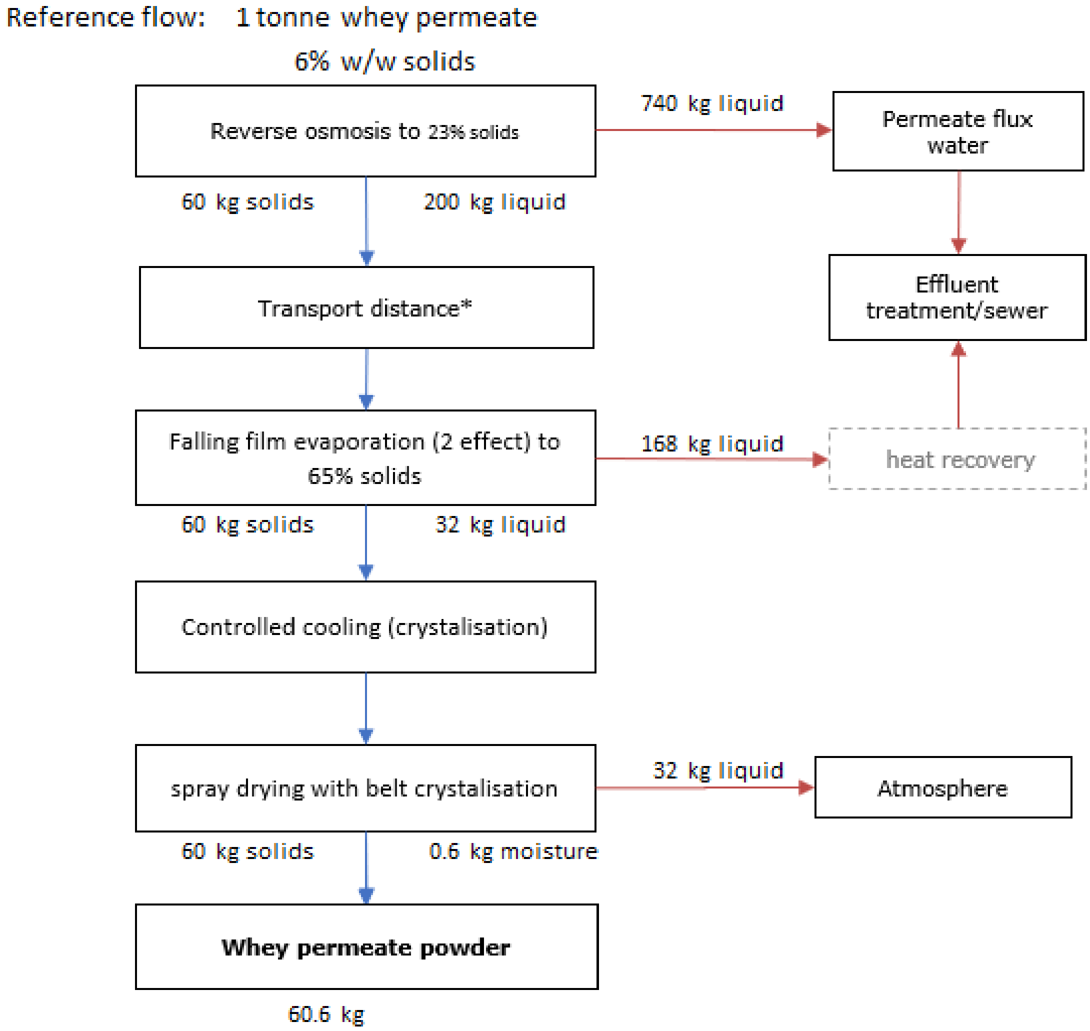

Table 39 Model inventory for processing 1 tonne of whey permeate into a powdered ingredient (transport steps excluded)

INVENTORY			
Concentration			
Input			
Ultrafiltration whey permeate at dairy	1	tonne	*6% solids - By-product from the ultrafiltration of whey protein concentrate*
Electricity at dairy	3.1	kWh	Reverse osmosis includes a 20% cleaning allocation (20 h/day 4h day cleaning).
Output			Based crude RO energy estimates from Peters (2005).
Whey permeate concentrate	260	kg	*23% solids*
Water permeate	740	kg	To effluent plant/sewerage treatment
Evaporation			
Input	*260*	kg	*23% solids*
Natural gas (steam generation)	4.7	m3	*Steam for a two- stage evaporation (Tetrapak 2017) is assumed as a default. This can be reduced with pre-concentration mechanical vapour compression for larger capacities. Different fuels are included in FORKLIFT the process heat needed was calculated to be 474*35,7 MJ/m³*0,7=117,4MJ=32,6 kWh (35,7 MJ/m³ LHV, steam supply efficiency 70% based on a primary data source)*
Electricity	2	kWh	*Thermal vapour recompression (electric motor driven)*
Flash cooling	-		*Refrigeration demand assumed negligible*
Output	92	kg	*65% solids*
Spray drying & belt crystallisation			
Input	92	kg	*65% solids*
Natural gas (steam generation)	5.2	m^3	*Based on data from Peters (2005). Process heat was calculated: 35,7 MJ/m³ LHV, heat generation efficiency 70%: 5,2*35,7*0,7=139,2 M J=38,7 kWh*
Electricity	12.6	kWh	''
Output			
Whey permeate powder	60.6	kg	*99% solids*

*broadly aligns with a datasheet for modern large volume permeate dryers, Tetrapak website accessed Dec 2017

Comparable products

Arla, a large dairy company that is marketing the benefits of whey permeate, identifies lactose or whey powder as comparable ingredients which whey permeate powder may substitute. However, it acknowledges that a slightly sweeter profile, may require adjustments to other ingredients when using whey permeate, which may complicate comparisons. For simplicity, but highlighting this as a modelling limitation, comparable ingredient products are assumed to be average lactose or skimmed milk powder on a one to one dry matter basis.

Limitations and uncertainties

Comparing the inventories for purified lactose (Table 38) and whey permeate powder considering energy use per kg product (1 tonne of whey permeate sideflow considered in both cases) it can be concluded that the production of purified lactose requires indicatively about half the amount of energy inputs compared to whey permeate powder. Modern commercial methods of production for lactose may halve the energy costs associated with evaporation and drying whey powders, but most likely at greater capital costs.

The lactose production inventory process, for example, employs 3 effect falling film evaporation mainly used for higher capacity concentration in the dairy industry (Tetra Pak 2017). This is more capital intensive but indicated to be half the steam consumption required of the evaporator applied in the whey permeate process. The Lactose process outlined also employs crystallised solids concentration using centrifugation prior to drying. However, with a lower relative yield but higher price, purified lactose may receive a greater proportion of economically allocated upstream milk production burden than whey permeate. Additional processing and transport of the mother liquor, for animal feed or waste disposal, has not been included[136] but may affect impacts and costs. No evidence was found to support a generic process/outcome, for a decision on attribution to sideflow (as waste) or physical or economic allocation of upstream process burdens to this material.

Adding a preheating step with mechanical vapor compression to pre-concentrate whey permeate from 23 % solids to 40% prior to a single falling-film tubular evaporation, may halve evaporative energy duty but with additional capital cost. In addition, Peters (2005) indicates a new drying process which may reduce the natural gas consumption to 2/3[rds] of that which is indicated for the two-stage spray drying used in the inventory model.

This highlights the key limitations of being restricted to model one specific process and scale from (available) data to represent a default GHG and cost impacts of a generic valorisation process model. However, the forklift tool provides users with the option to broadly modify default fuel and electricity consumption relative to yields to align with such process changes outlined above.

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[136] These are local circumstances that make any general comparison impossible in a tool like FORKLIFT.

5.3.4 Fuel grade ethanol

A process schematic of the Carbery process used for the spreadsheet inventory model is shown in Figure 54

Whey permeate is concentrated from around 4.5% to 6% lactose (or 6 to 8% solids) using reverse osmosis. This is then batch fermented for 12 to 24 hours. Staggering the timing of each batch allows a continuous distillation of potable alcohol. This is then further rectified into anhydrous fuel grade alcohol. These processes use heat from the site steam system which has been assumed an overall efficiency of 75%. Basic estimates of energy (steam) inputs and yields from the original Carbery plant in Ireland were provided by the Carbery plant services manager[137]. These are shown in the inventory in Table 40.

Limitations and uncertainties

The final estimated energy balance for fuel ethanol production is almost at parity with the energy inputs. However, it was not possible to obtain a detailed inventory of inputs and outputs specific to each ethanol product. Therefore, the inventory does not allocate a net energy consumption from shared auxiliary processes, some of which benefit from process heat recovery. In addition, net energy harvested from biogas production from AD of beer waste residues have not been allocated to the ethanol production process here due to the complexity of this procedure. These are only noted in the schematic and inventory.

Process and sanitation chemicals are excluded on the grounds of material significance following other studies on existing whey to ethanol (URS 2009).

Fonterra co-operative group (owner of Anchor Ethanol Ltd) has also made available site level inventory data from one of their acid (casein) whey to alcohol production sites at Reporoa, New Zealand[138]. Though the fermentation process conditions differ between acid and sweet whey, the dominant energy consumption, steam use reported for distillation, is of a similar magnitude per unit of ethanol and the mass balance methodology applied appears to intrinsically include any economies from heat recovery (URS 2009)[139].

[137] Personal Communication with Michael McCarthy, Services Manager responsible for alcohol production and site services including energy management, Carbery Group, Carbery, Ballineen, Co Cork, Ireland, Nov 2017.

[138] This has been published in a GHG assessment of the whey to fuel ethanol process commissioned New Zealand's Energy Efficiency and Conservation Authority (URS 2009)

[139] URS' (2009) assessment is reportedly calculated by physically attributing processing energy and other materials specifically to the production of fuel grade ethanol, and therefore the authors justify avoiding the use of any allocation methods for other grades of ethanol pertaining to the site level energy data. However, on reviewing the appended data inventory it appears that physical attribution is not based on process and sub process specific modelling but rather the quotient of measured site and sub-site level flows of inputs (i.e electricity, steam, waste water), and total volume of all co-products. Therefore,

The inventory has been peer reviewed by a UK consultancy working for the UK Government on biofuels policy. The reviewers observed that energy use from steam is twice that of contemporary ethanol fuel chain production sources, suggesting this should be checked for processes outside of the fuel product system boundaries, (E4Tech 2009). So, this it is a key uncertainty of the inventory model that the energy data obtained overlooks shared processes.

However, this may simply reflect the lower initial concentration of sugars in whey permeate compared to feedstocks typically used by the fuel ethanol industry. This is a key challenge for investment in stand-alone first generation fuel ethanol production plants from larger volumes of low sugar content wastes from the food industry[140]. The Carbery Groups' advantage may be in already processing whey permeate into food grade alcohol and biogas. Having already committed investment, shared process efficiencies may support further marginal, cost efficient investment decisions that allow expansion of fuel ethanol production. The topic of barriers and scaling is part of REFRESH T6.5 deliverables and is not dealt with in this report.

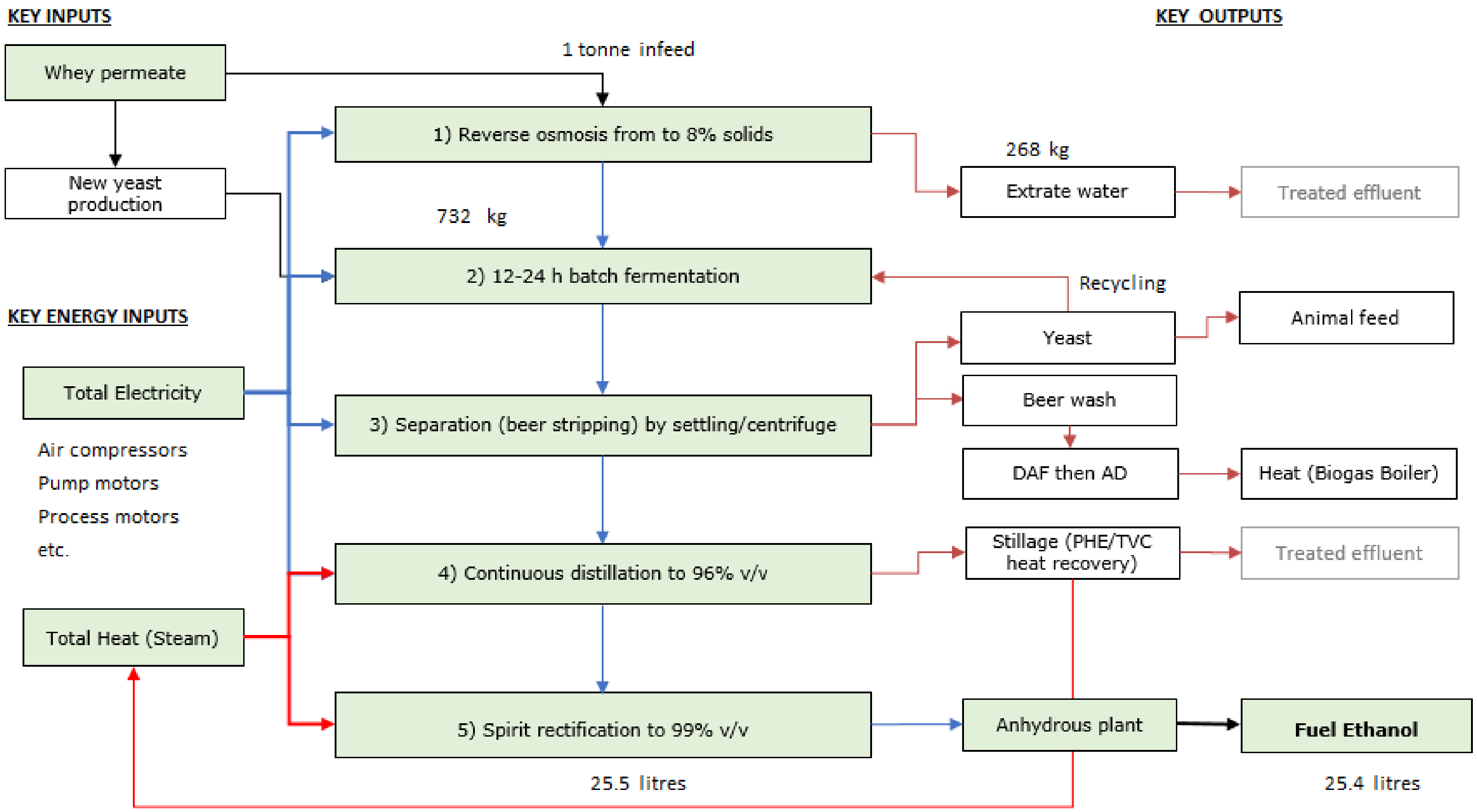
Comparable products

The identifiable comparable product is most easily identified as an average for the production fuel grade ethanol used in Europe.

the energy data intrinsically includes site level energy recovery processes in general, if indeed they may not be apportioned accurately to individual product related processes.

[140] Personal Communication with Robert E. Eickelberger, Vice President Business Operations, and CEO and president, Philip W. Madson, Katzen International Inc.

Figure 54 Model process flow for processing 1 tonne whey permeate to ethanol



Green shaded boxes indicate where energy and emissions estimates have been possible and have been included within the model boundary.

Table 40 Model inventory for processing 1 tonne of whey permeate into fuel ethanol

INVENTORY*			Notes
Reverse osmosis concentration			
Input			
Whey permeate	1	tonne	6% solids (~4% lactose)
Electricity	2	kWh	Reverse Osmosis (pump duties)
Output			
Separated extract water	268	kg	Concentration to 8% solids, approx. 6% or 45 kg lactose
Whey permeate	732	kg	
Fermentation distillation to 95%			
Input			
Whey permeate (8% solids)	732	kg	6% lactose w/w
Electricity*	10.9	kWh	*Liquid transfer and aeration pumps*
Yeast	-	kg	No data - assumed yeast culturing is negligible energy process
Steam*	130	kg	Carbery process estimates from services manager
Caustic and other chemicals**	0.3	litres	Assumed negligible (based on URS (2009) GHG LCA of Fonterra whey to ethanol)
Output			
96% Ethanol, Standard Ethyl alcohol*	26	litres	
Yeast	-	kg	No data - assumed non- recycled portion to animal feed use
Fusel oil**	0.1	litres	
Stripped beer, stillage, and waste water**	848	litres	**Stripped beer:** Carbery: to site AD, Fonterra: landspread 30km from plant **Stillage:** Carbery: Heat recovery (unable to quantify) for boiler feed/hot water
Rectification and anhydrous process to 99%			
Input			
Ethanol 96% v/v	25.5*	litres	
Steam*	52	kg	Combined for ED/ rectification and anhydrous process
Electricity*	8	kWh	
Estimated energy totals			
Natural gas used for steam generation	15	m^3	[based on combined steam duty]
Natural gas; (LHV) energy required	548	MJ	70% steam system efficiency assumed. Net heat requirement thus 548*0,7=383 MJ (107 kWh)
Electricity	21	kWh	Total from processes above
FINAL Output			
Anhydrous ethanol 99% v/v	**25.4** 20.1	**litres** kg	Min 98.7% v/v fuel ethanol for blending (EN 15376)

*Estimates based on Carbery process (Personal Communication M. McCarthy Nov/Dec 2017), ** Estimates based on URS (2009)

5.3.5 Anaerobic digestion of whey permeate with energy recovery

Energy recovery from whey permeate was modelled in accordance with the model used for all side flows in the spreadsheet tools (Östergren et al, 2018). The effect of co-digestion with other substrates is not considered and thus the value should be considered as conservative. This valorisation route leads to three specific utilities: electricity, heat and digestate (used as fertiliser). Table 41 and Table 42.and Table 27 provides an overview of the inventory used for whey permeate (6% DM).

Table 41 Biogas potential whey permeate, per tonne Fresh Matter (FM) with a Dry Matter content of 6%

Side-flows	Theoretical biogas yield in m3/t FM	Theoretical CH4 content in %	LHV in MJ/ MJ/t FM
Whey permeate	26,5	53.00	19,12

Table 42 Emissions and energy recovery whey permeate, per tonne Fresh Matter (FM) with a Dry Matter content of 6%.

Emissions AD kg $CO_{2\ eq}$/ t FM input	Net Electricity KWh/t FM input	Net Thermal energy KWh/t FM input	Digestate t FM/t FM input	Credit for digestate application kg $CO_{2\ eq}$/ t FM input
12,93	46,06	31,67	965,5	-0,86

Comparable products

The selected comparison products used in the model are:

- Electricity (country specific) and EU average heat production
- Electricity and EU average heat production
- Electricity and EU average heat production and production and application of mineral fertiliser (the digestate from the AD is spread on land, providing nitrogen, phosphorous and potassium to the soil)
- Hydropower electricity and wood chips

5.4 Description of the FORKLIFT spreadsheet model for whey permeate

5.4.1 Generic information

The model calculates the GHG emissions and costs associated with the handling of 1 tonne of whey permeate (dry matter content of 6%).

An average value of production of milk has been used being 1.1 kg CO_2eq. /kg milk at farm gate.

The upstream burden attributed to the valorised product is calculated through economic allocation according to the REFRESH report D5.4 Simplified LCA & LCC of food waste valorisation (Östergren et al 2018).

It should be noted that by definition, a side-flow should have a much lower relative value than its associated driving food product(s). Therefore, the proportion of the upstream GHG burden allocated to sideflow is generally low relative to any valorisation processing impacts. When the upstream burden increases the accuracy of the model will decreases, since upstream processing generating the whey permeate has been excluded from inventories in FORKLIFT. *For animal-based products as whey permeate the upstream burden may be very significant.*

Critical parameters were qualitatively assessed using the model developed previously in D5.4 Simplified LCA & LCC of food waste valorisation (Figure 55). Description of standardised models (Östergren et al 2018). Note that the matrix in some cases also includes parameters that cannot be changed (Annex 11) as an information to the user. The reason for keeping them constant is that they are generic numbers used in several models to allow comparison between different side flows. The assessment is based on the relative impact of a parameter compared to the total impact of the valorisation process.

An overview of the spreadsheet tool and options included in the model is provided in Figure 56 and in the next section the sub- models are described. The full inventories are provided in Annex 11 as supplementary information

Figure 55 Assessment of critical parameters

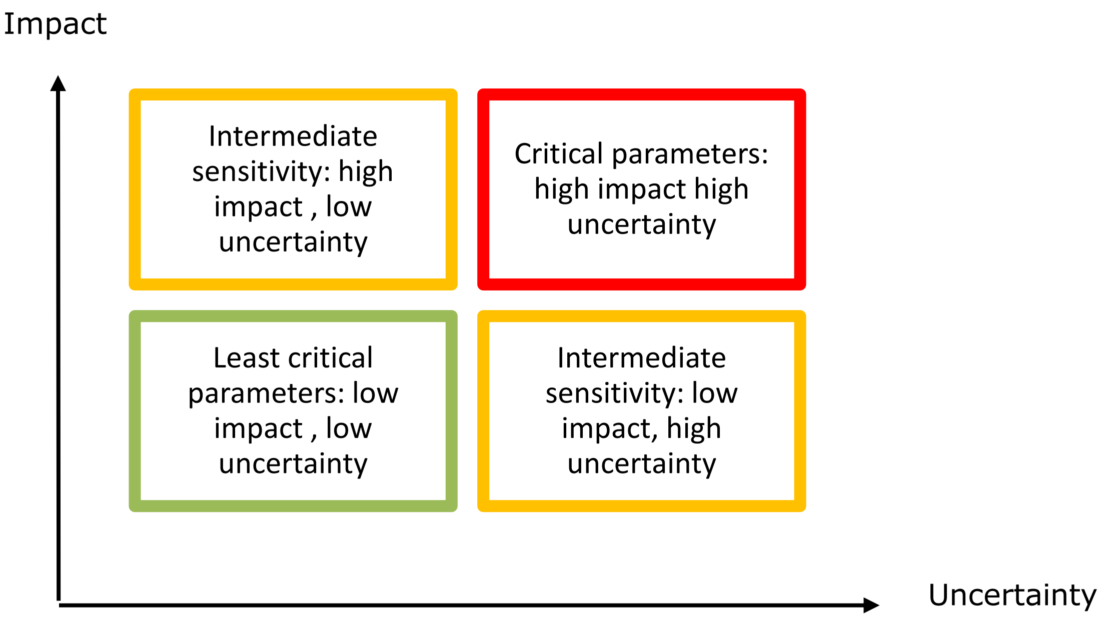
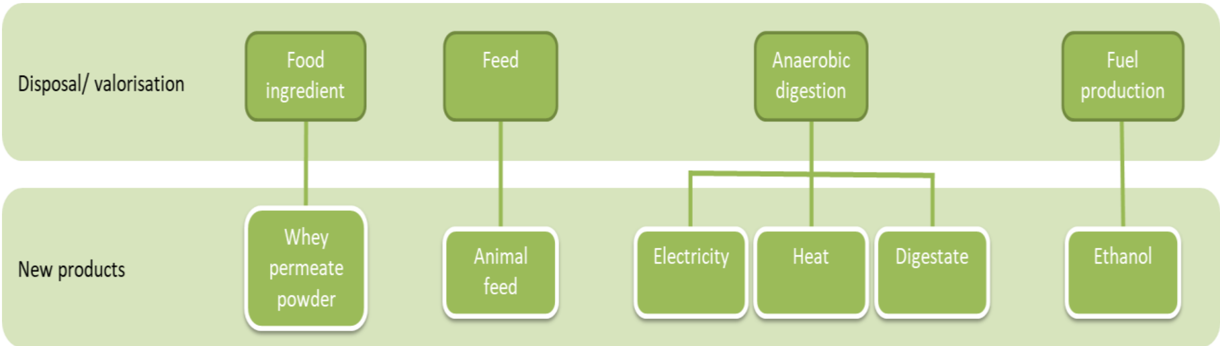


Figure 56 Overview of the spreadsheet model whey permeate



5.4.2 Whey permeate as feed

Figure 57 Whey permeate as feed option in FORKLIFT

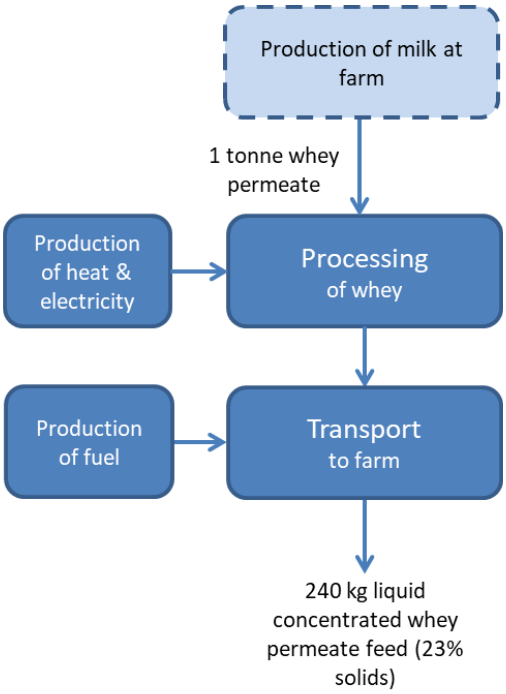


Figure 57 illustrates the processes that are considered in the calculation of GHG emissions and costs for using the whey permeate to produce concentrated whey permeate feed. The environmental impact and cost from the upstream processes (dotted line) are included if the whey permeate carries an economic value.

Due to the low content of its valued solids fraction, whey permeate is typically concentrated before being sold as an animal feed. This is done by reverse osmosis, requiring electricity. The liquid feed is then transported to the farmer by truck.

Regarding the use of fuel and electricity, the GHG calculation covers the emissions of producing the fuel and combustion in the truck, as well as emissions from production of heat and energy. The default cost considers only the average market price of the electricity, and fuel for transport and heat.

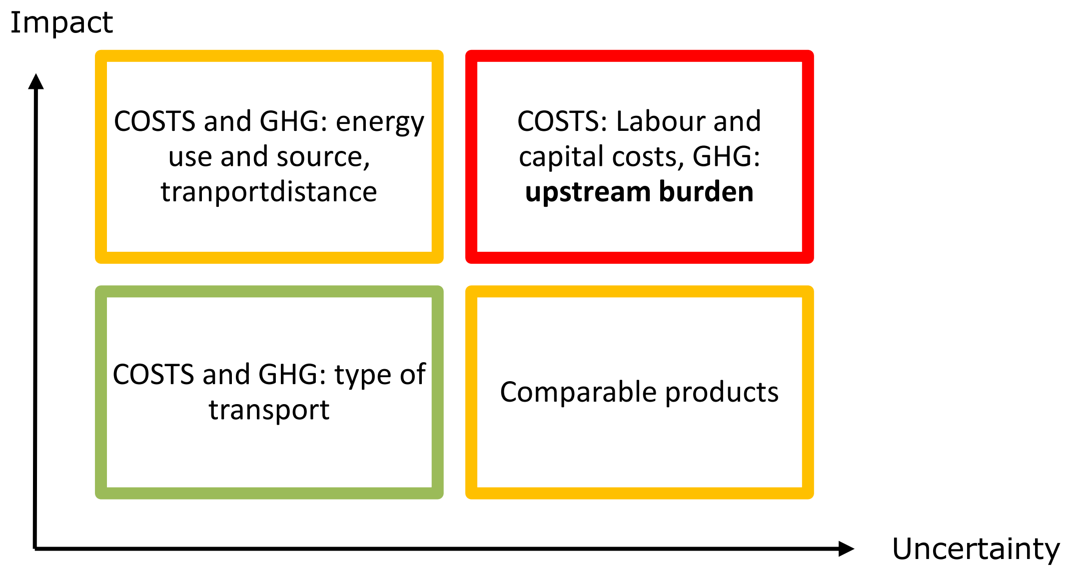
In this valorisation route, 240 kg of liquid concentrated whey permeate feed is generated. This corresponds to 65 kg dry barley grains based on energy content, which has been used as a comparison product.

The model parameters are provided in Table 43 and the assessment of critical parameters are provided in Figure 58

Table 43 Adjustable model parameters for whey permeate as feed

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transports to blood meal plasma production (Rigid truck, 20-26 t, Euro 4, 50% LF, cooling)	60	km	A pre-selection of transport options is provided, distances can be set freely.
Electricity use in processing	3,1	kWh/tonne whey permeate	Pumping to generate pressure for reverse osmosis separation.
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 58 Assessment of critical parameters for whey permeate as feed



5.4.3 Whey permeate as food ingredient/whey permeate powder

Figure 59 Whey permeate powder as food ingredient in FORKLIFT

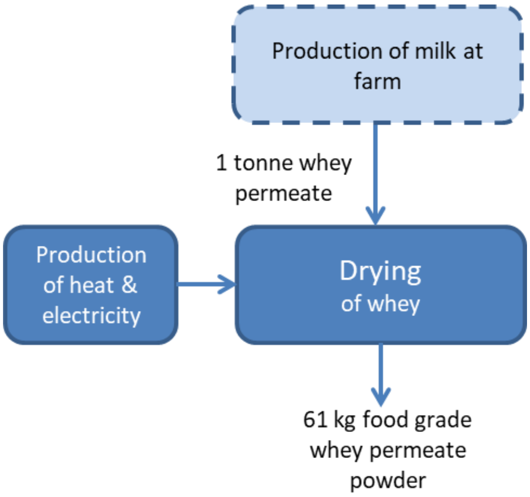


Figure 59 illustrates the processes that are considered in the calculation of GHG emissions and costs for using the whey permeate to produce food grade whey permeate powder. The environmental impact and cost from the upstream processes are included if the whey permeate carries an economic value (therefore in dotted line).

It is assumed that the processing of the whey is taken place at the dairy, thus the transport is by default set to be 0 km.

The whey permeate is concentrated in a number of steps, requiring electricity and heat. First, reverse osmosis is used, then spray drying followed by belt crystallisation drying.

Regarding the use of electricity and heat, the GHG calculation covers the emissions of production of heat and energy. The cost takes into account the cost of the electricity and heat.

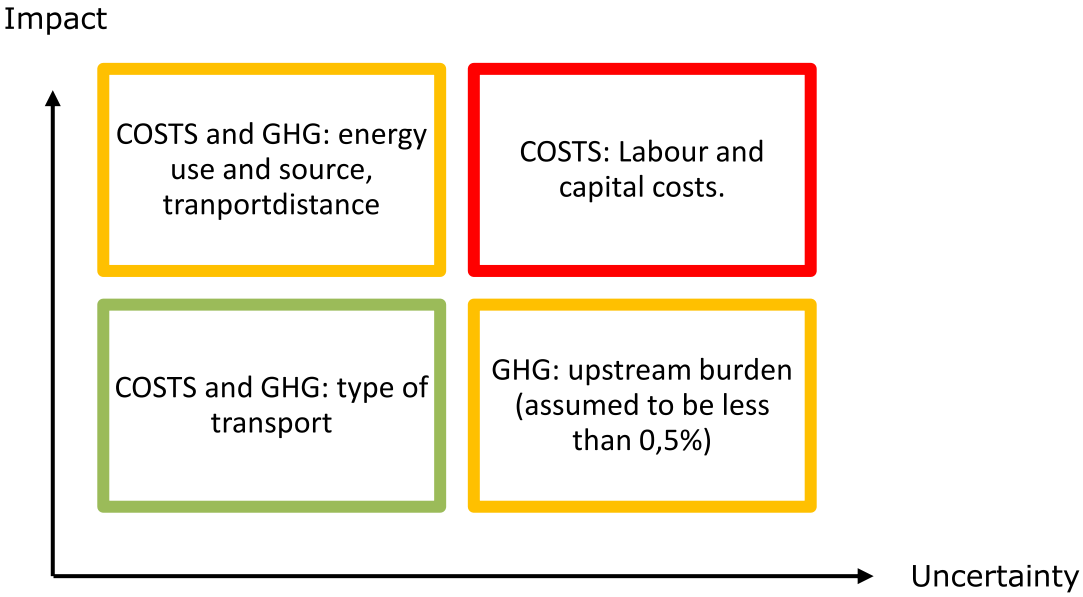
In this valorisation route, approx. 61 kg of food grade whey permeate powder is produced from 1 tonne of raw whey permeate. Lactose powder has been identified as a potential comparison product. However, cost and GHG figures could not be found for estimating an average lactose production (which includes other feedstocks such as milk UF permeate). Skimmed milk powder has been identified also for similar uses as a food ingredient to that of lactose.

The adjustable model parameters are provided in Table 44 Table 46 and the assessment of critical parameters are provided in Figure 60, Figure 58.

Table 44 Adjustable model parameters for whey permeate powder using 1 tonne of whey permeate

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transport of whey permeate to processing plant (Rigid truck, 20-26 t, Euro 4, 50% LF, cooling)	0	km	A pre-selection of transport options is provided, distances can be set freely.
Electricity use for processing	18	kWh/tonne whey permeate	
Heat use for processing	71	kWh/tonne whey permeate	N.B. The evaporator energy may be reduced with further investment in technology. subject to economies of scale and market demand.
Fuel used for generating heat	Light fuel oil		A pre-selection of fuels is provided (biogas, natural gas, hard coal, wood chips from forest, EU-average heat)
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 60 Assessment of critical parameters for whey permeate as a food ingredient



5.4.4 Energy recovery using anaerobic digestion (AD)

The calculations are based on the streamlined approach recommended in the REFRESH report "D5.4 Simplified LCA & LCC of food waste valorisation" (Östergren et all 2018). Figure 61 illustrates the processes that considered in the calculation of GHG emissions and costs for using the whey permeate to produce biogas. The environmental impact and cost from the upstream processes are included if the whey permeate carries an economic value (therefore in dotted line).

The whey permeate is transported to the AD plant by truck.

Regarding the use of fuel, the GHG calculation covers the emissions of producing the fuel and combustion in the truck, as well as fugitive biogas emissions from the storage, biogas engine (slip) generating heat and electricity. The cost takes into account the price of fuel for transport.

In this valorisation option, 46 kWh electricity and 31 kWh of heat are the products. Some alternative ways of producing heat and electricity to compare with are:

- Electricity (average for selected country in the model) combined with EU average Heat
- Hydropower and wood chips heat
- Electricity and heat EU average heat
- Electricity and heat EU average including production and application of mineral fertiliser since the digestate from the AD commonly is spread on land, and therefore provides nitrogen, phosphorous and potassium to the soil.

The adjustable model parameters are provided in Table 46 and the assessment of critical parameters are provided in Figure 62

Figure 61 Energy recovery from whey permeate

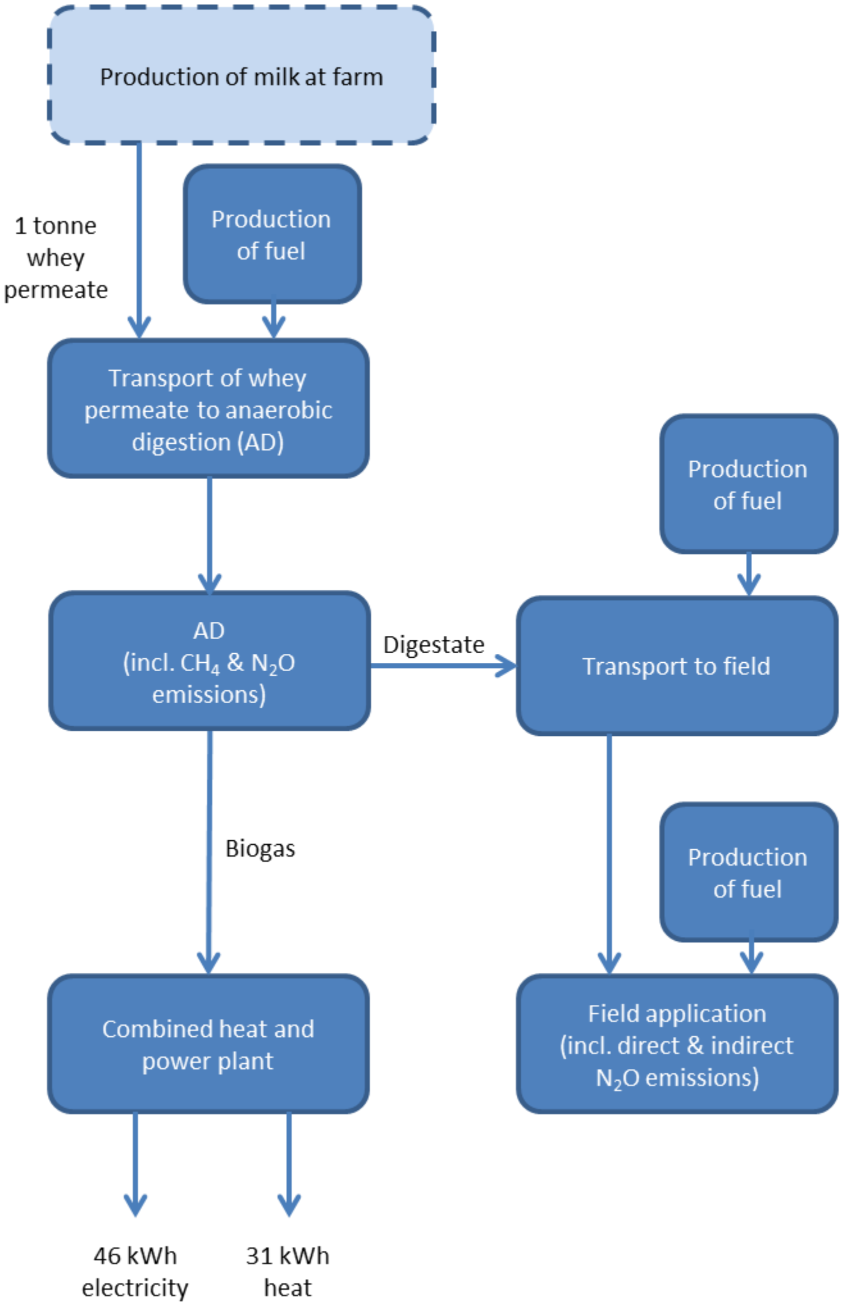
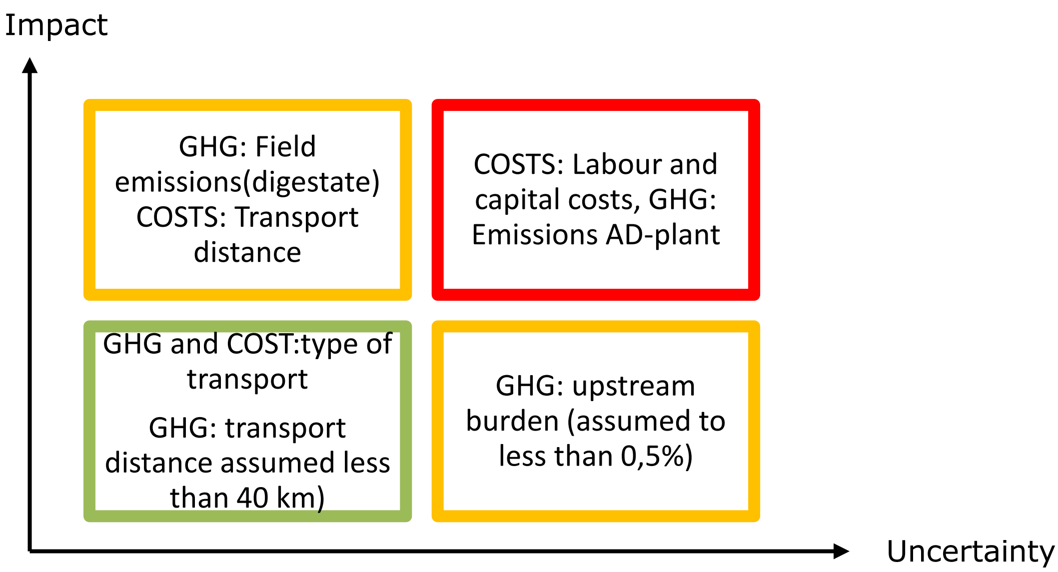


Table 45 Adjustable model parameters for biogas and energy production (AD) from 1 tonne of whey permeate

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transport of digestate to the field (tractor single trailer 50% Load Fraction (LF)	20	km	A pre-selection of transport options is provided, distances can be set freely.
Transports of whey permeate to the AD plant (Rigid truck, 20-26 t, Euro 4, 50% LF)	20	km	A pre-selection of transport options is provided, distances can be set freely.
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 62 Assessment of critical parameters for biogas and energy production (AD) ingredient (whey permeate).



5.4.5 Whey permeate as substrate for ethanol production (fuel)

Figure 63 Whey permeate used as substrate for ethanol production

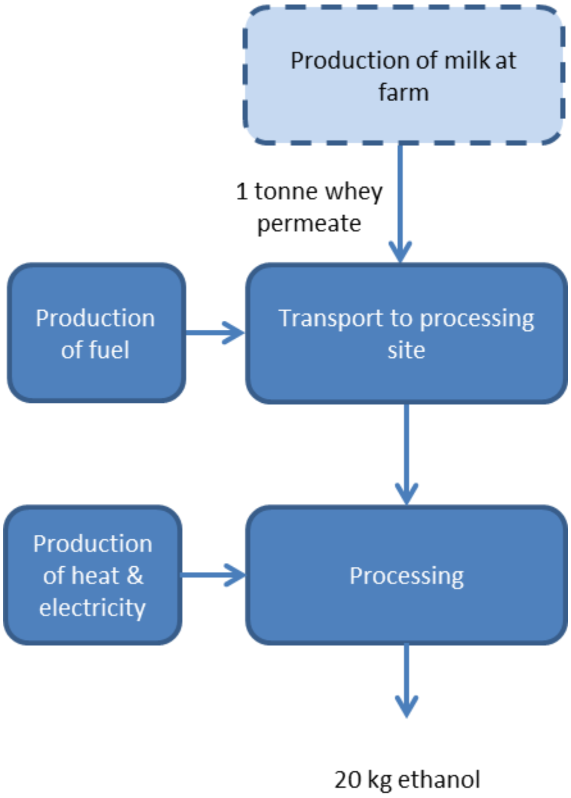


Figure 63 illustrates the processes that are considered in the calculation of GHG emissions and costs for using the whey permeate to produce ethanol. The environmental impact and cost from the upstream processes are included if the whey permeate carries an economic value (therefore in dotted line).

The whey permeate is first transported to the ethanol production plant by truck. Regarding the use of fuel, electricity and heat, the GHG calculation covers the emissions of producing the fuel and combustion in the truck, as well as emissions from production of heat and energy. The cost takes into account the cost of the electricity, and fuel for transport and heat.

At the processing plant, the permeate is concentrated using reverse osmosis and then fermented. The distilled alcohol is then further refined into fuel grade ethanol. In the calculation of GHGs and cost, only the production of heat and electricity is taken into account for this production step.

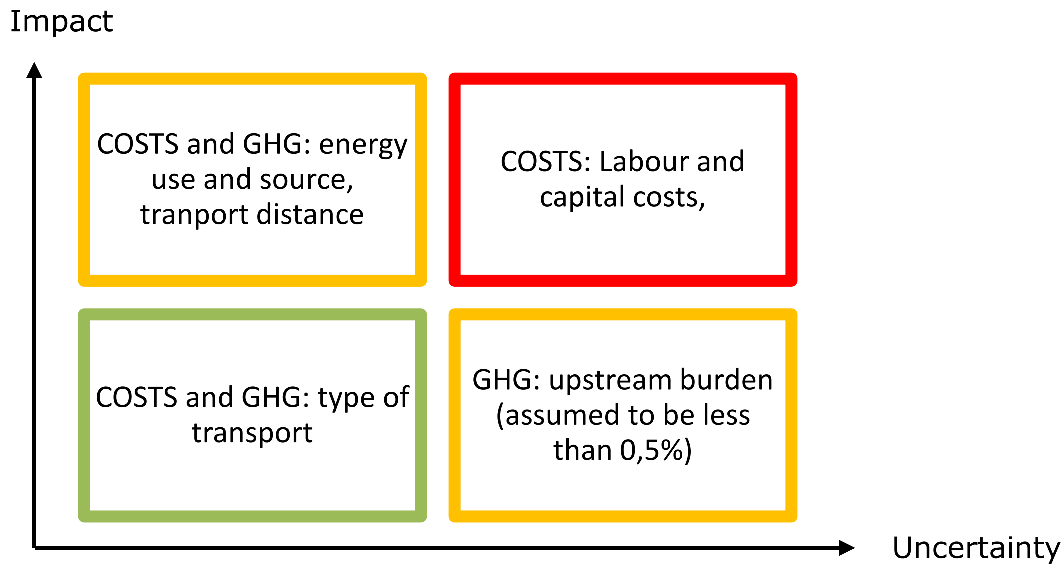
In this valorisation option, 20 kg fuel grade ethanol (>98%) is produced. The result may be compared with alternative ways of producing bio-based ethanol, from wheat and maize stover, in equivalent amounts (20 kg).

The adjustable model parameters are provided in Table 46 and the assessment of critical parameters are provided in Figure 64

Table 46 Adjustable model parameters for ethanol production from 1 tonne of whey permeate

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transports of whey permeate to processing plant (Rigid truck, 20-26 t, Euro 4, 50% LF, cooling)	200	km	A pre-selection of transport options is provided, distances can be set freely.
Electricity use for processing	21	kWh/tonne whey permeate	
Heat use for processing	107	kWh/tonne whey permeate	
Fuel used for generating heat	Natural gas		A pre-selection of fuels is provided (biogas, natural gas, hard coal, wood chips from forest, EU-average heat)
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 64 Assessment of critical parameters for whey permeate as substrate for ethanol production



6 Annex 6: Tomato pomace spread-sheet model

List of abbreviations

AD	Anaerobic digestion
ADF	Acid Detergent Fibre
CB.	Cold Break
CEL	Cellulose
DM	Dry Matter
GHG	Greenhouse gas
HB	Hot break
HM	Hemicellulose
HHV	Higher heating value of gross calorific value (total heat available from combustion reaction)
NDF	Neutral Detergent Fibre
LHV	Lower heating value or net calorific value (minus latent heat absorbed by combustion reaction products)
OM	Organic Matter
TP	Tomato Pomace
SCFE	Super critical fluid extraction

6.1 Background

6.1.1 Rationale

Tomato pomace (TP) is the major co-product of processed tomato products such as juice, soup, ketchup, etc. It is a mixture of tomato skin, pulp and seeds left over after the processing.

At the European level, tomato is the second most harvested product fruit or vegetables after potatoes. The tomato production in EU in 2015 was 35 kg/inhabitant (25 kg/inhabitant for apples and 10 for carrots in comparison). In gross quantity, this amounts for around 17.7 million of tonnes (Eurostat 2016a). In average, tomatoes represent 22.9% of share of fresh vegetable output at value price (Eurostat 2016b).

Italy (36.3% of total EU production) and Spain (27.4%) supplied in 2015 more than 60% of tomatoes produced in the EU. They were followed by Portugal (8.0%), Greece (6.2%), the Netherlands (5.0%) and France and Poland (both 4.5%) (Eurostat 2016a).

It is estimated that 10.5 million of tonnes of tomatoes in EU (in 2015) where processed (therefore generating pomace) and the rest was consumed as fresh tomatoes (DG Agri 2018). The main countries processing tomatoes in 2015 were by decreasing order Italy, Spain and Portugal (Tomatonews 2017).

6.1.2 Tomato pomace production process

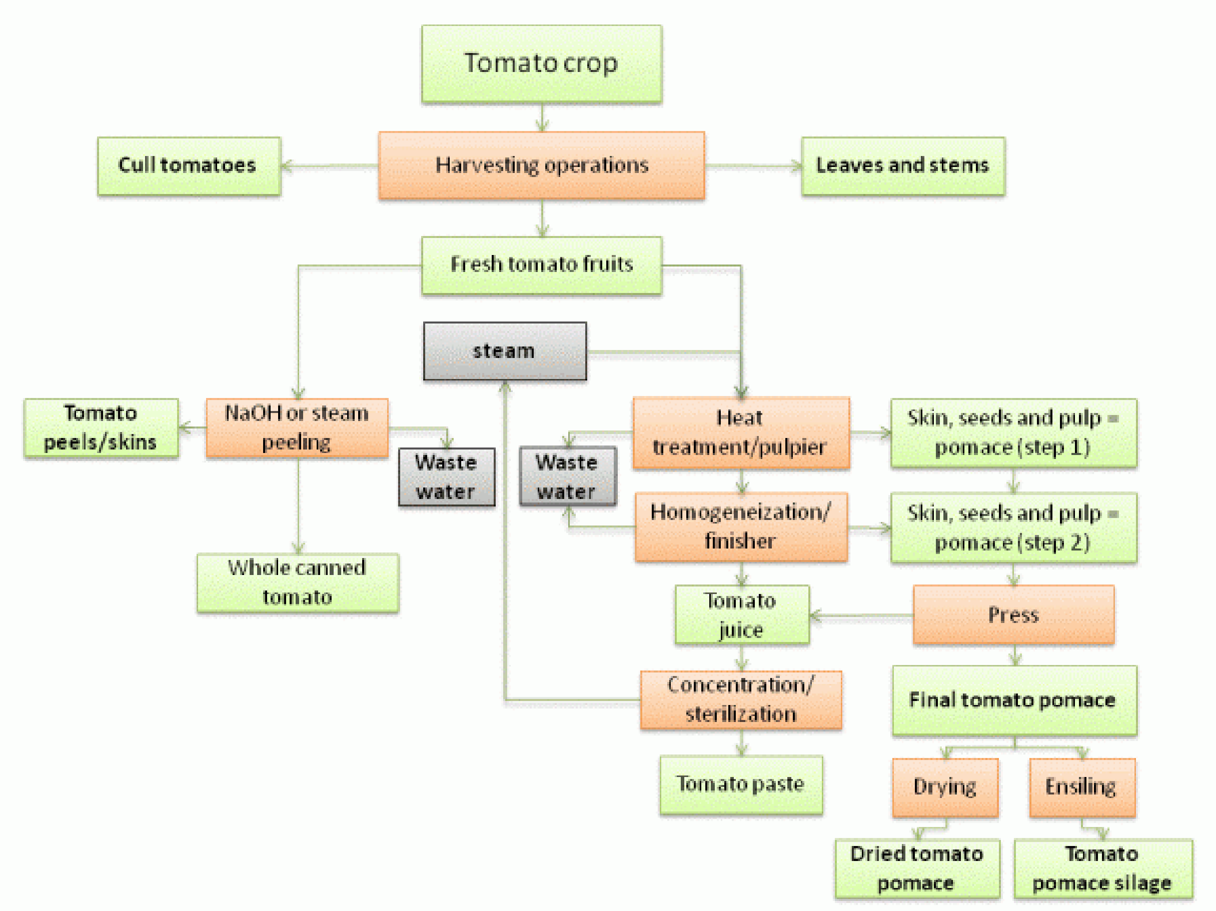
It is possible to distinguish two main routes of tomato processing (JBT 2015; Heuzé et al 2015):

- Whole canned peeled products
- Paste, juice and concentrate products

For both activities there are pre-processing steps of receiving, washing, and sorting (Figure 65). Tomatoes arrive in trucks filled with water and are discharged in a large pool to avoid shocks. During the sorting phase, green / damaged / uncoloured tomatoes and other materials (rocks, leaves, etc.) are removed (Tomato Jos 2014) but they are not considered as TP. This is treated as a bio-waste and may be land spread or composted[141].

[141] Interview - tomato processing plant 2018

Figure 65: Tomato processing



Source: (Heuzé et al 2015))

Peeled products

Sodium or potassium hydroxide, steam and water can be used to separate the skins from the tomatoes. Pinch bed systems or scrubbers refine the peeling process. Some of the by-products can be recovered for the concentrate process and what is left is mostly peels and skin. This is not properly speaking tomato pomace so these co-products will not be further developed (JBT 2015).

The peeled products are usually dedicated to cans or jars. Therefore, the other processing steps (sterilisation and packing) do not lead to a significant amount of waste.

Paste and concentrate products

After the preparation steps, two types of tomato paste can be produced: Hot Break (HB) or Cold Break (CB). HB is usually used for tomato sauces requiring 28-30% of solid material (Brix) while CB is used for concentrated paste (36-38% of solid material). Hence, the paste is 6 to 7 times more concentrated than the starting material which contains about 5% of solid materials/sugars and 95% water (Tomato Jos 2014).

After heating, the pulp composed of juice, seeds, skin and fibres is successively extracted by going through a pulper and a refiner (also called finisher in Figure 65). A refiner is composed of sieves sized according to the product required (soup, juice, concentrate, etc.). The retentate is tomato pomace and composed of seeds, skin and pulp. It has been estimated that about **5% in weight of a whole tomato ends up as pomace during processing, sometimes more** (Del Valle, Camara, and Torija 2006; Tomato Jos 2014).

Then, water is removed from the products by various means to obtain the juice at the desired concentration. This is the most energy consuming stage. Sterilization, filling and packaging occur afterwards to ensure the product is fit for distribution and consumption.

Tomatoes are seasonal products and cannot be conserved more than a few days. To smooth the production throughout the year, tomatoes can undergo a first transformation directly after their arrival at the plant. Transformed tomatoes can then be stored for months in sealed aseptic drums and undergo another transformation when needed[142]

6.1.3 Tomato pomace composition

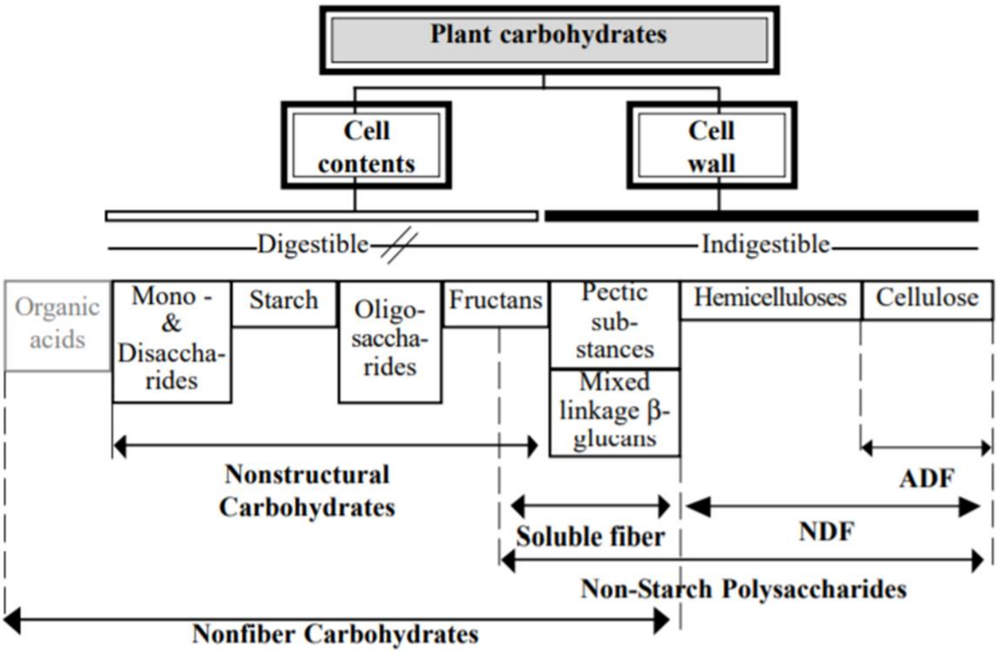
Since tomatoes have a high moisture content, water is also the main component of tomato pomace. Studies estimated that the moisture accounts for 64.3-92.6% of the total mass of the pomace (Del Valle, Camara, and Torija 2006), meaning that the dry matter (DM) content is approximately 7-36% of the mass of TP. For the purpose of the study, we consider an average DM content of **25.3%** (based on the food waste composition database).

Regarding the composition of the dry matter, results differ according to the variety of tomato, the ripeness, the localisation, the stage of the processing pomace is analysed, etc. Therefore, it is more relevant to define an average generic composition which can be adapted case by case.

There are many ways to quantify the fibre and carbohydrates contents of a plant. The scheme below summarises the most common carbohydrates used to assess the composition of tomato pomace.

[142] Interview - tomato processing plant 2018

Figure 66: Analytical classifications used to characterise plant carbohydrates



Source: (Hall, 2007)

In addition to carbohydrates (Figure 66), other key constituents of tomato pomace are:

- Pectin (a polysaccharide);
- Sugars (by definition monosaccharides, disaccharides, or oligosaccharides);
- Organic matter ;
- Proteins;
- Fat (ether extract);
- Minerals or ash.

The average composition of TP is detailed in Table 47. No correlation was clearly established between the amount of skin and seeds in tomato pomace and its proximate composition (Silva 2016).

Even if different sources of TP exhibit differing compositions, studies show similar results (Heuzé et al 2015); Del Valle, Camara, and Torija 2006; Bakshi, Wadhwa, and Makkar 2016; Lazos and Kalathenos 1988; Wadhwa and Bakshi 2013).

Table 47: Chemical composition (% DM basis) of tomato pomace

Pectin	Ash	OM	Proteins	Fat
7.55	4.8–6.0	94.0–95.2	19.0–22.1	10.0–11.5
NDF	**NDS**	**ADF**	**HC***	**CEL****
55.2–63.0	37.0–44.8	46.2–51.0	9.0–12.0	12.0

* Hemicellulose **Cellulose, Source: (Bakshi, Wadhwa, and Makkar 2016)

Table 48: Mineral composition of tomato pomace (g/kg DM)

Ca	P	K	Na
4.4	3.6	8.7	2.4
Mg	Mn	Cu	Fe
2.2	72	11	227

Source: (Heuzé et al 2015)

Table 49: Amino acid composition of tomato pomace (% protein)

Arg	Cys	Gly	His	Ile	Leu
11.5	2.0	5.3	3.9	4.1	7.1
Lys	Met	Phe	Thr	Tyr	Var
8.0	2.3	5.8	3.3	5.5	4.4

Source: (Heuzé et al 2015)

6.1.4 Tomato pomace storage

The following has been adapted from Heuze et al 2015:

As outlined above, reported water content for tomato pomace is high (65-90%). This is a significant issue for its valorisation since it is heavy so relatively expensive to transport and spoils within days. Moreover, this means that the nutritive value/kg is relatively low.

Drying or ensiling is employed to allow storage and concentrate its nutritive value. Artificial drying is more efficient but costly. Sun drying is an alternative, providing a facility is well adapted (in terms of space, geographical location, etc.).

Tomato pomace is co-ensiled for animal feed with fibrous forage to retain moisture and prevent effluent.

6.1.5 Information on potential and actual quantities

Reported quantities of tomato pomace differ notably:

- 10.5 million of tonnes of tomatoes are processed yearly in Europe (DG Agri 2018). Considering 5% of TP is generated during the processing phase, this would mean that around 525,000 tonnes of pomace are produced each year in Europe.
- At the worldwide level, around 150 million tonnes of tomatoes are produced and 30% of it is processed (45 million tonnes) (Heuzé et al 2015). The same source states that 4 million tonnes of pomace are generated yearly in the *world*, therefore around 9%. However, a study stated that 4 million tonnes of pomace is produced yearly in *Europe* (Pfaltzgraf et al. 2012) which is incompatible with the previous estimate.

As a conclusion, it appears that the quantity of European tomato pomace remains rather uncertain. Therefore, it is safer to consider a range. It is possible to estimate that **[420,000 – 1 050,000] tonnes of TP is generated yearly in Europe (i.e. 4-10% of the processed amount of tomatoes).**

6.2 Current valorisation options

This review of valorisation options covers both current applications as well as some theoretical valorisation options found in the literature, which, to our knowledge do not appear to be commercially proven. These are simply provided to indicate some research perspectives.

6.2.1 Food additives

Lycopene (carotenoid) extraction for ingredients and additives

Lycopene is known to be a strong antioxidant (Fritsch et al. 2017). It has been linked to reduced risks of cardiovascular disease, hypertension and epithelial cancer (Fritsch et al. 2017). Since it is responsible for the redness of tomatoes, lycopene is mostly used as a colorant in food, drinks, and pharmaceuticals. Using lycopene to enrich edible vegetable oils in order to develop a new functional food has been also been explored (Fritsch et al. 2017).

Lycopene is the major carotenoid found in tomatoes, and therefore TP is a rich source. Carotenoids, in the form of oleoresins, are currently commercially extracted from tomatoes specifically grown and selected for high lycopene concentration[143], so it is assumed to be a commercially demonstrable approach, but not specifically for TP, though there are many research studies investigating extraction from TP in the literature. Such studies indicate lycopene yields can vary considerably. (Allison and Simmonds 2017: table 3). To our knowledge sideflows of TP are not currently exploited commercially for extraction.

Solvent extraction is commonly cited as a method to extract lycopene oleoresin (using hexane, acetone, ethanol, dichloromethane, ethylene acetate, benzene ethyl ether or petroleum ether). Enzyme, supercritical fluids and high pressure can be used to assist the extraction (Fritsch et al. 2017).

The extraction process of lycopene leads to tomato fibre and tomato oil as by-products. However, no evidence has been found to indicate valorisation processes have been developed to find markets for these by-products (Bioactive 2008).

6.2.2 Animal feed

The distinction is often made between dried and fresh tomato pomace. For animal feed fresh pomace requires an ensiling stage for storage and use.

Ruminant

[143] e.g. Lycored produce extracts for food ingredients enhancers and nutraceutical products from whole tomatoes http://www.lycored.com/methodologies/.

Many papers study the effects of including tomato pomace (fresh or dry) in ruminant feed. If added in suitable proportions, it is considered to complement the regular feed of ruminants with no negative impacts.

Fresh tomato pomace can be ensiled with dry forage materials such as straw. The mixture can replace maize for cows, lambs and sheep (Heuzé et al 2015). Dried tomato pomace may be combined in rations for beef cattle, dairy cows, sheep, lambs and goats with other feeds such as soybean, sunflower protein, barley grain etc. (Heuzé et al 2015).

Pig

Studies shown that feeding growing pigs with 6% fresh tomato pomace significantly increases feed consumption compared to the results with commercial mash. Feed cost per kilogram is also reduced thanks to the use of TP. Moreover, a 35% fresh pomace in the diet of finishing pigs lead to a higher final weight, a total weight gain, an average daily gain and feed consumption. Feed efficiency was comparable to commercial products but with a lower cost per kilogram (Heuzé et al 2015).

It was also demonstrated in diets with dry tomato pulp that nutrient digestibility (DM, OM, protein and crude fibre) was significantly reduced with an 8% inclusion rate compared to 4%. Furthermore, adding a mixed enzyme preparation (amylase, protease, cellulase) to 8% tomato pulp rations resulted in increasing DM and crude fibre digestibility to the levels of the 4% tomato pulp diet, but not the organic matter and protein digestibility (Heuzé et al 2015).

Poultry

Dried tomato pomace can be used in poultry feeds, even if the high fibre constrains the metabolisable energy content and thus its practical use in poultry feed formulation.

For broilers, dried tomato pomace should be avoided in very young animals for optimal performance. It can be recommended at 5-8% for growers and up to 10-12% for finishers. After 4 weeks, a 20% diet can be used but with possible efficiency loss. Dried tomato pomace was also included successfully in diets for layers, which require a lower energy concentration than broilers. It was a substitute for wheat bran. However, inclusion rate above 10%may depress egg production (Heuzé et al 2015).

Rabbit

Dried tomato pomace is usable to feed rabbits. It is one of few products that are at the same time rich in digestible energy (13.7 MJ/kg), rich in digestible protein (71-74% digestibility) and rich in fibre – especially lignin (Heuzé et al 2015).

The optimum level of tomato pomace was determined to be 13.2% in the diet of growing rabbits. However, it was observed that dried TP can be incorporated up to 20-30% (replacing alfalfa meal or maize grain) in the diet of growing rabbits without affecting performance (Heuzé et al 2015; Bakshi, Wadhwa, and Makkar 2016).

Pet food

Tomato pomace is also used in pet food. The soluble fibre and the antioxidants properties make of it an ingredient with attractive properties (Globalpetfoodshrm 2012).

6.2.3 Anaerobic digestion (AD)

Examples of anaerobic digestion of tomato pomace can be found in Europe[144].As on organic putrescible material, tomato pomace meets the criteria to be used in AD. (Saghouri et al. 2017). Since tomato pomace is relatively acid (pH around 4) the effect of an alkaline pre-treatment was analysed. The conclusions were that TP is a suitable substrate for AD, and that alkaline pre-treatment does not give higher yields and even slows down the process. It has also been shown that extracting lycopene (a carotenoid) from tomato pomace does not increase the digestion yield (Calabro et al. 2015), high lycopene recovery even decreases methane production (Allison and Simmons 2017). Therefore, it appears that the best solution for AD would be to use tomato pomace without pre-treatment.

It is also possible to use a mixture of tomato pomace and other by-products (e.g. cucumber waste) to produce methane through anaerobic digestion (Gil et al. 2015). Dark fermentation for biohydrogen production from tomato pomace (Gadhamshetty et al. 2010) is also been posited, but to our knowledge not commercially implemented.

6.2.4 Composting

We do not have data that demonstrates commercial composting approaches specifically utilising tomato pomace, or how this can be distinguished from land spreading or biosolarisation (see below). However, it is reasonable to assume that some composting facilities, common in the EU, will treat tomato pomace as a co-substrate to other vegetal wastes, where it arises locally.

The undegraded tomato waste is transformed and stabilized thanks to aerobic thermophilic bio-oxidation. The composition of the starting material is of course a determinant to adapt the conditions, but it is estimated that composting of tomato wastes usually takes 2 – 4 months. It has been shown that this compost has adequate organic matter to help plant growth. The presence of bio-protective microorganisms (against plant pathogens and promoting plant growth) is another advantage of tomato pomace. Finally, composts might as well be used for the extraction of soluble humic substances with bio-fertiliser activity (Fritsch et al. 2017). Research has also shown that the results of tomato waste vermicomposting is suitable for use in plant growth and soil improver. For regular composting, it is recommended to wash the final compost in order to reduce the electrical conductivity (Fornes et al. 2012).

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[144] e.g. 1MW AD plant in Chiesea Northern Italy co-digests grape marc, tomato and olive pomace as feed stocks, Source: BTS Biogas GmbH.

6.2.5 Approaches found in research literature

Other food applications

Simply adding lyophilised or powdered tomato pomace may also enhance products such as tomato purée (Previtera et al. 2015) and other researchers indicate its potential for processing into new product applications (Dhungana, Chauhan, and Singh 2014; Karthika et al. 2016). However, the commercial demonstration of these applications has not been substantiated.

Pyrolysis

Pyrolysis of tomato waste leads to three phases:

- Liquid: can be used as liquid fuel or as organic compounds source.
- Solid: can be used as fuel, precursor for the manufacture of activated carbons or briquettes.
- Gaseous: can be used to heat the pyrolysis reactor or generate heat / electricity through a turbine. The formed gas are H_2, CO, CH_4 and CO_2.

The relative amount of the 3 phases depends from the reaction temperature but not from the sample size or weight. However, the composition of the gaseous phase varies according to these three parameters (Encinar, Gonzalez, and Martinez 2008).

Tomato seeds oil extraction

Tomato seeds are a principal constituent of tomato pomace. It has been found that those seeds present a high content of oil (up to 35%) (Giannelos et al. 2005). It is a potential renewable energy source and a substitution of diesel fuel which could help EU member states to reach the objectives set by the Renewable Energy Directive regarding renewable in transport. It has also been underlined that tomato seed oil could be used for nutritive purposes (Botinestean, Gruia, and Jianu 2014).

Cutin extraction

Cutin is the major component of the tomato skin. It consists of lipids, polypeptides, polysaccharides, phenolic compounds and hydrocarbon polymers. Cutin can be extracted with organic solvents, or recovered by acid hydrolysis (Fritsch et al. 2017). This substance can be used as a bio-plastic, and especially as a source for packaging material (Heredia-Guerrero et al. 2017).

Packaging and plastic from tomato pomace

The BIOCOPAC project aim was to develop a bio-lacquer dedicated to the protection of metal food packaging to increase the competitiveness of metal cans industry while ensuring good consumer health. The project developed an extraction method, worked on the formulation and the application of the lacquer with a supporting LCA of the new coating compared to the former one. However, the process is not yet mature for industrial applications (BIOCOPAC 2016).

Another study funded by the EU demonstrated the possibility to synthesise bio-plastic from tomato waste but this technology is not mature either (Fondazione istituto italiano di tecnologia 2016).

Biosolarisation

The residues of tomato processing can be used as soil amendments, and especially for biosolarisation. The solarisation is a soil disinfection technique that uses solar radiation to raise the temperature of the surface layer of soils (≤ 30 cm) to values above 40 °C.

Most pest treatments use chemicals and some of them have negative impacts on the environment. Biosolarisation can be a way to limit the environmental damage while keeping pests at a low level. Some products (chicken manure, poaceous crop residues, etc.) have already been shown to be compatible with biosolarisation. It was also demonstrated that tomato pomace and wine grape pomace are very promising products for biosolarisation (Achmon et al. 2015).

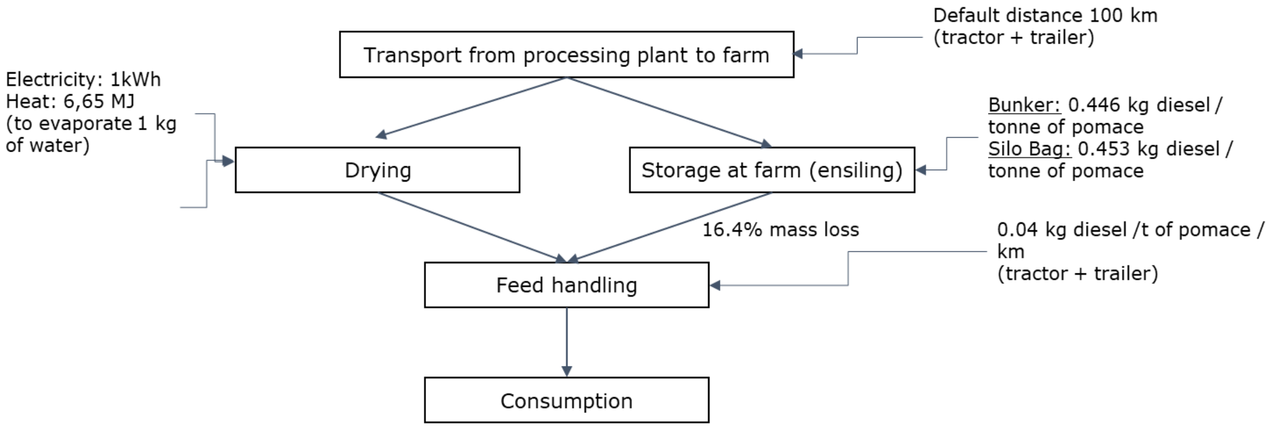
6.3 Technical description of valorisations options modelled

6.3.1 Animal feed

The process flow for use of tomatoes pomace as animal feed is shown in Figure 67

Figure 67: Process flow for use of tomato pomace as animal feed

Flow: 1 tonne fresh tomato pomace



Transport and cost for the producer

Since the pomace has a relatively high water content, transportation cost can limit AP's potential use as an animal feed. Therefore, this option is only viable for short distances between the processing plant and the farmer (from 5-10 km (ADEME 2000) to 150 km (Interview - tomato processing plant 2018)). However, since the tool will allow the type of transport and distance to be modified by the users, there is no need to improve on these initial default assumptions.

It appears that the treatment cost for the tomato pomace producer is zero (Interview - tomato processing plant 2018). Interviews have shown that there are usually intermediaries (feed merchants) between the producer and the farmer using pomace (Interview - tomato processing plant 2018).

Drying

Section 6.2 presents the potential use of both fresh and dried tomato pomace for animal feed (be it ruminant or not). The drying step should therefore be considered as optional. Different drying methods exist (Isik and Topkaya 2016; Goula and Adamopoulos 2005; Al-Muhtaseb et al. 2010) and vary in cost. This is why sun drying might be preferable (Heuzé et al 2015). Fresh tomato pomace is usually dried to 8% to 14% moisture to prevent spoilage (B. Yegorov and I. Malaki 2015). However, it seems that in practice drying is not performed (Interview - tomato processing plant 2018).

Ensiling

The direct storage of tomato pomace is complicated due to the high moisture content of the product which rapidly degrades. Indeed, the use of fresh tomato pomace is only possible for 3-4 days, after which the product becomes unfit for animal consumption (ADEME 2000).

To prevent this spoilage, it is possible to ensile the material. Ensiling is commonly used for storing forage stocks, especially for times when forage is less available. The method can also be applied to various food sideflows used for feed in order to extend their conservation life. Ensiling requires a tractor to pile pomace into a silo, then pack & press out air before covering or capping it hermetically. It has to be done immediately after the arrival of the material to prevent degradation. During a few days, the ensiled material ferments and after 2 to 3 weeks the products is stabilized. It can be then conserved up to 6-12 months. When moisture content is too high (around 90%), ensiling is not feasible alone. Fresh tomato pomace's high water content in outputs of processing plants may therefore require mixing with drier and more fibrous forage materials for ensiling.

The ensiling can either be done in covered bunker silos usually made of concrete or by bagging in plastic wrap. The latter are cheaper and allow reducing dry matter loss while being stored anywhere the farmer desires (Bacenetti and Fusi 2015). The environmental impact of both methods slightly differ since ensiling in bunker silos is performed with tractors while machinery is used for ensiling in plastic (Bacenetti and Fusi 2015).

Shrinkage is a common phenomenon during ensiling. Shrinkage can be estimated in a roughly average at 16.4% (The Beef Site 2014). Therefore, assuming 16% loss in mass the final usable tomato pomace silage gives 840 kg of silage from the original tonne of sideflow.

Feed handling and consumption

The feed handling can be mostly considered as transport between the silo and the place animals are fed. This is likely to be small or negligible contribution to fuel cost and GHG inventories.

Table 50: Model inventory for 1 tonne of fresh tomato pomace used as animal feed

INVENTORY			
Input			
Tomato pomace (fresh)	1	tonne	*Moisture 64-93% (select data 25.3%)*
Transport and treatment			
Transport-producer to farm	100	km	*With truck, then tractor and trailer (Based on interview)*
Drying (optional)			*Drying is not common* *Electricity: 1kWh** *Heat: 6,65 MJ** *(Ecoinvent 3)*
Storage at farm (ensiling) via silo bags	836	kg	*Plastic film 0.48 kg* *Diesel fuel 0.453 kg* *Lubricant oil 0.0136 kg* *Tractors 0.0145 kg* *Implement 0.0125 kg* *(Bacenetti & Fusi 2015)*
Storage at farm (ensiling) in bunkers	836	kg	*Concrete 5 kg* *Diesel fuel 0.446 kg* *Lubricant oil 0.0134 kg* *Tractors 0.022 kg* *Implement 0 kg* *(Bacenetti & Fusi 2015)*
Feed handling			*0.04 kg diesel/t TP/km by tractor and trailer (Ecoinvent 3)*
Output			
TP for feed	836	kg	*Loss due to shrinkage (The Beef Site 2014)*

* *Calculated Value. Data are given for the functional unit 'evaporation of 1 kg of water'. This allows users to use their own data for water content before and after drying. To analyse e.g. the drying of 1200 kg of wheat from 18 to 14 % water content, a user should:*

1) Calculate the amount of water evaporated per kg: (0.14 - 0.18) / (0.18 - 1) = 0.05 kg water evaporated per kg dried product (formula Wevap = (We – Wi) / (Wi – 100)).

*2) Calculate the amount of water evaporated: 1200 kg * 0.05 kg = 60 kg of water evaporated.*

*3) Link to the corresponding ecoinvent activity: 60 * activity 'drying of feed grain'.*

Calculated Value. Data are given for the functional unit 'evaporation of 1 kg of water'. This allows users to use their own data for water content before and after drying. To analyse e.g. the drying of 1200 kg of wheat from 18 to 14 % water content, a user should:

1) Calculate the amount of water evaporated per kg: (0.14 - 0.18) / (0.18 - 1) = 0.05 kg water evaporated per kg dried product (formula Wevap = (We – Wi) / (Wi – 100)).

*2) Calculate the amount of water evaporated: 1200 kg * 0.05 kg = 60 kg of water evaporated.*

*3) Link to the corresponding activity: 60 * activity 'drying'*

Comparable products

Many studies (refer to section 6.2) have demonstrated the possibility to use either fresh or dry tomato pomace for a wide range of animals (ruminants, pigs, poultry, etc.). The main products that could be substituted are summarised in Table 51.

Table 51: Substituted products by species and by type of tomato pomace

	Species		Substituted product	Maximum amount
Dry	Ruminant	Cow	Maize	12%
		Cow	Barley grain	32.5%
		Cow	Whole cottonseed meal	32.5%
		Beef	Straw	70%
		Sheep	Alfalfa hay	50%
		Goat	Soybean	100%
	Non-ruminant	Poultry	Wheat bran	10%
		Rabbit	Alfalfa meal or maize grain	13%
		Pig	Maize	2%
Wet	Ruminant	Cow	Maize	12% (DM basis)
		Lambs	Maize	30%
		Sheep	Hay	75%
		Sheep	Straw	15% (DM basis)
	Non-ruminant	Pig	Commercial mash	35%

Adapted from (Heuzé et al 2015)

There is no consistent relationship apparent between dry or wet pomace, the species fed and the content of product the pomace substitutes. Therefore, it is challenging to identify the common feed which would be replaced by tomato pomace – be it fresh or not. Not only has the feed to be palatable it also must allow rations to meet an animals overall nutritive requirements. Many papers identify both the nutrient requirement tables for each species and the contributions of each foodstuff (Kyntäjä et al. 2014; National Research Council 2001).

To determine the baseline for animal feed we propose to use **maize as the main comparable product**. Based on Table 51 the amount of substituted maize could be set at 15%. It would also be possible to consider wheat, since it is the most used cereal in animal feed (DEFRA 2017). To clear up ambiguities, the best option would be to allow the user to select himself the feed he wants to substitute and in which quantity.

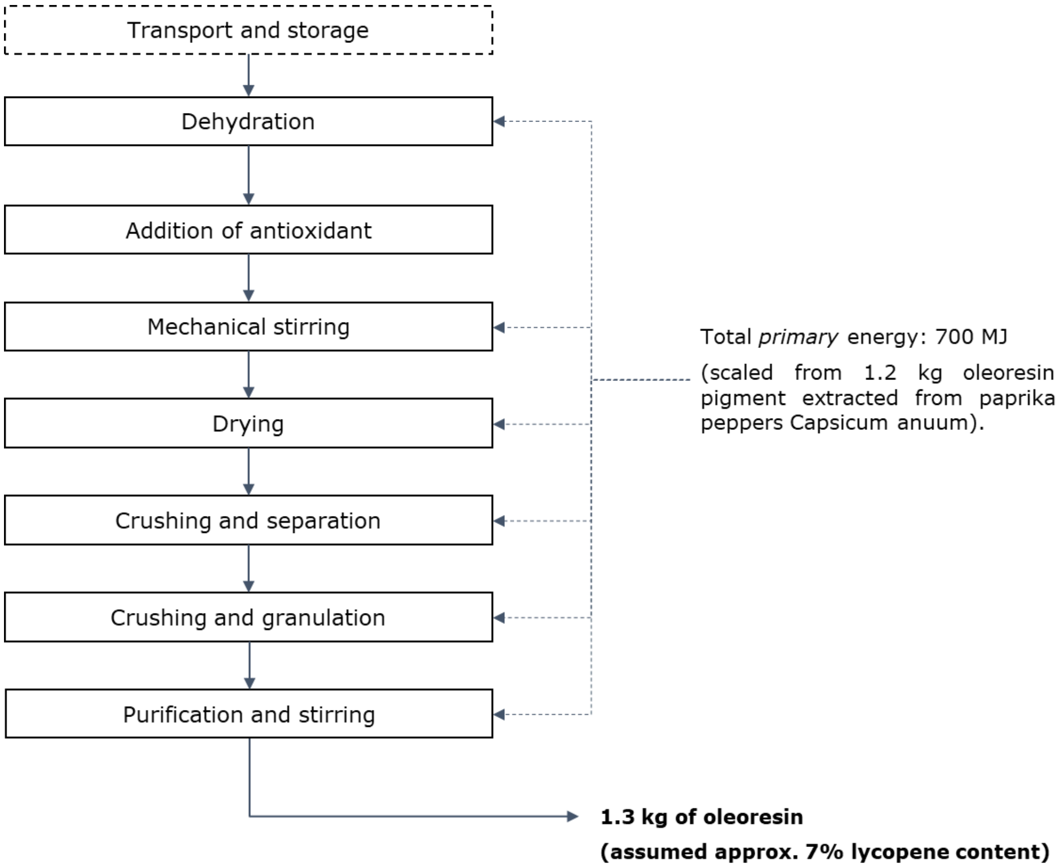
Interviews indicated that even if TP provides a reasonable content of protein and fibre, its relatively low energetic value makes it less attractive for farmers. TP is typically a cattle feed, though it can be used for other ruminants such as sheep (Interview - tomato processing plant 2018). Based on the interviews, TP mostly substitutes coarse fodder or alfalfa (Interview - tomato processing plant 2018).

6.3.2 Lycopene recovery

The process flow for use of tomatoes pomace for lycopene oleoresin extraction is shown in Figure 68 below. Primary energy[145] taken from the study is converted to process energy at point of use.

Figure 68: Process flow for use of tomato pomace in lycopene oleoresin recovery

Flow: 1 tonne of tomato pomace



145 In general primary energy also includes the sum of energy contributing to the production chain of energy carriers such as fuels and electricity, in addition to the actual energy content transferred from the fuel to the process. Primary energy factors can be applied, but these vary in methodology and context.

Transport and storage

Lycopene is a high value product. This is why it is very important to ensure that the source material is extremely well preserved before lycopene extraction. The product can for example be frozen or cooled down to prevent degradation (Lavecchia, Zuorro, and S.R.L 2007). This is a key sensitivity and caveat in assuming generic yields for the purposes of the inventory modelling. For this reason the raw pomace is assumed to be transported a short distance (20km) to a lycopene processing site for specialist drying, rather than dried on the juice processing site.

Lycopene oleoresin extraction

As described previously, there are several ways to extract lycopene oleoresin from tomatoes. Preferably the lycopene oleoresin extract should contain between 2%-10% lycopene. The two most common approaches are solvent extraction and super critical fluid extraction (SCFE). Lycopene is sensitive to oxygen and light, so all the manipulations should take place without contact with air or light. Extraction usually follows pre-treatment (drying and crushing). Drying can be performed by a tray dryer, a drum dryer or a fluid bed dryer (Bioactive 2008).

After the extraction, a purification phase is needed to separate lycopene oleoresin from the other carotenoids. Generally, HPLC method is used. Other methods are e.g., thin layer chromatography, adsorption chromatography, filtrations (membrane, microfiltration, gel, etc.), reverse osmosis or crystallisation (Choksi and Joshi 2007; Bioactive 2008). The process can terminate with a drying of the extracted compounds (freeze drying, spray drying or rotary vacuum drying) in order to produce lycopene oleoresin powder (Bioactive 2008).

The amount of lycopene oleoresin recovered after the process varies according to different process examples found. For oleoresin, between **0.56 and 1.29 kg from 1 tonne of wet pomace (90% moisture)** can be estimated **for solvent extraction (**Lu et al. 2014) **and around 0.7 kg per tonne for SCFE (**Bioactive 2008). An assumption is also necessary here on the relative lycopene content of the oleoresin. Residual Tomato fibre obtained after extraction can be sold (Bioactive 2008).

Super critical fluid extraction (SCFE):

The major advantage of SCFE is that it does not use organic solvents with associated health and environmental risks. Examples of extraction performed by a Soxhlet extractor can be found in the research literature. Topal et al. 2006 present this approach with the following conditions:

Vessel size	10 mL
CO_2 flow rate	2,5 mL/min
Pressure	40 Mpa
Temperature	373 K
Lycopene recovery	94%

Once lycopene is extracted, the purification of lycopene may be performed the following way (Choksi and Joshi 2007):

HPLC of SCF Extract
Solvent (CO_2) is evaporated under a stream of nitrogen and subsequently re-dissolved in dichloromethane. Mobile phase, a mixture of eluent A: Methanol-water 96:4 w/v and eluent B: Methyl tertbutyl ether with 1000 ml/min flow rate (linear gradient was applied in 60 minutes) from initial conditions (A:B, 83:17 v/v) to those maintained until the end of analysis (A:B, 33:67 v/v).

Clearly this extraction method relates to a laboratory approach. The only useful commercial scale extraction description found uses ethyl acetate for solvent extraction (FAO 2009). This describes processes for crops grown/selected specifically for high extraction yield, rather than foodchain sideflows.

Solvent extraction

This has been take from a patent published by Lu et al 2014 (Figure 68):

Preparation[146]

The starting raw material containing lycopene is tomato pomace with the seeds. The first step, **dehydration** is carried out by compression to reach a water content of the dehydrated material at about 70% of the total weight. After, a water soluble **antioxidant** (e.g. proanthocyanidin, grape polyphenol, tea polyphenol, ascorbic acid, etc.) is added. Then, the material is **dried** through a belt dryer (drying temperature 200-300°C) to reach a water content of 10-20% by weight. The pomace is then **crushed** into 4-6 mm pieces. The weight of the tomato seeds is less than 0.5% of the total weight, and the weight of the tomato skins is greater than 99% of the total weight. A **second crushing** occurs, to particles of 40-60 mesh. A **granulation** can also be performed to obtain particles with a diameter of 0.3-0.5 cm and length of 0.5-1 cm.

Extraction

The organic solvent can be an alkane, esters or ethers (e.g. ethyl acetate). The addition of the organic solvent is 1-10 times weight of the granules. After extraction, powdered active carbon treatment is carried out. The weight ratio of the active carbon to the resultant extraction is 1150-500, the stirring temperature is 40-80° C, and the stirring time is 30-150 minutes. Extraction can also be assisted by ultrasound, microwaves or high-temperature solvents (Bioactive 2008).

No data has been found to enable practical assumptions to be made for process energy consumption at a commercial scale for lycopene oleoresin extraction from

[146] This specific preparation has been identified for solvent extraction, but the scheme drying – milling – extraction is also used for SCFE extraction.

tomato pomace. Instead inventory data has been derived from Saling et. al (2008) for extracting carotenoids from paprika (Capsanthin, Capsorubi). This has been assumed on the basis of 1.2 kg of oleoresin produced, not the yield from the orginal feedstock, which is presumed to be similar. Therefore, care should be taken interpreting the results[147].

Table 52: Model inventory for lycopene oleoresin extracted from 1 tonne of fresh tomato pomace

INVENTORY				
Inputs				(Saling et al 2006 energy data has been scaled to tomato pomace oleoresin yield)
Tomato pomace (fresh)		1	tonne	*Presscake from fresh juicing with 90% moisture*
Transport & treatment				
Transport- producer to plant		20	km	*With truck, estimated distance*
Drying heating fuel energy		407	MJ	*Taken from Saling et al 2006 (379 MJ fuel per 1.2kg oleoresin). Applying 80% efficiency factor conversion of fuel to process heat approximates to* ***90.5 kWh drying heat***
Drying electricity		6	kWh	*Taken from Saling et al 2006 (20MJ electricity per 1.2 kg oleoresin)*
Extraction heating fuel energy		82	MJ	*Extrapolated from Saling et al 2006 (Extraction converted from ~100MJ primary energy per 1.2 kg oleoresin to utility energy of 76MJ fuel per 1.2 kg oleoresin), CAVEAT:assumes average primary to process energy conversion factor based on similar split to drying – this assumes electricity is a minor component for extraction. Applying 80% efficiency factor conversion of fuel to process heat approximates to* ***18 kWh extraction heat***
Output				
Lycopene oleoresin yield from tomato pomace		1.3	kg	*Based on Lu et al. 2014 Bioactive 2008*

[147] The reference was checked with other researchers working on extraction processes and was to their knowledge the only available reference on industrial extraction relevant for this study. Their judgement was that the energy consumptions was toward the lower end compared to their expectations. However since this view, extraction energy reported by Saling et al has been added to the inventory. This was omitted from the original inventory.

Comparable products

Lycopene oleoresin is a high value product. However, the price depends a lot on the purity of the product. A kilogram of lycopene oleoresin may worth between $12 and $6000, with most of the values ranging [$150-$500] (Bioactive 2008). Considering that yields from raw processing tomatoes varies from 80 to 150 kg/t this means that after extraction, 1 tonne of tomato pomace would worth approximately 12-75 k€ (Bioactive 2008). The applications of lycopene are multiple:

- Food additive (because of its antioxidant properties);
- Pharmaceutical products (because of its anticancer properties);
- Food colorant.

Market share of synthetic carotenoids from the chemical industry accounted for 76% of the market in 2014. The 24% left are natural extracted carotenoids. However, the latter is expected to have the strongest growth between now and 2020 (3.9%) in response to the increasing consumer demand for natural products. With a global expected growth rate of 3.5%, the market should reach $1.8 billion for 1,800 metric tons 2020 (Deinove 2015). Lycopene represents 7% of this carotenoid market but actual projections of the proportion of synthetic and extracted lycopene were unavailable.

Lycopene pills as food supplements suggest that lycopene for food products is mostly extracted from tomatoes harvested for that purpose. The varieties of tomatoes exploited are chosen based on their lycopene content but also on the availability of the cofactors which carry the lycopene to the cell nucleus. Thus, it would make sense to consider as a substituted product lycopene from tomatoes dedicated to this purpose.

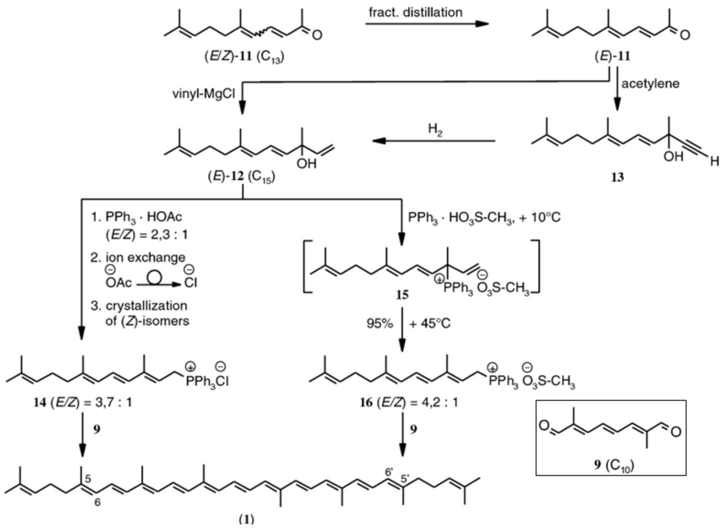
There is no other product with the exact same properties and applications which could be substituted by lycopene but rather and range of products. However, several approaches can be considered regarding the substituted products. It would therefore be possible to compare lycopene extracted from tomato pomace with:

- Other extracted food colorant / additive / pharmaceutic product.
- Lycopene extracted from tomatoes harvested for this purpose[148].
- Lycopene extracted from blakeslea trispora (a fungus) [148].
- Chemically synthesized lycopene[148].

Below is detailed the chemical synthesis of lycopene (Ernst 2002):

[148] According to Commission Regulation (EU) No 231/2012 of 9 March 2012 synthetic lycopene, lycopene from red tomatoes and lycopene from blakeslea trispora are all listed as food additives (respectively E160d (i), E160d (ii) and E160d (iii))

Figure 69: Industrial synthesis of lycopene



Saling et al compared chemically synthesized and extracted carotenoids (Saling et al. 2006). The details of the normalised impacts of the two production routes (synthesis and extraction) of carotenoids is shown in Table 52. In the context of the inventory impacts from energy consumption relating to material flows are considered. The "Total Primary Energy" (from cradle to grave) reported is approximated as 650 MJ / 1.2 kg Oleoresin extracted[149] (Saling et al. 2006). The production primary energy of a functionally equivalent synthetic product ('Lucantin red') was reported to be 225 MJ / 0.41 kg of chemical. This has been converted to process energy using broad assumptions.

Assumptions and limitations

The energy data presented by Saling et al (2006) is ostensibly for the drying and extraction required for a pigment rich oleoresin yielded from an unreported quantity of capsicum peppers for dried 'paprika'. The study goal is to compare the environmental impact with a synthetic (Canthaxanthin) poultry feed additive used for influencing egg colour. Saling et al (2006) report both 140g of carotenoid and resin content in 1 kg of 'paprika', (dried is 0.25 kg) but no clear yield or extraction process information is given.

The study's energy inventory is in relation to a mass of 1.2 kg of parprika carotenoid oleoresin which is scaled based on a reference yield of 1.29 kg (~1.3kg) lycopene containing oleoresin per tonne of tomatoe pomace. Using this data as such assumes that it is reasonably reflective also of the energy requirements for feedstock bulk processes e.g. drying, extraction processes and yields of carotenoid rich oleoresin from tomato pomace after fresh juice pressing. These assumptions are not adequately substantiated and should be taken with caution as a key limitation of this inventory. Lycopene content of tomato peel, pomace and pulp varies depending on conditions, but Lycopene extracted per mass of pomace reported in laboratory studies differ by orders of magnitude, but with limited

[149] This includes growing, harvesting and transportation of the material to be extracted (For TP in our case this is not considered).

information reported to draw strong conclusions as to why this is (Allison and Simmonds 2017).

The total *primary* energy for the whole process is shown to be approximately 650 MJ per 1.2kg of Oleoresin. Drying, the greatest component of energy, is estimated to be 510-520 MJ primary energy per 1.2kg oleoresin extracted. 30 - 40MJ of this are attributed to the peppers agricultural production so must be excluded from the processing inventory. The *primary* energy Saling et al attribute to the extraction process is an additional 100 MJ for 1.2 kg of oleochemical resin.

The data presented by Saling et al (2006) only details specific process energy consumption for the dominant paprika pepper drying process. This has been split into process electricity (20 MJ) and heating fuel (379 MJ) reported in relation to the producton of 1.2 kg oleoresin.

For the extraction energy, the primary energy for electricity or heat are not described so factors cannot be applied to obtain the precise process electricity and heat Saling et al have identified for the extraction step. Instead it has been assumed that extraction energy will predominantly be heat (used in solvent processing). Therefore, applying a primary energy to process energy conversion factor, which is loosely based on the quotient of the drying process energy data and primary energy data reported, the heat energy estimate for extraction may be approximated in the inventory as 75 MJ/ 1.2 kg oleoresin. This is a crude assumption, but in the absence of specific published extraction data it has been assumed for tomato pomace. This is uncertainty must also be seen in the context also of significance of the large uncertainty, and sensitivity, of lycopene content of feedstock and resulting yields on inventory results (Allison and Simmonds 2017). This is perhaps one reason why commercial lycopene extraction is based on whole crops selected specifically selected for consistently high lycoepene content[143].

6.3.3 Anaerobic digestion

Energy recovery from whey permeate was modelled in accordance with the model used for all side flows in the spreadsheet tools (Östergren et al, 2018). The effect of co-digestion with other substrates is not considered and thus the value should be considered as conservative. This valorisation route leads to three specific utilities: electricity, heat and digestate (used as fertiliser). Table 53 and Table 54 provide an overview of the inventory used for tomato pomace (23% DM).

Table 53 Biogas potential tomato pomace, per tonne Fresh Matter (FM) with a Dry Matter content of 25,3%

Side-flows	Theoretical biogas yield in m3/t FM	Theoretical CH4 content in %	LHV in MJ/ MJ/t FM
Tomato pomace	117	59	21.20

Table 54 Emissions and energy recovery tomato pomace. per tonne Fresh Matter (FM) with a Dry Matter content of 25.3%.

Emissions AD kg $CO_{2\ eq}$/ t FM input	Net Electricity KWh/t FM input	Net Thermal energy KWh/t FM input	Digestate t FM/t FM input	Credit for digestate application kg $CO_{2\ eq}$/ t FM input
54.2	225.5	105.0	856.5	-6.36

Transport and storage

As described in the animal feed section, tomato pomace has a high moisture content so transport time should be as short as possible.

Moreover, the quality if the biogas produced decreases if the products are not used directly after the processing phase. The solution to avoid material degradation is to store it at 0°C but this can turn relatively energy consuming if the storage is performed for a too long period.

Inputs mixing and AD process

The tomato pomace is usually not digested alone. It was demonstrated that the addition of TP into cattle dung increased the biogas yield and a stable co-digestion could be achieved (Saev, Koumanova, and Simeonov 2009; Saghouri et al. 2017).

The optimal conditions are presented in the table below.

Parameter	Value
Condition	Mesophilic
Temperature	~35°C
Best TP/manure ratio	~20/80
Solid content	7-8%
Stirring	5 min in 150 min, 120 rpm
Starting pH	7.2
Fragments size	1.3-10 mm

Comparable products

The selected comparison products used in the model are:

- Electricity (country specific) and EU average heat production
- Electricity and EU average heat production
- Electricity and EU average heat production and production and application of mineral fertiliser (the digestate from the AD is spread on land, providing nitrogen, phosphorous and potassium to the soil)
- Hydropower electricity and wood chips

6.3.4 Landspread

Landspread of tomato pomace is considered principally for the purpose of disposal in the model. It is assumed to be carried out on existing agricultural land where there may be some benefits as a soil conditioner and recovery of some trace nutrients, but these are not the principle reason for this option. However, this is considered to be different from landfill as a municipal waste disposal option.

Comparable products

The comparable action was assumed to be "doing nothing" – since the benefits of land spreading of apple pomace is small. The disposal service is the principle product here. Comparison with other disposal options such as landfill or incineration are not considered viable options in this model due to regulatory and technical feasibility.

6.4 Description of the FORKLIFT spreadsheet model for tomato pomace

6.4.1 Generic information

The model calculates the GHG emissions and costs associated with the handling of 1 tonne of tomato pomace with a dry matter content of 25%.

An average value of cultivation of tomatoes to a tomato processor has been assumed (0.17 kg CO_2eq./kg tomatoes).

The upstream burden is calculated though economic allocation according to the REFRESH report D5.4 Simplified LCA & LCC of food waste valorisation (Östergren et al 2018). It should be noted that generally the revenue from side-flows of food or drink producers compared to the main products have a much lower value. Therefore, the proportion of the upstream GHG burden allocated to the valorisation approach is also typically low relative to its processing impacts since economic allocation is applied. Since the upstream burden is an approximation (tomato processing) large allocation factors will decrease the accuracy of the model.

An overview of the spreadsheet tool and option included in the model is provided in Figure 70 and in the next section the sub - models are described. The full inventories are provided in Annex 11 as supplementary information.

Critical parameters were qualitatively assessed using the model developed previously in D5.4 Simplified LCA & LCC of food waste valorisation -Description of standardised models (Östergren et al 2018). Note that the matrix (Figure 71also includes parameters that cannot be changed (Annex 11) as an information to the user. The reason for keeping them constant is that they are generic numbers used in several models to allow comparison between different side flows. The assessment of the critical parameters is based on the *relative* impact of a parameter compared to the total impact of the valorisation process modelled.

Figure 70 Overview of the spreadsheet model for tomato pomace

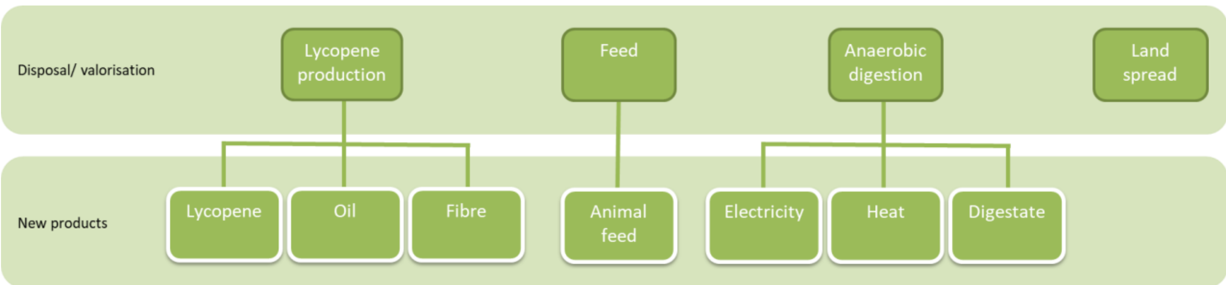
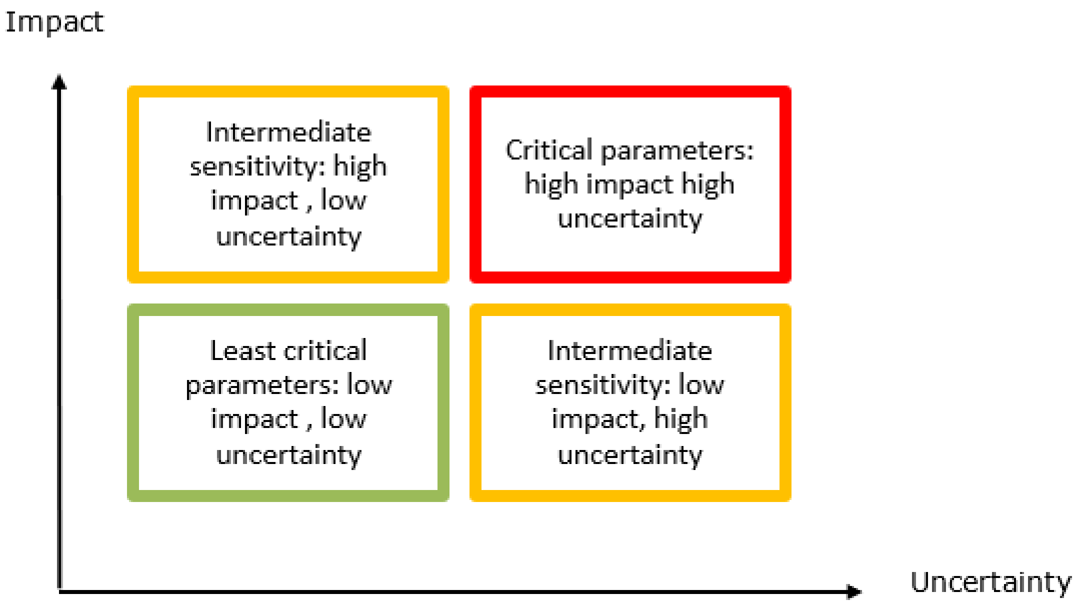


Figure 71 Assessment of critical parameters



6.4.2 Tomato pomace as feed

Figure 72 Tomato pomace used as feed in FORKLIFT

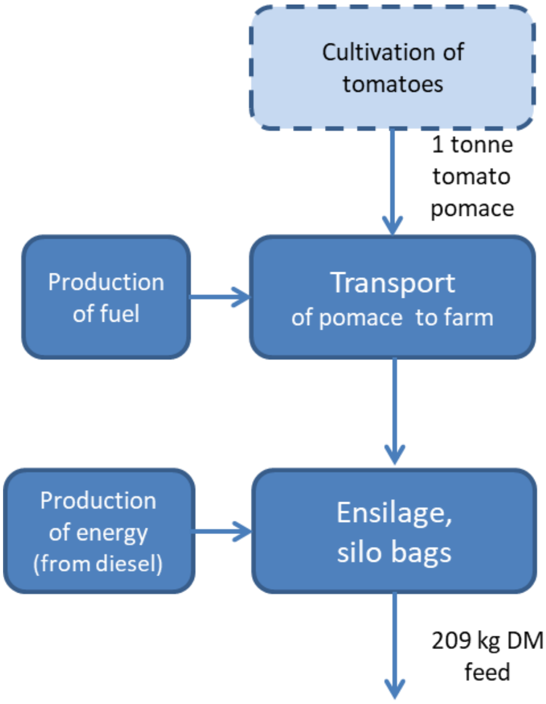


Figure 72 illustrates the processes that are considered in the calculation of GHG emissions and costs for using the tomato pomace as feed. The environmental impact and cost from the upstream processes are included if the tomato pomace carries an economic value (therefore in dotted line).

The pomace is transported to the farm by truck. To prevent spoilage, the pomace is ensiled in silo bags requiring some energy.

Regarding the use of truck, the GHG calculation covers the emissions of producing the fuel and combustion in the truck. The cost takes into account the cost of the fuel.

In this valorisation option, 209 kg DM of feed is the useful product providing mainly fibre and energy to the animals. Common feeds that also provide energy and fibre are hay and maize which the results are compared with. Two examples of production systems of hay are provided as comparable products being

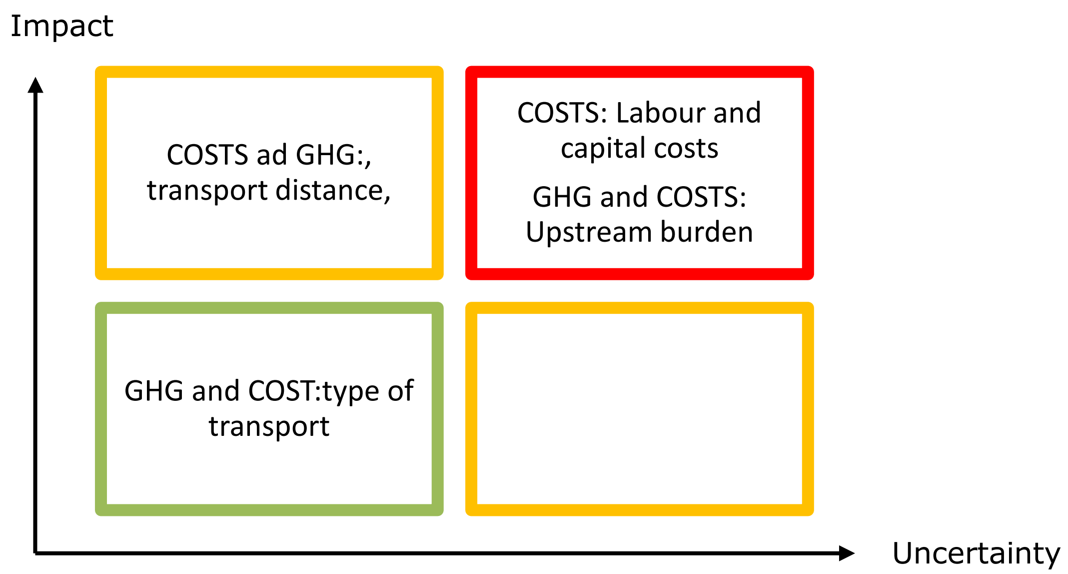
- extensive hay production (using no mineral fertiliser)
- intensive hay production (using mineral fertiliser),
- maize, in the same amount of dry matter.

The modelling parameters are provided in Table 55 and the assessment of critical parameters is provided in Figure 73

Table 55 Adjustable model parameters for tomato pomace used as feed

Parameter	Default value	Unit	Comments
Country	EU		Determines energy mix and cost
Transports to farm (Tractor Single trailer 50% LF, cooling)	20	km	A pre-selection of transport options is provided, distances can be set freely.
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 73 Assessment of critical parameters for feed production of tomato pomace



6.4.3 Tomato pomace as food ingredient (lycopene)

Figure 74 Lycopene oleoresin from tomato pomace in FORKLIFT

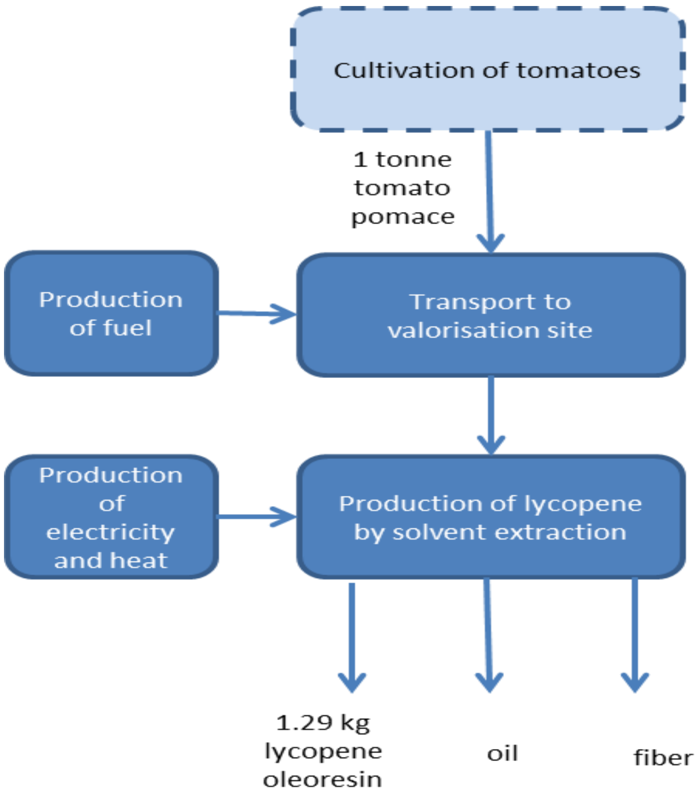


Figure 74 illustrates the processes that are considered in the calculation of GHG emissions and costs for using the tomato pomace to produce lycopene oleoresin. The environmental impact and cost from the upstream processes are included if the tomato pomace carries an economic value (therefore in dotted line).

The pomace is first transported by truck from a nearby juice processor to the processing plant. The drying step is more likely to be carried out at the pomace production site to prevent spoilage and reduce costs. However, here it is included as part of the plant process assuming typically a short distance from plant to source.

At the plant, the pomace undergoes several processing steps involving e.g. drying crushing, extraction and purification. In the calculation of GHGs and cost, only the production of heat and electricity is taken into account in the lycopene plant. Apart from the lycopene, the process also yields oil and fibres.

The modelling parameters are provided in Table 56 and Table 57 and the assessment of critical parameters is provided in Figure 75.

Regarding the use of fuel, electricity and heat, the GHG calculation covers the emissions of producing the fuel and combustion in the truck, as well as emissions from production of heat and energy. The cost takes into account the cost of the electricity, and fuel for transport and heat.

In this valorisation of 1 tonne of pomace, approximately 1.3 kg of lycopene oleoresin is produced in addition to oil and fibre by-products. There is no other product with the exact same properties as lycopene, but it could be compared to other extracted natural food colorants. Synthetic colorants are alternatives but are not perceived as "natural" and thus the market use can be different from a consumer perspective. GHG for production of 1.3 kg of a carotenoid product obtained from microalgae is included for comparison. Note that a higher yield of lycopene oleoresin will imply a large quantity of comparing product (and large impacts of these) – this is **not** considered in the model! Changes in yield will not change the impact of the process itself.

Table 56: Model inventory for lycopene oleoresin extracted from 1 tonne of fresh tomato pomace

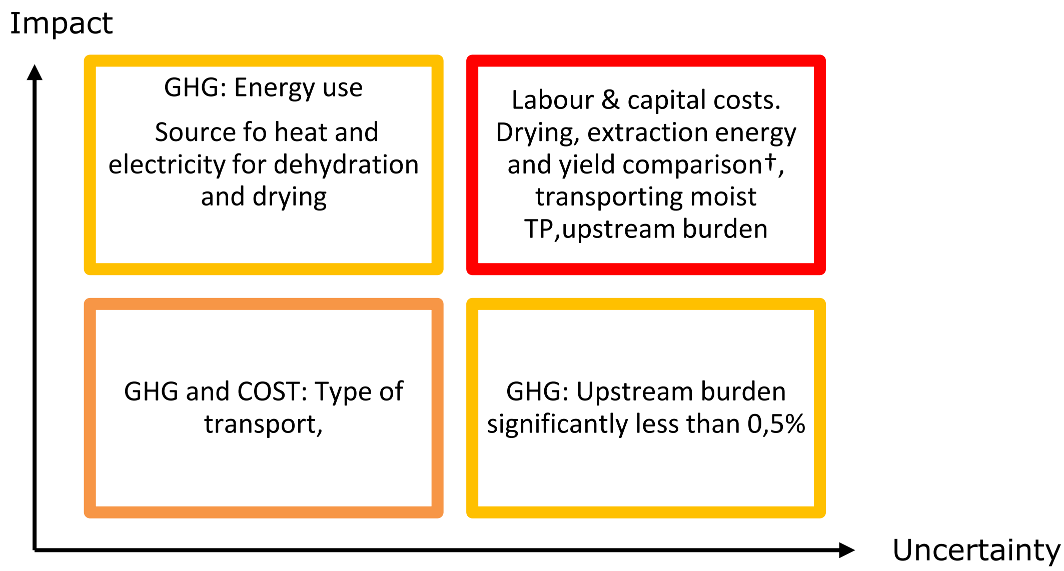
INVENTORY	Default value	Unit	Comments
Input			
Tomato pomace (fresh)	1	tonne	*Moisture 70% (based on Lu et al 2014)*
Transport & treatment			
Transport- producer to plant	20	km	*With truck, estimated distance*
Total heat energy of the process	109	kWh	*Adapted from Saling et al (2006) assuming 80% efficiency in heat generation.*
Total electric energy of the process	6	kWh	*Adapted from Saling et al (2006)*
Output			
Lycopene oleoresin	~1.3	kg	*Yield has been assumed from patent (lu et al 2014)*
(6.7% Lycopene content)	(86	g)	

Table 57 Adjustable model parameters for lycopene oleoresin using 1 tonne of tomato pomace (fresh weight)

Parameter	Default value	Unit	Comments
Country	EU		Determines energy mix and cost
Transports of Tomato pomace to processing plant (Rigid truck, 20-26 t, Euro 4, 50% LF, cooling)	20	km	A list of transport options is provided, distances can be set freely. However, the high water content of the pomace prior to transport in this inventory process is considered to limit distance (cost and spoilage) so default is 20km.

Parameter	Default value	Unit	Comments
Energy use for extracton	20	kWh/tonne pomace	Saling et. al (2006) general extraction process of carotenoids - assumed to be mostly heat for solvent recovery.
Heat use for drying	90.5	kWh/tonne pomace	See above
Fuel used for generating heat	Light fuel oil		A pre-selection of fuels is provided (biogas, natural gas, hard coal, wood chips from forest, EU-average heat)
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 75 Assessment of critical parameters for lycopene oleoresin



† approximated from energy per extracted mass of paprika pepper oleoresin

6.4.4 Energy recovery using anaerobic digestion (AD)

The calculations are based on the streamlined approached recommended in the REFRESH report "D5.4 Simplified LCA&LCC of food waste valorisation" (Östergren et all 2018).

Figure 76 Energy recovery from tomato pomace

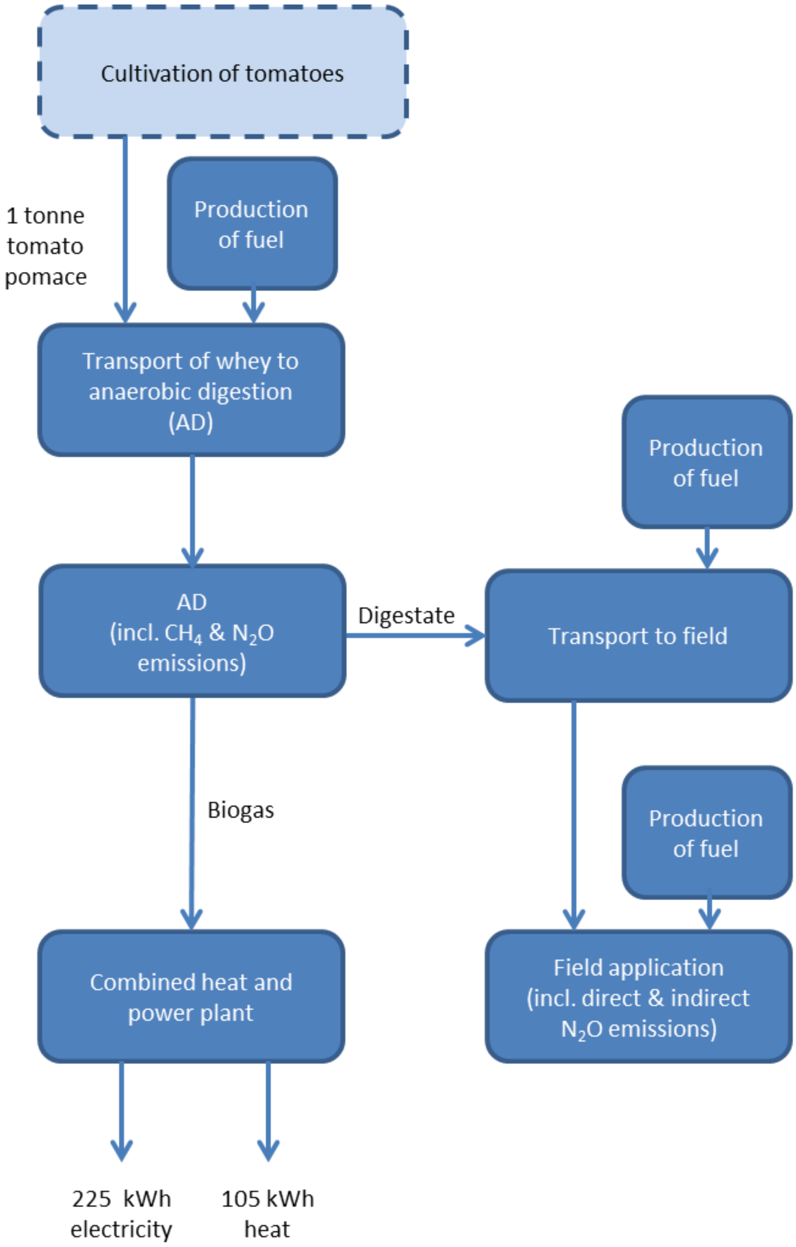


Figure 76 The figure above illustrates the processes that are considered in the calculation of GHG emissions and costs for using the tomato pomace to produce

biogas. The environmental impact and cost from the upstream (dotted line) processes are included if the tomato pomace carries an economic value.

The pomace is transported to the AD plant by truck.

Regarding the use of fuel, the GHG calculation covers the emissions of producing the fuel and combustion in the truck, as well as fugitive emissions from biogas storage and the biogas engine (slip) generating heat and electricity. The cost takes into account the price of fuel for transport.

In this valorisation option, 225 kWh electricity and 105 kWh of heat are the products. Alternative ways of producing heat and electricity are.

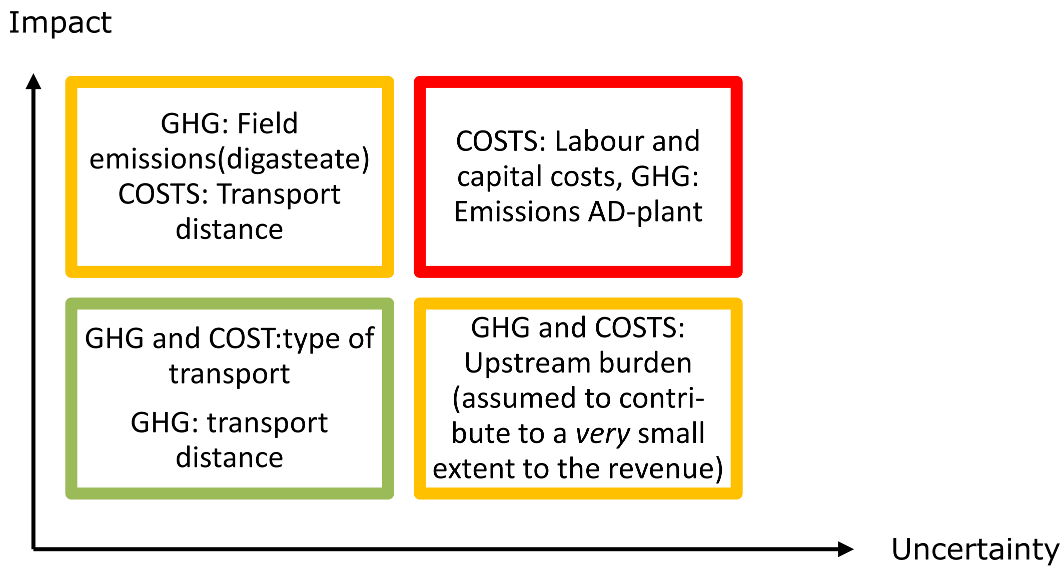
The modelling parameters are provided in Table 58 Adjustable model parameters for biogas and energy production (AD) from 1 tonne of tomato pomace Table 58 and the assessment of critical parameters is provided in Figure 77.

- Hydropower and wood chips heat
- Electricity and heat EU average heat
- Electricity and heat EU average including production and application of mineral fertiliser since the digestate from the AD commonly is spread on land, and therefore provides nitrogen, phosphorous and potassium to the soil.

Table 58 Adjustable model parameters for biogas and energy production (AD) from 1 tonne of tomato pomace

Parameter	Default value	Unit	Comments
Country	EU		Determines energy mix and cost
Transports of digestate to the field (tractor single trailer 50% Load Fraction (LF)	20	km	A pre-selection of transport options is provided, distances can be set freely.
Transports of pomace to the AD plant (tractor single trailer 50% Load Fraction (LF) (	20	km	See above
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 77 Assessment of critical parameters for biogas and energy production tomato pomace (AD)



6.4.5 Tomato pomace as landspread

Figure 78 Tomato pomace used as landspread

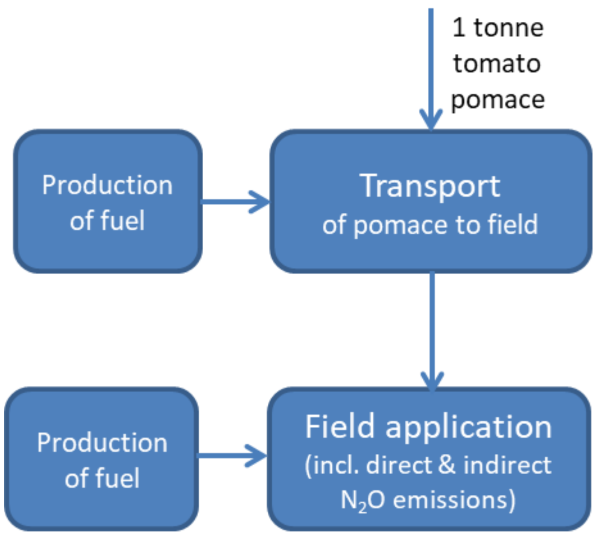


Figure 78 illustrates the processes that are considered in the calculation of GHG emissions and costs of this option for handling tomato pomace. The system starts with transport of the tomato pomace to the field by truck. In this scenario it is assumed that the tomato pomace carries no economic value, and therefore the side flow does not carry any environmental impact or cost from the upstream processes (production and transport of tomatoes to the tomato processor).

The tomato pomace is spread by use of tractor onto the field. The climate impact of direct and indirect emissions of nitrous oxide (N_2O) is taken into account in the calculations.

Regarding the use of truck and tractor, the GHG calculation covers the emissions of producing the fuel and combustion in the truck/tractor. The cost takes into account the cost of the fuel.

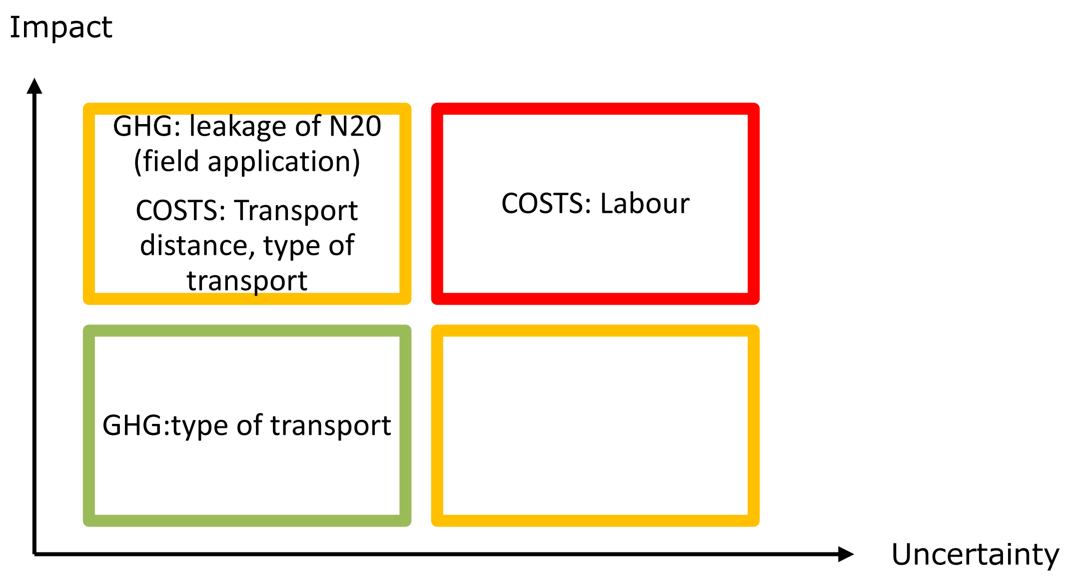
In this valorisation option, no product is produced, and hence no comparison products are shown in the result figures.

The modelling parameters are provided in Table 59Table 58 Adjustable model parameters for biogas and energy production (AD) from 1 tonne of tomato pomace and the assessment of critical parameters is provided in Figure 79.

Table 59 Adjustable model parameters for landspread of tomato pomace

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transports to the field (tractor single trailer 50% Load Fraction (LF)	20	km	A pre-selection of transport options is provided, distances can be set freely.
Labour and capital costs	0	EURO	Set by the user

Figure 79 Assessment of critical parameters for land spread of tomato pomace



7 Annex 7: Vegetable oil press cake

List of abbreviations

AD	Anaerobic digestion
ADF	Acid Detergent Fibre
DM	Dry Matter
FAN	Free amino nitrogen
GHG	Greenhouse gas
IP	Inorganic Phosphorous
HHV	Higher heating value of gross calorific value (total heat available from combustion reaction)
NDF	Neutral Detergent Fibre
LHV	Lower heating value or net calorific value (minus latent heat absorbed by combustion reaction products)

7.1 Background

7.1.1 Rationale

Vegetable oil is by definition a triglyceride extracted from a plant. The term can either refer only to plant oils that are liquid at room temperature (Saroj 2007) or regardless of a substance's state of matter at a given temperature (Dand 1999). Therefore, vegetable oils solid at room temperature can be called vegetable fats, while vegetable waxes lack glycerine in their structure. Although most of the plant parts might yield oil, vegetable oil is commercially extracted primarily from seeds or fruits. **In the context of this Annex section the term 'oil' refers exclusively to food grade vegetable oil**, unless otherwise specified.

Oil can be extracted from a great number of plants, for example coconut, corn, palm fruit, rapeseed, soybean, almond, colza, etc.

Vegetable oils are used mainly for culinary purposes, thanks to their flavouring, texturing, frying, etc. properties. They are also used for pet food and animal feed formulations. Industrial applications have been developed as well for vegetable oil, with applications as wide as cosmetics, candles or paints. The last major use of these oils is fuel, since they are used to make biodiesel with properties equivalent to conventional diesel.

Vegetable oils can be classified either by sources (e.g. nut oils) or by use (e.g. edible oils). The inventory and model focusses only on food grade rapeseed oil processing sideflows for valorisation since this has been identified in the previous REFRESH reports to be one of the top 20 valorisable food chain sideflows (Moates et al 2016). Typically, this is from crop varieties developed for their lower erucic and glycosinolate content. For example, originating in Canada, the term Canola is used to represent rapeseed varieties bred for oils containing less than 2 per cent erucic acid and the solid component of the seed must contain less than 30 micromoles per gram of glucosinolates (Canola Council of Canada 2017). In Europe erucic acid levels must not exceed 5 per cent, by law for food grade use, with maximum contract levels in practice set to 2 per cent. The 2 per cent limit is likely to be adopted shortly in the EU legally standard (AHDB).

Crude oilseed rape press cake is the solid remaining after the mechanical pressing of the plants/ seeds to extract crude press oil. Whilst it is feasibly possible to obtain yields up to 90% of the rapeseed oil through single or two stage mechanical 'full pressing', the much lower pressing rates (1/70th) and increased capital costs to meet throughputs required which can restrict wider uptake of this approach (Boeck n,d). Instead commercial plants typically employ 'pre-pressing' to remove 65-75% of the oil leaving an expeller meal with 20% oil content and then employ solvent extraction processes to obtain the remaining 20% of the oil down to 0.8% of the remaining press cake (Anderson n.d.).

In 2017, 9.9 Million tonnes of rapeseed oil were produced in the EU-27 and 23.7 Million tonnes of rapeseed were crushed[150]. The high mass balance average yield of 42% suggests that high yielding techniques typical of solvent extraction dominates the process. However, it must also be understood that food grade use is only a quarter of the total domestic consumption, the remaining use is for industrial or biofuels use, so would have a lesser influence on such an average.

Nevertheless, this supports information from older literature sources that solvent extraction process is the major process in both food grade and industrial processing. And whilst it is possible to obtain high yields from mechanical pressing only, its application for similar throughputs can require significant capital consderations and plant configuration (Boeck). Therefore, a solvent de-oiled rapeseed meal would appear to be the main sideflow from commercial food grade rapeseed oil production. A pre-pressed oil rich press cake going into solvent extraction is therefore predominantly an intermediate process material, rather than a sideflow. The exceptions will probably be medium or small and cold pressing sites, or technically advanced double pressing plants but as in other large rapeseed processing areas such as Canada (Canola Council 2017) their contribution to this sideflow at the EU level is considered to be relatively small.

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[150] Oilseeds and products productions 2017 EU-28: USDA Foreign Agricultural Services.

7.1.2 Vegetable oil production process

There are three main phases in oil production: pre-treatment, extraction and post-treatment / purification.

Pre-treatment

The first step of pre-treatment is cleaning in order to remove impurities such as dust, stones or leaves. Then seeds can be pre-heated to avoid bursting. The following step is flaking, where the objective is to break out the husks without degrading the oil quality. The best size for flakes is 0.30-0.38 mm. The latter are then heated at 80-105°C during 15-20 min (Fediol 2017; Canola Council of Canada 2017).

Extraction

The extraction depends on the oil content of the starting material. For seeds with high oil content (with more than 20% content e.g. rapeseeds), the first extraction is mechanical pressing, generating the press cake. The remaining oil content in the press cake can be up to 14% (Amisy 2012). Screw presses or continuous presses are usually used (Canola Council of Canada 2017). These press cakes with relatively high oil remaining content are called *expellers* or *expeller meal*.

Seeds with lowest oil content (with less than 20% content e.g. soy) after heating and flaking are subject to solvent extraction. For oilseeds with higher oil content such as rapeseed (40% w/w oil) mechanical pre-pressing is employed and up to 14% of the residual oil in the press cake or expellers is then extracted using solvents. Hexane is the most widely used solvent thanks to its low boiling point (67°C) and the fact that oil is strongly soluble in it (Amisy 2012). Counter-current extraction is generally used to obtain the highest yield. After solvent extraction, there is generally **less than 1% of remaining oil in cake** (Amisy 2012; Canola Council of Canada 2017).

Solvent is then removed from the cake with a de-solventiser and can be reused. Most of the solvent evaporates thanks to steam heating and the final elimination is performed thanks to steam injection in the cake (sparging). During this phase, the cake is heated between 95 and 105°C and its moisture rises to 18% after which is indirect steam heat is applied conductively via drying trays. Air is then injected to cool and dry it to a 12% water content. The result is a desolventised animal feed meal that is milled and pelletised as for efficient handling and transport (Canola Council of Canada 2017).

Post-treatment / purification

Once oil is extracted, it needs to be purified, which includes refining, water degumming, neutralisation, bleaching and deodorising. These operations remove compounds like cake particles, mucilaginous gums, free fatty acids, colour pigments and phospholipids, which can be added to the cake in order to have more nutritious materials (Canola Council of Canada 2017; Fediol 2017). According to its final destination, oil can then be subject to other post-treatments.

7.1.3 Information on potential and actual quantities

In Europe, the great majority of vegetable oils come from rape, soybean, sunflower and palm. However, palm oil is exclusively imported so it is not transformed in Europe and is not within the scope of this study.

Table 60: Average vegetable oil balance sheet (2012-2017) Million tonnes.

Product	Production	Use	Imports	Exports
Rape	9.7	9.5	0.2	0.4
Soybean	2.7	2.1	0.3	0.9
Sunflower	3.2	3.9	1.1	0.4

Source: (European Commission 2017a)

Table 61: Average oilseeds balance sheet (2012-2017) Million tonnes

Product	Production	Use	Imports	Exports
Rape	21	24.2	3.5	0.3
Soybean	1.8	15.2	13.6	0.1
Sunflower	8.6	8.6	0.4	0.5

Source: (European Commission 2017a)

The mass fraction remaining after oil removal represents around 50-75% of the mass of seeds (Actu environnement 2017). For example, the Diester plant in Meriot (France) processes around 1.1 Million tonnes of rapeseeds per year, producing 600 000 tonnes of rapeseed meal (55%), 450 000 tonnes of oil (41%) and 25 000 t of glycerine (2%) (coproduits.blogspot 2009).

Therefore, including typical moisture:

- For 1 tonne of rapeseeds, 0.550 tonnes of rapeseed meal are produced (coproduits.blogspot 2009);
- For 1 tonne of soybeans, 0.715 tonnes of soy meal are produced (Keller, s.d.); and
- For 1 tonne of sunflower seeds, 0.443 tonnes of sunflower meal are produced (Keller, s.d.);

From these estimates the yearly amount of press cake for the three major oilseeds is given in Table 62.

Food chain and non-food oilseed meal sideflows

However, with regard to the scope of REFRESH, only **sideflows from the food chain** are of concern. In 2017 just over **a quarter of the rapeseed meal in**

Table 62 below results from food oil production. The remainder is from industrial rapeseed use, principally driven by the EU demand for biodiesel production. This contrasts with sunflower oil and soy oil which indicate 90% and 60% of the domestic supply being used for food consumption respectively, with approx. 20% and ~10% of this oil imported (USFAS 2017).

Table 62: Average oilseeds meal balance sheet (2012-2017) Million tonnes (includes industrial non-food use)

Product	Production (Approx. % food chain sideflow)*
Rape	13.3 (25%)
Soybean	10.9 (60%)
Sunflower	3.8 (90%)

**Bracketed percentages are an indication based on the proportion of domestic oil consumption for food use, roughly allowing for net oil import/export using separate data source: USFAS (2017).*

Vegetable oil seed meal composition

The composition of the press cake depends of course on the oilseed used but also of the extraction process used. The table summarises parameters for indicating the qualities of de-oiled meals as an animal feed commodity, which is their most common use.

Table 63: Composition of key oilseed meals

Main analysis	Unit	Rapeseed	Soybean	Sunflower
Dry matter	% as fed	88.8	87.9	89
Crude protein	% DM	38.3	51.8	32.4
Crude fibre	% DM	14.1	6.7	27.9
NDF	% DM	31.1	13.7	45
ADF	% DM	20.4	8.3	32
Lignin	% DM	9.5	0.8	10.7
Ether extract	% DM	2.7	2	2.2
Ash	% DM	7.8	7.1	7.1
Total sugars	% DM	10.4	9.4	6.1
Gross energy	MJ/kg DM	19.4	19.7	19.4

Sources: (Heuzé et al.2016a 2017, 2018a)

7.2 Current valorisation options

It must be made clear that example inentories given here relate to different types of oilseed cake sideflow; solvent extracted, mechanical pressed, both pre-treated, rapeseed (see 7.1.2) and protein extraction from a cold pressed rapeseed with not pre-treatment. For the cold pressing rape cake example, mechanical pressing is assumed to be optimised for higher oil yield (75% oil recovery) without impacting the available protein extraction yield and quality.

7.2.1 Animal feed

Oilseed meals, especially from soybean, rapeseed and sunflower are essential agricultural commodities for animal feed. For example, in France, excluding fodder, oil seed meal represents around 30% of the raw materials incorporated in compound feedstuffs. Cereals represent almost half of the other raw materials, the rest being notably minerals and other transformation co-products (Agreste 2017).

Meal resulting from a solvent based oil extraction process is the main commodity available. Typically, an extraction hexane (mixed isomers, not pure hexane) is used as the solvent. However, there are regulatory limits on feeding hexane solvent de-oiled meals, according to the Catalogue of Feed Materials and enforced by the Feed Marketing Regulation 767/2009:

- The hexane content cannot exceed 1000 ppm (0.1%):
- The sum of used bleaching earth and filter aid (e.g. diatomaceous earth, amorphous silicates and silica, phyllosilicates and cellulosic or wood fibres) cannot exceed 1%;
- The crude lecithins cannot exceed 1.3%
- The soap stocks cannot exceed 2% (European Commission 2017b)

Rapeseed meal also contain antinutritional factors such as glucosinolates or erucic acid. At high consumption rates these may affect feed intake in ruminants and result in physiological disorders in the liver, kidneys or thyroid glands of monogastrics. Therefore, processing conditions for animal feed are applied and inclusion rates in feed rations may be restricted. Copper toxicity due to fertilisers may also be considered. Antinutritional factors (like trypsin inhibitors and lectins) are present in soybean meal as well (Heuze et al 2017).

However, in view of all these issues the **rapeseed meal market in EU-27 in 2017 was reported to be exclusively for animal feed** (USFAS 2017).

Table 64, Table 65 and Table 66 present the potential inclusion rate of each cake for diverse animals.

Table 64: Uses of sunflower meal for animal feed. Source : (Heuzé et al.2016e)

Sunflower meal							
Animal	**Dairy cows**	**Sheep**	**Lambs**	**Pigs**	**Poultry**	**Rabbit**	**Fish**
Inclusion rate	18-76%	20-38%	5-36%	16-21% in finishing pigs	up to 30%	12%	up to 50%
Comparable products	Soybean Rapeseed Groundnut & mustard meal Maize Cottonseed	Soybean Groundn ut	Cottonseed Groundnut Soybean Maize	Soybean	Soybean		Soy-bean
Comments				Not recommended for growing pigs	Rather for laying hens than for birds with high energy requirements		

Table 65: Uses of rapeseed meal for animal feed. Source : (Heuzé et al.2018a)

Rapeseed meal						
Animal	**Dairy cattle**	**Sheep**	**Pigs**	**Poultry**	**Rabbits**	**Fish**
Inclusion rate	20%	Up to 30%	Up to 100% of protein intake, up to 20% in diets	Up to 20% for broilers and laying hens, 45% for turkeys	12-15%	20-30%
Comparable products	Soybean Sunflower Cull beans		Soybean	Soybean	Sunflower Soybean	Soybea n meal
Comments		Ideal supplement for the production of wool and mohair				

Table 66: Uses of soybean meal for animal feed. Source : (Heuzé et al.2017)

Soybean meal							
Animal	**Dairy cattle**	**Ewes**	**Calves and lambs**	**Pigs**	**Poultry**	**Rabbits**	**Fish**
Inclusion rate	35%	30%	20%	30%	25% in chicks to 30-40% in broilers, breeders and laying hens	15-20%	
Comparable products	Preferred meal	Preferred meal	Preferred meal	Preferred meal	Preferred meal	Preferred meal	Preferred meal

7.2.2 Protein extraction

Food grade rapeseed protein is suitable for both human food and animal feed (ruminant and monogastric farm animals). It is not (yet) common but such proteins are available on the market, both for human and animal nutrition (Burcon 2018; DSM 2017; Canpro ingredients 2018).

Rapeseed protein isolates may be used similarly to existing protein isolates for various applications such as nutritional supplements or fortification of processed foods, emulsification of oils, functional ingredients, e.g. foaming agents or improving rising for baked goods or protein fibres for meat analogues or egg white substitute or binders (Campbell, Rempel, and Wanasundara 2016). Non-food applications may be for pet foods, animal feed and industrial and personal care products. For animal feed fibre fraction of rapeseed meal (coming from the hull or cell walls) that can exert a negative effect on protein availability in monogastrics (Wanasundara 2011) is removed for isolates. Therefore rapeseed protein concentrates may be used in wider animal feed applications such as fish meals provided that phytate levels are low (Wanasundara 2011).

An example of the composition of rapeseed and the extracted proteins presented by researchers is shown in Table 67. Where the extracted protein content is greater than or equal to 90% on a dry weight basis it meets the definition of a protein isolate. Cruciferin and napin account for 85-90% of the total protein content of rapeseed meal (Campbell, Rempel, and Wanasundara 2016). The three challenges to be met when it comes to their extraction are:

- Phenolic protein interactions can cause negative colours and flavours;
- Protein content and extraction yield are lower than soy, which can make this financially unattractive;
- It can be hard to recover protein from transformed rapeseed meal which has gone through a desolventiser-toaster (due to heat damage) and expeller press meal oil content can be too high (Campbell, Rempel, and Wanasundara 2016).

Desolventising and toasting for animal feed, the major co-product from commercial rapeseed oil production, may limit the available soluble protein suitable for extraction. Commercial food grade rapeseed meal production also employs solvent extraction for de-oiling and desolventising. However different processes such as flash desolventising and flake stripping, or double mechanical pressing can be employed to preserve protein quality and yields but are likely to represent a small percentage of the overall sideflow volume (Kemper, n.d. Boeck n.d, Canola Council of Canada 2018).

Table 67 An example of the chemical composition of a de-oiled rapeseed, rapeseed protein isolate and de-oiled soybean (Yoshie-Stark, Wada, and Wäsche 2008)

	Dry matter (%)	Protein (% DM)	Ash (% DM)	Fat (% DM)	Fibre (% DM)
Rapeseed (raw)	93.0	19.0	3.6	54.2	23.2
Rapeseed (hexane de-oiled)	92.2	48.2	7.9	6.4	37.5
Precipitated protein isolate	91.0	70.8	10.8	8.2	10.2
Ultra-filtered protein isolate	92.3	98.7	3.1	1.2	–
Hexane de-oiled soybean	90.0	61.0	6.0	2.0	6.0

7.2.3 Energy

Combustible fuel source

The relatively high fat content of partially de-oiled oilseed cake makes it a suitable candidate for as a burnable fuel, if its typically higher value for animal feed cannot be realised. However, it generates relatively more ash and further precautions may need to be taken to ensure air emissions are controlled to meet regulatory standards if used exclusively as a fuel for industrial or domestic purposes (Bio-based News 2007).

The influence of oil recovery yield on the heat value of press cake can be seen in Table 68 (values from a study by Bernessson 2007) compared to wood chips (both with no moisture). A lower heating value of 20.7 MJ/kg has been reported for pelleted rapeseed cake, as received, with a moisture ~9%, corresponding to 22.4 MJ/kg dry basis[151]. No data on oil content was given but Table 68 indicates that 20.7 MJ/kg is reasonable for rapeseed cake containing ~25% w/w oil, resulting from 60% oil recovery during pressing.

Parameter	Original Rapeseed	Expeller press cake (% oil recovery)			De-oiled rapemeal	Wood chips
		60%	70%	75%	>95%	Fir, Spruce, Pine etc
Crude fat %	45	24.7	19.7	17.0	4.5	-
Ash %	5	6.8	7.3	7.5	7.7	<4%
Oil removed (g) per 100 g	-	27.0	31.5	33.8	42.4	-
'Effective heat content'† (MJ/kg DM)	26.7	22.5	21.4	20.8	18.2	18 -19 (LHV dry)

†Swedish translation to effective heat is assumed to means lower heating value, Rapeseed data source Bernesson (2007). Wood chip data source: various (Phyllis 2).

Table 68 Data on heating values of rapeseed and its expeller cake with various degress of oil recovery compared to wood chips.

[151] Source: Phyllis database: 'rapeseed cake' accessed Nov 2018.

Anaerobic digestion (AD)

Sunflower and rapeseed cakes have been supplied to AD plants for biogas production, even though the nitrogen content of rapeseed cake may be somewhat inhibitive to digestion due to ammonium accumulation in the reactor (Kolesárová et al. 2011). The inhibition effects can be countered by co-digesting oil cake and glycerol (Kolesárová et al. 2012).

7.2.4 Other applications

The following applications found in the research literature are not substantiated to be at a TRL 9 commercial level and may not be within the scope of valorisation models in this report. However, these represent additional background on some potential avenues to further valorisation uses.

Fertiliser

It was demonstrated that the use of oilseed rape cake coupled with other materials (e.g. rice straw and poultry manure) could increase vegetable growth and enhance soil properties. The high N content of oilseed rape cake is very useful to decrease the C/N ratio of other materials such as rice straw (Abdelhamid, Horiuchi, and Oba 2004; Byung-Ju and Park 1997). This fertiliser mixture presents a dual advantage of recycling materials to benefit compost without additional chemicals.

Pyrolysis

Yorgun et al. detailed in 2001 parameters (temperature of pyrolysis, particle size and sweep gas flow) for maximising yields from pyrolysis (Yorgun, Şensöz, and Koçkar 2001).

Oil cake as a natural composite

Though at an early stage of research, vegetable oil press cake can potentially be converted into biocomposite materials with various applications. For example lignocellulosic fibers or globulin can be shaped like thermoplastic materials (Rouilly et al. 2006; Geneau-Sbartaï et al. 2008).

Production of a generic microbial feedstock

It was shown that rapeseed could be used as a raw material for the production of a generic microbial feedstock through a consolidated bioconversion process. Hydrolytic enzymes produced through fermentation could release free amino nitrogen (FAN), inorganic phosphorus (IP), small amount of glucose, and possibly many other microbial nutrients from rapeseed cake. That was used to support the production of dry *Saccharomyces cerevisiae* cells in aerobic incubation (Wang et al. 2010).

Production of activated carbon

Pyrolysis of soybean oil cake between 600 and 800°C with K_2CO_3 or KOH activation generates activated carbon. The ash and sulphur content remains however lowest to commercial products (Tay, Ucar, and Karagöz 2009). These substances can notably be used successfully to remove organic compounds like dyestuff from industrial textile wastewater (Tay et al. 2012).

7.3 Technical description of options modelled and comparable products

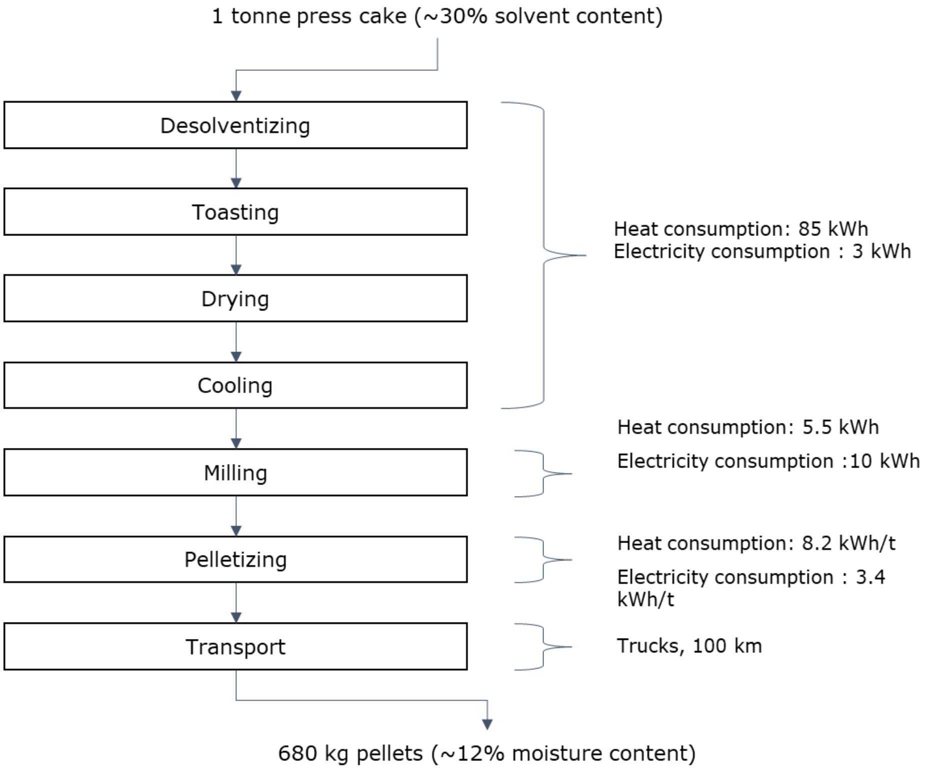
7.3.1 Animal feed

Animal feed is the major valorisation route for vegetable oil press cake. Indeed, the latter constitutes a central nutrient of farm animals in Europe..

Figure 80 presents the process steps typically applied to convert the oilseed press cake into a meal suitable for animal feed. The steps are described below.

Figure 80: Process flow for solvent extracted press cake towards animal feed

Flow: 1 tonne of solvent extracted press cake



Desolventising-toasting

After mechanical pressing, the rapeseed oil remaining in the press cake is extracted using the solvent hexane. Prior to the extraction stage, however, it has become common to pelletize the rapeseed press cake to allow for more even solvent distribution and percolation (Quinsac, Carré & Fine 2016).

To be usable as animal feed, the resulting rapeseed meal should be solvent-free and have low levels of anti-nutritional compounds. Therefore, it undergoes a series of four processes called desolventising, toasting, drying, and cooling. It is important to dry and cool the meal to prevent further evaporative cooling in storage or transport, which will cause reduced flowability, solidification and bridging of the meal inside storage and transport vessels.

The following is summarised from the more detailed description of Kemper (n.d):

> The desolventising, toasting, drying and cooling processes can be accomplished in a single vessel (called DTDC). However, it is more common to combine the desolventising and toasting processes in a vessel (DT) and the drying and cooling processes in another one (DC). Separate processes have been assumed here.
>
> The heat needed to increase meal temperature and evaporate the solvent is supplied by both direct (mainly during pre-desolventising trays) and indirect steam (heating trays for toasting) in different stages of the DT. The indirect steam is usually held at 10 bar g pressure within pre-desolventising trays, providing a surface temperature of 185°C and reducing pressure to maintain 155 °C for the drying tray surfaces. In between these stages direct steam is sparged into the meal. The retention time in the vessel is about 60-90 minutes for rapeseed meal with 75% of the heat energy used in the DT related to direct sparged steam consumption . In both cases the de-oiled oilseed cake enters the DT at 60°C, with approximately 25 to 35% by weight of solvent. The remaining fraction consists of around 60% solids 5-10% moisture and residual oil <1%.
>
> The meal temperature is increased to ~68°C and approximately 10 to 25% of the solvent is evaporated during pre-desolventising steps. Direct steam evaporates solvent from meal but also increases the moisture content to between 17 to 22%. The protein solubility is reduced because of high humidity and temperature conditions. More than 99% of the solvent is evaporated at this stage. The final desolventising occurs when ascending steam passes through the meal slowly. The residence time depends on the quality parameters set (Kemper, n.d.).
>
> The meal at 100°C containing 15- 20% moisture is then transferred to the DC air dryer. The heat of the meal contributes to evaporating its moisture. Additional heat is supplied via steam heated coils to the air injected through the meal. The quantity depends on the influent air temperature and humidity. Evaporative cooling causes the temperature of the meal to fall. When the meal exits the DC air dryer trays, it is typically 60°C and contains 12-13% moisture. Then, it is conveyed to the DC cooler where air flow reduces the material temperature to about 10°C with further evaporation of moisture.
>
> Source: (Kemper, n.d.).

Milling and pelletising

The dried and cooled meal is then milled for subsequent pelletising (Canola Council of Canada 2017) before being transport and served to animals.

Table 69: Model inventory for 1 tonne of press cake going to animal feed

INVENTORY		
Input		
Solvent extracted press cake	1	tonne, assuming 30% w/w of solvent, 9-10% moisture <1% oil, 60% solids
Treatment		
Desolventising, Toasting, Drying & Cooling		
Heat consumption	85	kWh based on industry reference reported by Quinsac, Carré, et Fine (2016) not accurately scaled – no mass throughput †
Electricity consumption	3.0	
Milling		
Input	680	(approx. 600kg dm with ~12% moisture)
Electricity consumption	7-10	kWh, Approximated from feed milling energy.
Output	680	kg caveat : no data on moisture change or losses, assumed none.
Pelletising		
Input	680	kg
Heat consumption	8-10	kWh
Electricity consumption	<5	kWh
Output	680	kg [caveat: no data on moisture change, no change assumed].
Transport		
Truck	100	km
Output		
Rapeseed pellets 12% moisture	680	kg [caveat: no data on moisture change, no change assumed].

† This however aligns broadly with steam consumption 153kg steam/tonne infeed based on Crown Iron works steam consumption reported for separate DT + DC sized for a site extracting oil from 1300 tonnes initial soy per day. DT infeed 112% of initial oilseed infeed mass, given 30% of mass is from solvent that has been added by the extraction step.

Comparable products

Focusing on **rapeseed meal** as a feed, the main comparable product is considered to be **soybean meal or fishmeal** with some adjustment based on crude equivalent nutritive parameter, such as protein content.

7.3.2 Protein extraction

To produce higher value protein isolates for food grade use from oilseed press cake it is either necessary to use different desolventising steps than standard feed meal processing or instead de-oil (or defat) crude press cake by other means prior to or as part of the protein isolation process. In part this is to meet food grade requirements for minimum solvent residues, but also to ameliorate damage to the protein extraction potential and qualities.

As mentioned in 7.2.2 processes such as flash desolventising and then flake stripping with subsequent air cooling can be applied (Kemper, n.d.). Overall a much smaller volume of (mainly soy) press cake is indicated by Kemper to be used for food grade processing compared to animal feed. In addition to this the functional properties of the extracted proteins and their potential applications, can be influenced by the extraction processes applied. Here two examples are given, protein extracted from a pre-treated and suitable solvent de-oiled rapeseed cake and an example for a mechanical cold pressed rapeseed cake that is not pre-treated but otpimised for a high oil yield (75% recovery). Only the last one is used on the model.

Protein from de-oiled or defatted (solvent extracted) rape seed meal

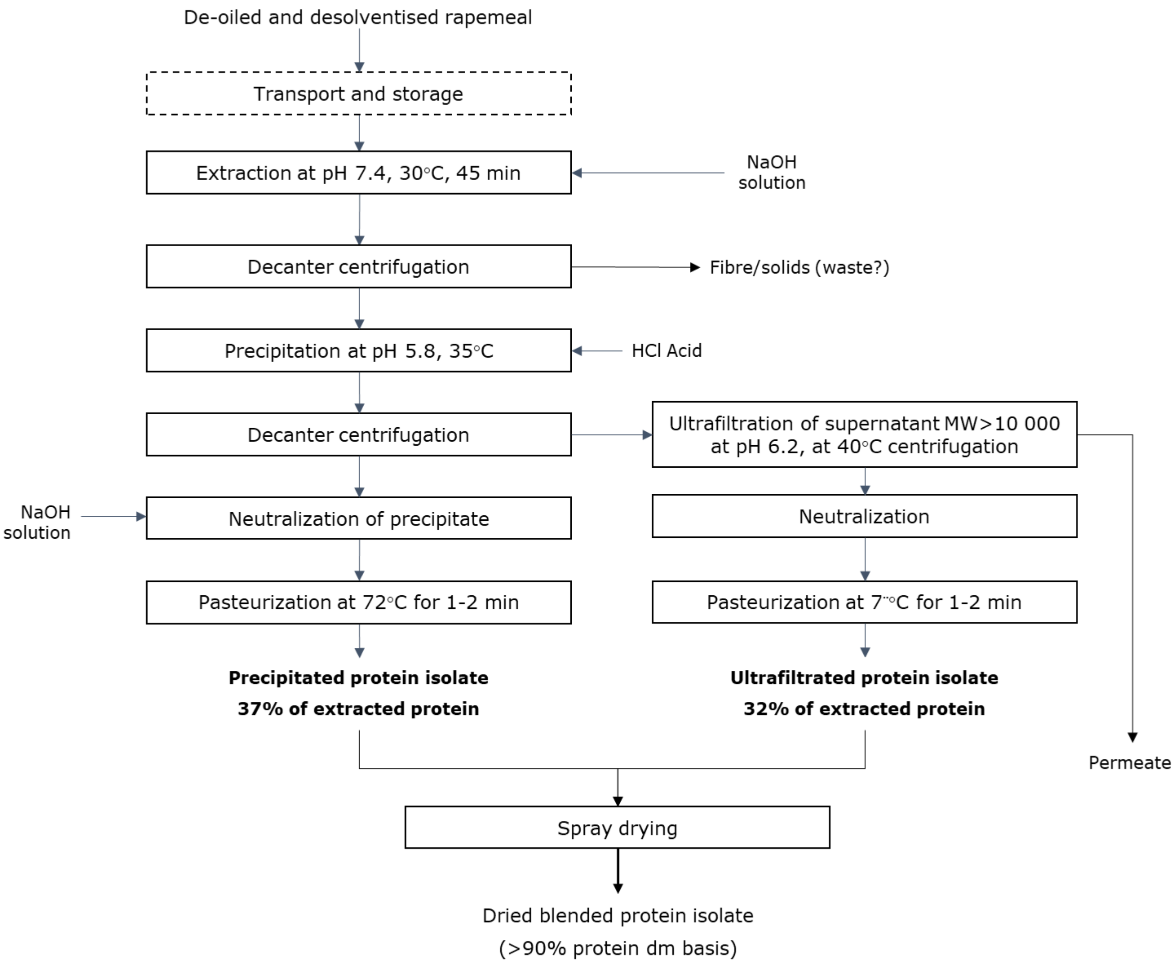
Data on specific defatting process relevant for preserving protein concentration (e.g. flash desolventising and flake drying) has not been inventoried. This is highlighted since the **boundaries of the inventory differ** compared to protein extraction from the partially defatted mechanical pressed cake or de-oiled expeller press cake in the next example.

The main methods are extraction with an alkaline solution or using a protein micellar mass method. Enzyme assisted extraction has also been documented (Aluko and McIntosh 2005). Even though the two processes present dissimilarities, the main steps are in both cases extraction, centrifugation, filtration and drying. Here alkaline extraction is modelled for a de-oiled rapeseed meal.

The model process and inventory are not based on a commercially demonstrated approach, (TRL9) as is the scope set out for the REFRESH D6.10. Rather the process is based on extraction approach for rape seed protein published in a laboratory research paper focussing on the chemical composition, functional properties, and bioactivities of rapeseed protein isolates (Yoshi-Starke et al 2008). Such research indicates that process conditions may be determinants of the functional properties of isolated proteins. These may impact amino acid composition, molecular weight, molecular structure, solubility, hydrophobicity and thermal behaviour and food functional properties such as emulsifying, foaming and gelling aspects.

For the purposes of this model a generic protein isolate extraction process regardless of the further applications of the proteins is presented. This is an accepted limitation for such streamlined models. The main process steps are shown in Figure 81.

Figure 81: Process flow for alkaline protein extraction from de-oiled rapeseed meal



Extraction parameters and laboratory-based yields

For an alkaline solvent extraction times may range between 30 to 60 min at temperatures between 45 to 65°C (Shi et al. 2017). Yields of 89% have been reported for approaches applied to hexane de-oiled soymeal flour (Yoshie-Stark et al. 2004). Slightly lower yields of 68% of extracted protein (37% precipitated protein isolate and ultra-filtered protein isolate 32%) were obtained by Yoshie-Stark, Wada, and Wäsche (2008) using the laboratory scale process represented in Figure 81.

It is important to distinguish the initial basis of the yields reported in literature and those for commercial applications. Yields of up to 45 - 60% are reported for protein isolates on the basis of the protein available within the initial aqueous extraction, not the original rape meal. Other reported approaches extract a mass of protein into the starting solution that is equivalent to 12 to 18% of the original rapeseed meal weight (Barker et al 2014). This can be around a ¼ to 1/3rd of the original

40-45%[152] protein content of rapeseed meal. The initial extraction yield is not available in the sources used for the process in Figure 81 so an inventory cannot be produced directly from this source. In addition the laboratory processes of fine milling of defatted rape meal into a flour (<0.1 mm) prior to extraction (Yoshie-Stark et al. 2008) is not apparent in commercial patent literature for rape seed isolates, meaning the yield may be less applicable to valorisation approaches[153].

Protein from cold pressed, partially defatted, rapeseed press cake

Here a process represented for protein extraction from partially-defatted cold press cake based on a process example published in a patent from Burcon Nutra Science, a Canadian company which is reported to supply functional rapeseed protein isolates for commercially relevant for food and drink applications[154] (Campbell, Rempel, and Wanasundara 2016). The residual oil remaining in the press cake is removed in two stages of the patent process involving chilling and physical separation methods to improve protein extraction. It is not known if the patent from which this example is taken is actually commercially demonstrated and whether the removed oil and meal are also co-products or treated as waste residues. **This example may not meet the TRL 9 scope** set out for the inventory models. The patent example uses 30 kg of press cake, which has been scaled linearly to 1 tonne of press cake for the inventory in Figure 82.

Traded rapeseed typically contains around 45% oil, (as received, moisture 8%) and the patent cold pressing example recovers just under 60% of the oil (approximately under ¼ of the oilseed weight). However since the driving product is oil, this is considered to be a little low. So the process has been assumed for similar extraction yield (protein) relative to 1 tonne of press cake, but with 70-75% oil recovery requiring 1.54 tonnes of oilseed rape for 1 tonne of presscake, as the sideflow here. In this sense a greater quantity of absolute protein is available in the sideflow, unnfortunately protein extract concentrations have not been reported for this change in the sideflow. Instead the protein concentrations in the extract are assumed to remain the same as reported in the source reference for the lower protein solids content. Therefore **the efficacy of extraction appears subsequently lower and therefore is more conservative in this model**. However, the patent only demonstrates a process using an example taking extract solution that is only 2/3rds of the volume added to the meal. So to obtain the full extract yield here the full extract volume has been assumed to be processed. This has been taken to be equivalent to the total extract solution volume minus a small fraction abosorbed by the meal. This is approximated to be

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[152] Based on Yoshie-Stark et al. (2008) reported protein content of 48% (dm basis) for defatted, desolventised rape meal, but allowing for variation in residual oil and moisture.
[153] (Barker et al 2014) indicate protein equiv. to 18% of solvent de-oiled meal weight can be extracted into a brine solution that has been adjusted to 9.5 pH with food grade NaOH. However, only 48% of the protein extraction solution was processed into protein isolate. So the resulting overall protein isolate yield is around 9% of the original de-oiled rape seed meal weight.
[154] Burcon Nutra Science Website advertises Canola Protein products Puratein® and Supertein® for globulin and albumin rich rapeseed proteins isolate products, respectively. https://www.burcon.ca/products/canola-proteins/. Accessed Nov 2018.

equivalent to the rapeseed meal mass assuming it has absorbed its equivalent mass (water density not brine is assumed in extract solution for simplicity) to indicate roughly the volume loss. This assumption has been made by others (Berardy et al 2015) and is also indicated as moisture absorbed by spent grains removed by lautering in the brewing industry. So an approximated 9 m^3 of aqueous protein solution is assumed with the same protein concentration of 19.5 g/l reported by Barker et al 2014. The key process steps published in the patent example by Barker et al 2014 are interpreted for the inventory model below:

1) **Sideflow:** 1 tonne of rapeseed cake is assumed to result from 1.5 tonnes commercial rapeseed (at typical traded moisture). This is based on 510 litres oil cold pressed from 1.54 tonnes of rapeseed.

2) **Extraction** The cold pressed rapeseed press cake is mixed with 0.15M NaCl solution at 20° C at a ratio of 1:10 by weight, for 40 minutes, followed by a thirty minute settling period.

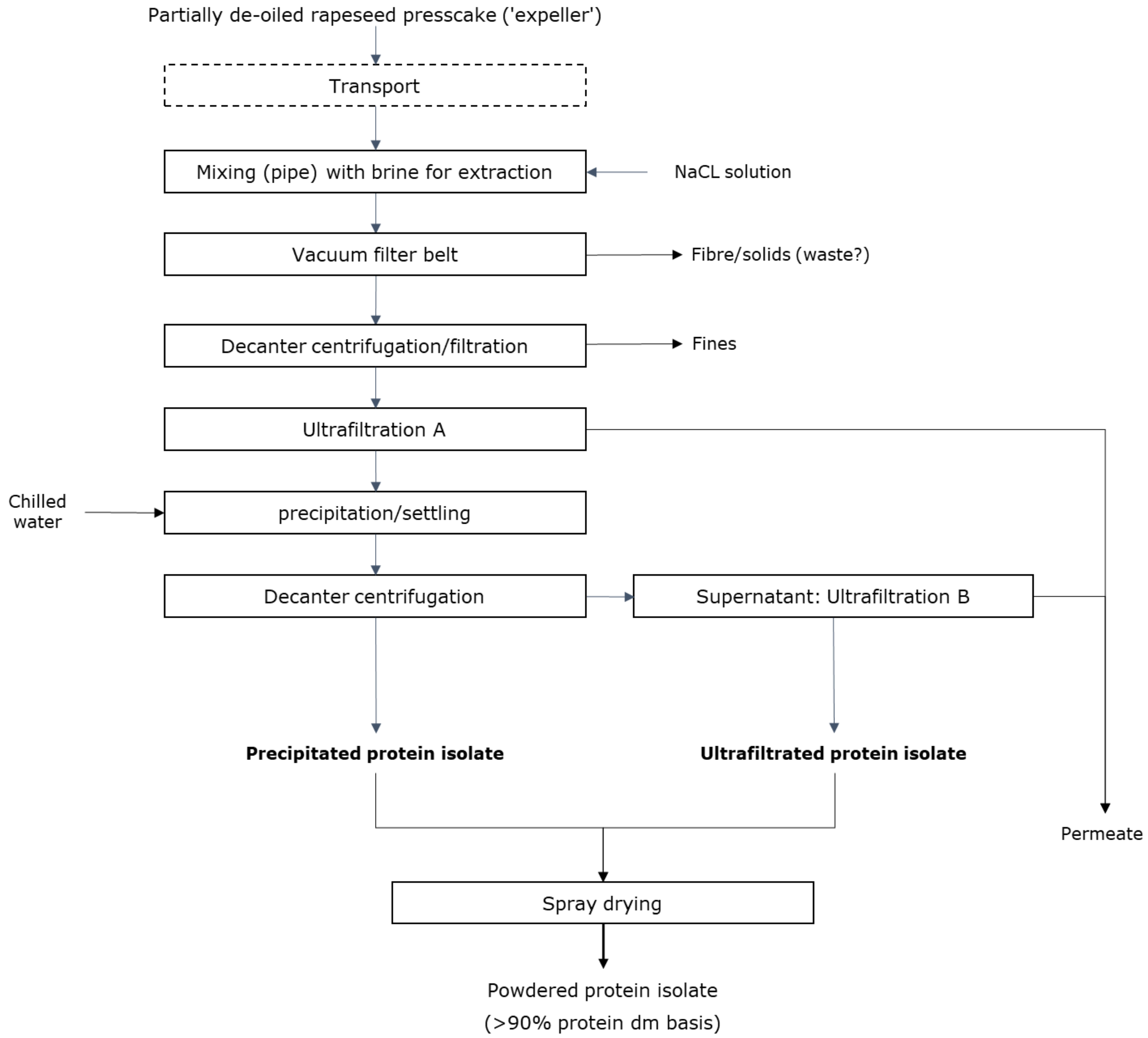
3) **Oil removal** The aqueous protein solution is then chilled to 4° C for 16 hours, to allow a oil/fat layer to separate from the meal and solution for removal. Physical decanting and vacuum belt filtration of the remaining aqueous protein solution removes residual fat, meal fines and some protein leaving a concentration of 14.6 g/litre.

4) **Ultrafiltration and further de-oiling**. The resulting aqueous protein solution is then further reduced to just over 5% of its volume with equivalent concentration by ultrafiltration membranes with a 10,000 molecular weight cut off. The resulting protein solution concentration is 200 g/L. The reduced volume is refrigerated at 4° C for 16 hours then centrifuged to further any residual separate fat.

5) **Precipitation**. After this the protein solution is warmed to 30° C then added to chilled water (4° C) at a dilution ratio of 1:9 (Barker et al 2014). Following overnight settling, the supernatant volume is separated in a decanter centrifuge leaving approximately 10% volume of precipitated, viscous, sticky protein micellar mass (PMM).

6) **Supernatant ultrafiltration**. The supernatant centrifuged from the PMM is concentrated to approx. 90 g/litre and 13% of volume on an ultrafiltration system using 10,000 molecular weight cut-off membranes.

7) **Spray drying**. This is combined with the PMM and spray dried. The net protein solids yield is assumed to be 50% of the extract yield on a dry basis.



Based on a patented example **(Barker et al 2014).**

Figure 82 Protein extraction from partially de-oiled cold press rapeseed cake.

Table 70 Model inventory for protein extraction from rapeseed cake[155].

INVENTORY			Details and assumptions
Extraction			
Rape cake	1000	kg	
Brine solution	10	m3	20C (NaCL 0.15M)
Electricity	No data	kWh	40 min agitation, 30 min settling then vacuum filter belt
Out			
Protein filtrate	9	m3	protein concentration of 19.5 kg/m3 [Total protein extracted ~130kg]
Meal fibre/solids	No data	kg	
Fat removal			
Filter press 20 µm	No data		Omitted, assumed negligible
Total electricity	70	kWh	Chilling to 4°C, assumed 170 kWh heat removed with ~2.5 refrigeration COP.
Out	9	m3	Protein concentration of 14.6 kg / m3
Ultrafiltration			
Electricity	43	kWh	Based on ~5 kWh per m3 permeate
Out	473	litres	Concentrated to 200g protein/litre
Chilling/centrifuge (fat removal)			
Electricity	~1	kWh	Assumption ~1.5 kWh per m3 infeed, chilling assumed negligible
Out			
Residues removed	50		
Protein solution	423	litres	Calculated from yield indications given in Barker et al 2014
Dilution /Centrifuge Decanting			
Heat	10	kWh	Warming protein solution from 4°C to 30°C. Assumed specific heat 3.6-4 kJ/kg °C and density of 0.8 kg litre for protein micellar mass
Water, chilled to 4 C	3.8	m3	1:9 dilution with water
Chilling electricity	10	kWh	Approx. 26 kWh heat removed assuming ~10°C groundwater supply chilled to 4°C.
Diluted solution	4.2	m3	
Decanter centrifuge	6.3	kWh	Assumption ~1.5 kWh per m3 infeed
Out			
Protein micellar mass	405	litres	Precipitated 32.1 kg protein
Supernatant	3.8	m3	
Supernatant Ultrafiltration			
Electricity	17	kWh	Based on ~5 kWh per m3 permeate
Out			
Protein concentrate	0.5	m3	~90g protein/litre, (no non-protein solids)
Spray drying			UF filtrate of the supernatant and PMM combined
Heat	1130	kWh	1.4 kWh/kg moisture based on Kemp 2007 and 812 kg evaporated
Electricity	60	kWh	kWh electricity based on 27:1 fuel to electricity ratio from UK survey (Baker 2000) and fuel to heat conversion of 75%
Final product	**90**	**kg**	Dried to 3-5% moisture

155 Based on a patent example (Barker et al 2014). It is beyond the report authors knowledge as to whether this is demonstrated commercially (TRL9).

Comparable products

EFSA concluded in 2013 that rapeseed protein isolate is safe to be used as a food ingredient (EFSA 2013). However, for US GRAS documentation the material FDA approved ingredient is extracted from a first press - press cake, which is not subject to solvent extraction (FDA 2016).

The protein extraction concentrates assumed here are from the rapeseed cake (not de-oiled meal). These are compared to other feed protein sources such as:

- **Soy protein** concentrate
- **Whey protein isolate**
- **Animal based protein** (fish meal, poultry meal, etc.)

7.3.3 Biomass heat

Press cake pellets can be used either for domestic (~5-30 kW) or for industrial heat production (~ 50-950 kW) (ATMOS 2008; Ökotherm 2018). They are used in adapted biomass heaters.

Again it is considered that pressing will be optimised for yield and 75% oil recovery has been assumed which is at the high end of commercial pre-pressing mechanical expeller yields (Boeck n,d.) so should be representative of commercial throughput. Unlike the previous cold pressed example, the rapeseed cake here can be from rapeseed that has been cooked and flaked to improve oil removal (see 7.1.2). Here only the resiudual oil content is considered to be the key determinant of the press cake heat value.

Here we have estimated the net heat value based on the relative oil content which has 38.3 MJ LHV per kg oil and solids content of 17.3 MJ LHV per kg dry solids from Bernesson (2007), with additional losses assumed from latent heat of vaporisation of pellet moisture of 9% (Quinsac et al 2016). For 75% oil recovery of rapeseed containing around 44% oil when accounting for around 7-8% moisture by weight, the remaining oil content of the rapeseed press cake would be around 17% with moisture losses assumed from pressing friction and heat (Quinsac et al 2016). The assumed mass flows are indicated in Table 71. Pelleting introduces moisture into the cake with the use of steam. The lower heating value here is estimated at 19.4 MJ/kg with no moisture. With a moisture content of 8% after pelleting, allowing for heat lost in vapourisation, the net effective heat value estimated for burning in a biomass furnace would be approximately 19.2 MJ/kg.

Boiler efficiency

The efficiency of a furnace using rapeseed press cake as a fuel depends on many parameters: the technology of the boiler (size, power), pellet moisture content, pellet quality, and ash management, and correctly adjusted fuel to air ratios etc.

Commercial data estimated the efficiency of boilers in the range [90-92%](ATMOS 2008). However, literature demonstrated these values might be overestimated, since average work efficiency of the boiler was calculated to 83.5% and average useful work efficiency was estimated at 78.4% (Klugmann-Radziemska and Ciunel 2013). Based on this different, an **80%** boiler efficiency has been assumed.

Figure 83: Process flow for press cake as a heating fuel

Flow: 1 tonne of rapeseed press cake (~75% oil removed by presses), 8-9 % Moisture, 17% oil residue)

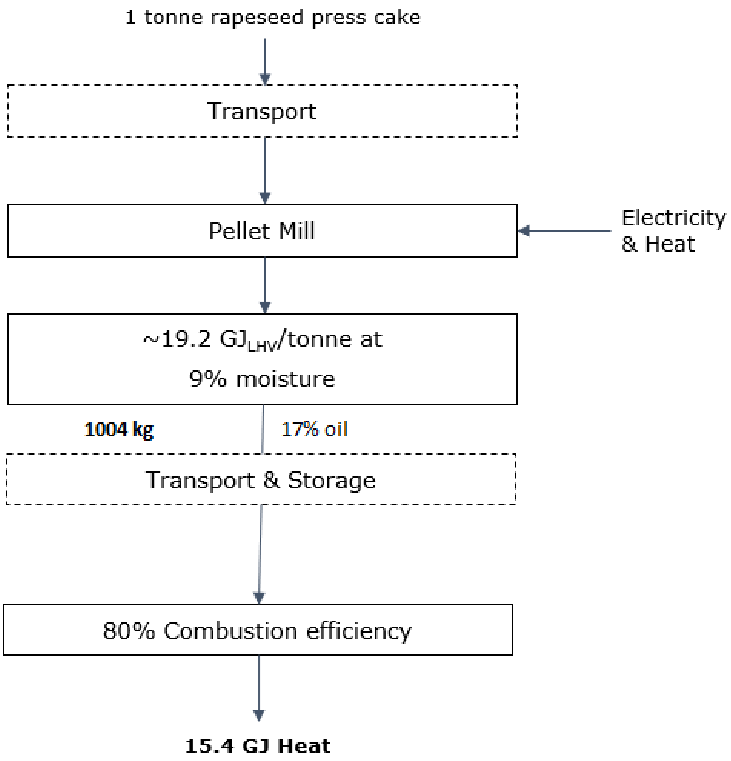


Table 71 Mass flow assumptions (kg)

Rapeseed		1541
oil	44.1%	680.0
moisture	7.7%	119
solids	48.2%	743

Pressed		1000
Moisture	8.6%	86
Oil	17.1%	171
Solids	74.3%	743

Pelleted		1004
Moisture	9.0%	90
Oil	17%	171
solids	74%	743

Table 72: Model inventory for 1 tonne of press cake pellets going to incineration

INVENTORY			
Input			
Press cake *(from 75% pre-press recovery)*	1	tonne	*8 - 9 % moisture, 17% residual oil*
Pelletising	5	kWh	*Electricity (Quinsac et al 2016)*
	12	kWh	*Heat for steam (Quinsac et al 2016)*
Output: Press cake pellets	1	tonne	*9% moisture content (no solids losses assumed)*
Transport & storage	100	km	*Assumed*
Heat content, as received.	19.2	GJ/t	*LHV (Bernesson 2007) Phyllis 2, assumed 9 % moisture after pelleting (Quinsac et al 2016)*
Furnace/boiler efficiency	80	%	*Assumed*
Output			
Approximate net heat energy, as received.	15.36	GJ	*Assuming moisture content increases to 10- 12% during transport/storage*

Comparable product

The press cake pellets would have their principal application in furnace heaters. (Bernesson 2007). Therefore, it should be considered that **the substituted product is heat from other fuel sources used in similar applications**:

- Heat from fuel pellets (data in Table 73 and Table 74)
    - Wood (e.g. oak)
    - Woody biomass (e.g. sawdust)
    - Herbaceous biomass (e.g. barley straw)
    - Fruit biomass (e.g. olive pomace)
- Heat from gas
- Heat from coal
- Average heat mix

Table 73: Limit values for pellets from woody biomass (Miranda et al. 2015)

Property	Commercial and Residential Applications			Industrial Applications		
	A1	A2	B	I1	I2	I3
M (% wb)	≤10	≤10	≤10	≤10	≤10	≤10
BD (kg/m^3·wb)	≥600	≥600	≥600	≥600	≥600	≥600
DU (%)	≥97.5	≥97.5	≥96.5	≥97.5	≥97.0	≥96.5
N (% db)	≤0.3	≤0.5	≤1.0	≤0.3	≤0.3	≤0.6
S (% db)	≤0.04	≤0.05	≤0.05	≤0.05	≤0.05	≤0.05
Ash (% db)	≤0.7	≤1.2	≤2.0	≤1.0	≤1.5	≤3.0
LHV (MJ/kg·wb)	≥16.5	≥16.5	≥16.5	≥16.5	≥16.5	≥16.5

Table 74: Limit values for pellets from non-woody biomass (Miranda et al. 2015)

Property	Herbaceous Biomass	Fruit Biomass	
		A	B
M (% wb)	≤10	≤12	≤15
BD ($kg/m^3 \cdot wb$)	≥600	≥600	≥600
DU (%)	≥97.5	≥97.5	≥96.0
N (% db)	≤0.7	≤1.5	≤2.0
S (% db)	≤0.10	≤0.20	≤0.30
Ash (% db)	≤6.0	≤6.0	≤10
LHV (MJ/kg·wb)	NR	≥14.5	≥14.5

NR, not required.

Moisture (M, % wb= wet basis), bulk density (BD, kg/m3 wb), durability (DU), chemical composition (C, H, N y S, % dry basis, db), ash content (% db) and low heating value (LHV).

7.3.4 Landspread

Landspread of rapeseed presscake is considered principally for the purpose of disposal in the model. It is assumed to be carried out on existing agricultural land where there may be some benefits as a soil conditioner and recovery of some trace nutrients, but these are not the principle reason for this option. However, this is considered to be different from landfill as a municipal waste disposal option.

7.4 Description of the of FORKLIFT spreadsheet model for press cake and de-oiled rapeseed meal

7.4.1 Generic information

The upstream burden is calculated though economic allocation according to the REFRESH report D5.4 Simplified LCA & LCC of food sideflow valorisation (Östergren et al 2018). An average value of 0.78 kg CO_2eq. (Annex 11) for cultivation and drying of 1 kg rapeseed at farm gate has been used as a basis for calculating the upstream burden. Pre-treatment processes outined in 7.1.2 are not included in the upstream burdens. Also this varies for different cases presented.

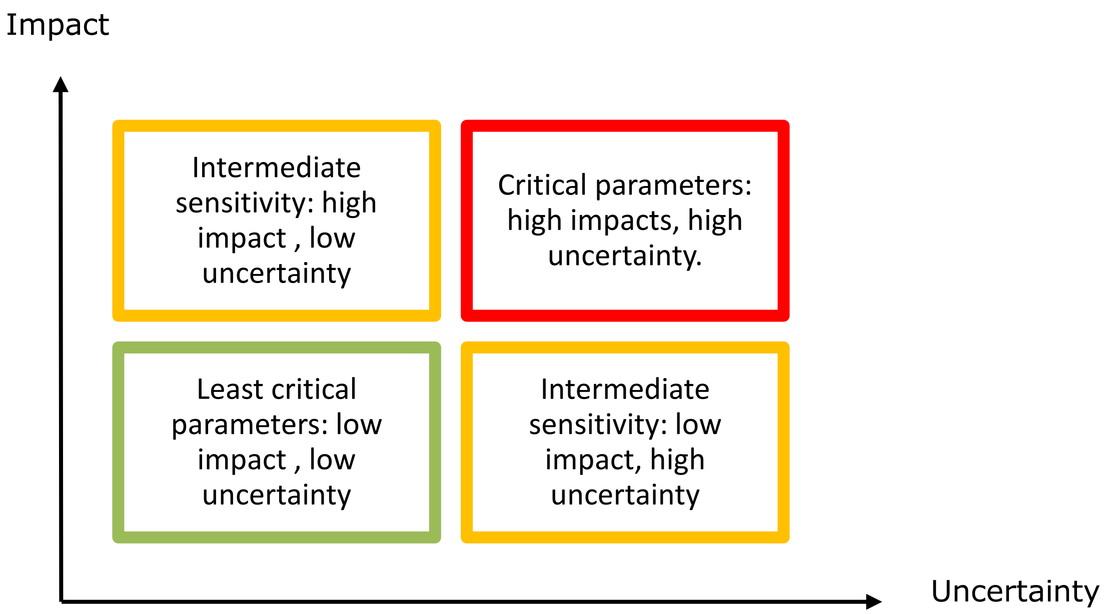
The basis for all calculations is 1 tonne of side-flow according to the process descriptions provided. The exact specification of the sideflow will vary depending on the extraction process (e.g solvent extraction or not). For example in the animal feed case the most common solvent based oil extraction process, typical for the processing of oilseeds for animal feed is assumed, since this is what typically happens to most of the expeller press cake. The sideflow exiting the oil extraction process will therefore contain a proportion of solvent. Typically, this is an *extraction* hexane which is not pure hexane but a mixture of isomers (Anderson n.d.). In the other examples mechanical pressing has been assumed.

It should be noted that, by definition, the upstream burden for a side-flow should have a much lower relative value than its associated driving food product(s). Therefore, the proportion of the upstream GHG burden allocated to side-flow valorisation is generally considered to be minor. When the upstream burden increases the accuracy of the model will decrease, especially where the contribution of flaking, cooking, pressing, extraction, solvent recovery and other attributed site services that have been excluded from the model will become relatively significant when estimating the GHG impacts.

Critical parameters have been qualitatively assessed using the model developed previously in D5.4 Simplified LCA & LCC of food waste valorisation (Figure 84)

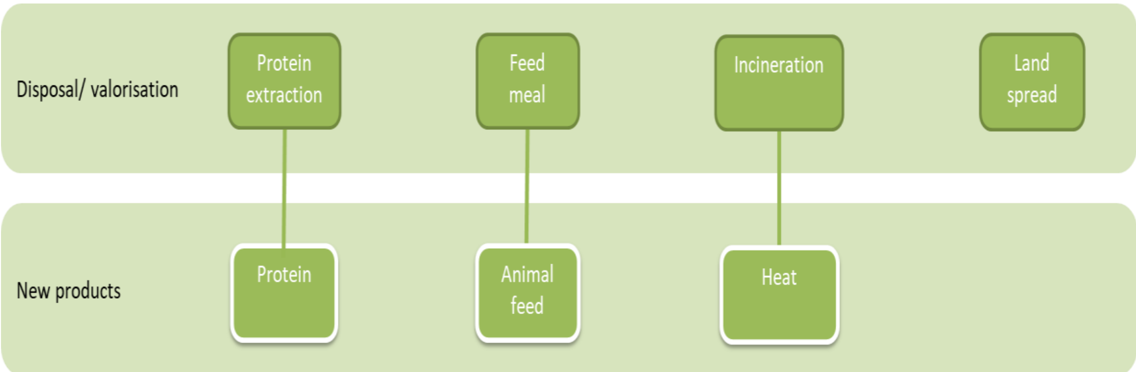
Description of standardised models (Östergren et al 2018). Note that the matrix in some cases also includes parameters that cannot be changed (Annex 11) as an information to the user. The reason for keeping them constant is that they are generic numbers used in several models to allow comparison between different side flows. The assessment is based on the *relative* impact of a parameter compared to the total impact of the valorisation process.

Figure 84 Assessment of critical parameters



An overview of the spreadsheet tool and options included in the model is provided in Figure 85 and in the next section the sub-models are described. The full inventories are provided in Annex 11 as supplementary information along with associated data sources and references.

Figure 85 Overview of the spreadsheet model for rapeseed press cake

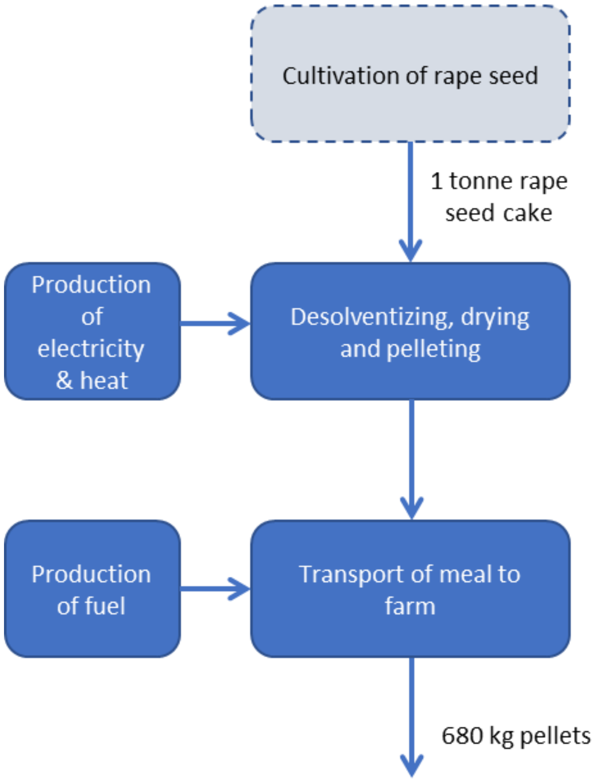


7.4.2 Rapeseed meal animal feed

The sideflow input for this particular model is 1 tonne of press-cake containing 30% solvent, 9% moisture and 0.8% oil. As such, it differs from the other examples.

Figure 86 illustrates the processes that are considered in the calculation of GHG emissions and costs for using the rapeseed press cake as feed. The environmental impact and cost from the upstream primary production processes (dotted line) are allocated in relative proportion of the economic value received for the press cake compared to the rapeseed oil produced. For simplification the gross price payed to the generator of the side flow represents the economic value. The true economic value at the point of separation could allow for additional costs of handling to the point of sale, but also in part, removal costs absorbed by feed merchants, which may be accounted for in payments processors receive.

Figure 86 Rapeseed press cake used as animal feed in FORKLIFT



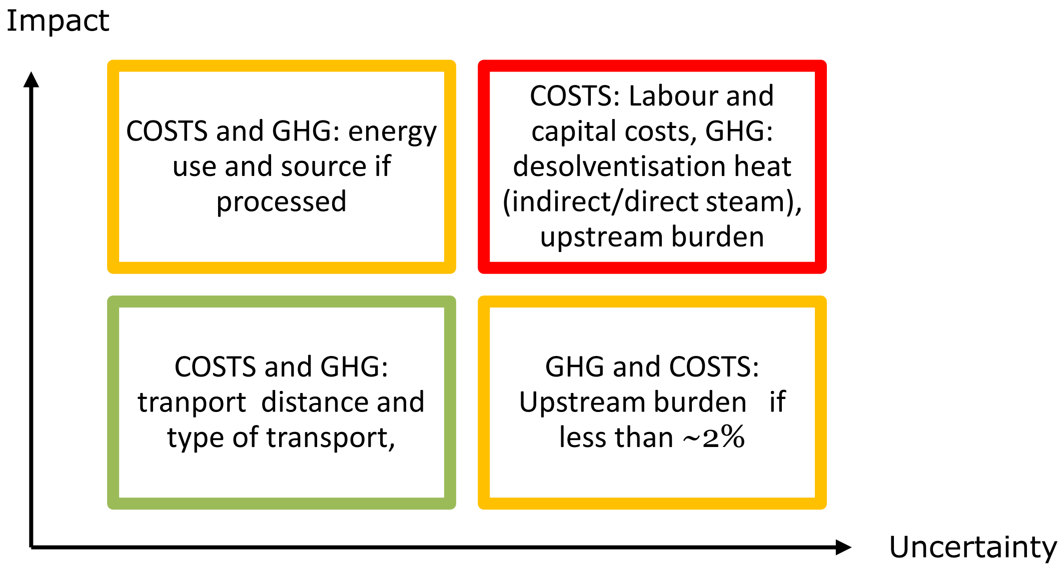
De-solventising (distinguished from solvent recovery from oil extraction) is included as an integral part of the feed processing rather than upstream processes. Pre-pressing, (forming press cake), press cake oil extraction with solvent and subsequent desolventising are likely to all take place within the rapeseed oil production site. For simplicity the solvent consumption and its recovery and distillation for re-use is attributed entirely to the oil extraction process.

In this valorisation option, 680 kg of feed is the product, providing protein to the animals. Common feeds that also provide protein are soy meal and fishmeal, therefore an example of these two feed products are also provided in the grey bars in the result figures, in an equivalent amount based on the crude protein content (~255 kg protein). This corresponds to approximately 590 tonnes of soy meal and 400 kg fishmeal. Parameters being modelled are provided in Table 75 and the assessment of critical parameters are provided in Figure 87.

Table 75 Adjustable model parameters for rapeseed press cake used as feed meal

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transports of rapeseed press cake to processing plant (Rigid truck, 20-26 t, Euro 4, 50% LF)	100	km	A pre-selection of transport options is provided, distances can be set freely.
Electricity use in the process (desolventising, grinding, pelletising)	16	kWh/tonne press cake	
Heat use for processing	93	kWh/tonne press cake	The heat for increasing meal temperature and evaporating the solvent is supplied by steam, introduced directly and indirectly into the meal via the trays. The split between direct and indirect heat transfer per kg steam is not given by reference source, only heat.
Fuel used for generating heat	Light fuel oil		A pre-selection of fuels is provided (biogas, natural gas, har coal, wood chips from forest, EU-average heat)
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.
Country	EU		Determines energy mix and cost
Transports to farm (Tractor Single trailer 50% LF, cooling)	100	km	A pre-selection of transport options is provided, distances can be set freely.
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 87 assessment of critical parameters for rapeseed press cake used as feed meal



7.4.3 Protein concentrate from oilseed press cake (partially de-oiled)

Figure 88 illustrates the processes that are represented in the calculation of GHG emissions and costs for using the rapeseed press cake to produce a protein isolate. If to be used for food products it need needs to be under the assumption that it is produced according to the legal requirements and that health constraints are met. In the EU it requires the approval of EFSA.

The environmental impact and cost from the upstream processes (dotted line) are included in proportion to the economic value rapeseed press cake compared to oil processing co-products.

Unlike commercial extraction, rapeseed press cake from cold pressing in the patent protein extraction example is assumed to recover just over 50% of the oilseed content. However here the assumption is 75% recovery, but with a lower extraction efficacy than the patent example. The partially de-fatted press cake is transported to the processing plant by truck. Regarding the use of fuel, electricity, and heat, the GHG calculation covers the emissions of producing the fuel and combustion in the truck, as well as emissions from production of electricity and heat (steam). The cost takes into account the cost of the electricity, and fuel for transport and heat.

At the processing plant, the RSC undergoes several processing steps involving e.g. extraction, fat removal steps, ultrafiltration, precipitation, centrifugation, further ultrafiltration of centrifuge supernatant and spray drying. In the calculation of GHGs and cost, only the use of heat and electricity is taken into account for this production step. The end products are blended and dried precipitated protein isolate and ultra-filtrated protein isolate powder. By-products of this process are the residual oil and meal solids removed from processing which may require further processing (e.g. to animal feed) or disposal cost. These have been omitted for simplicity.

In this valorisation option, 88 kg of protein isolate is produced (dm basis, protein >90%) approximating to 90kg with typical moisture. Two other types of protein isolates that can be used in food products are soy protein and whey protein, are included as comparable products.

Parameter being modelled are provided in Table 76 and the assessment of critical parameters are provided in Figure 89.

Figure 88 Protein from rapeseed press cake in FORKLIFT

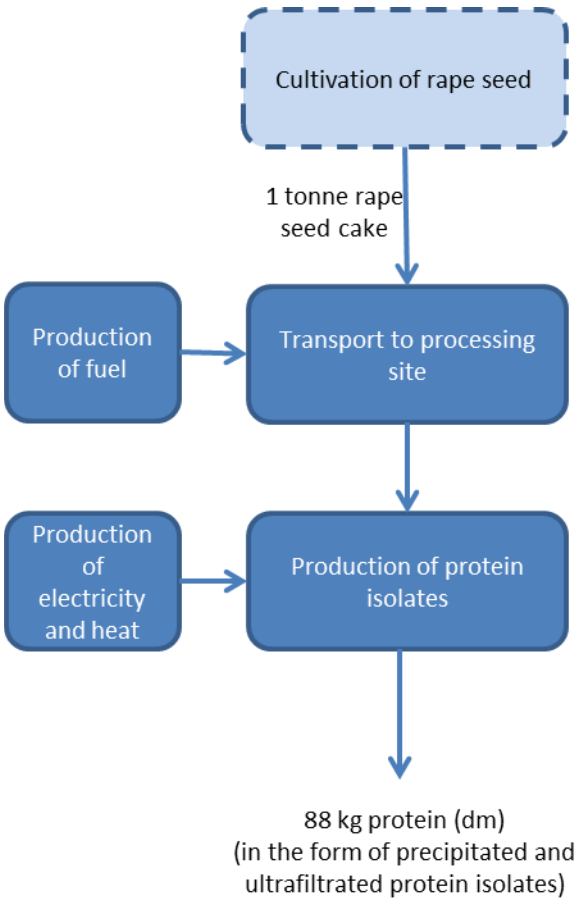
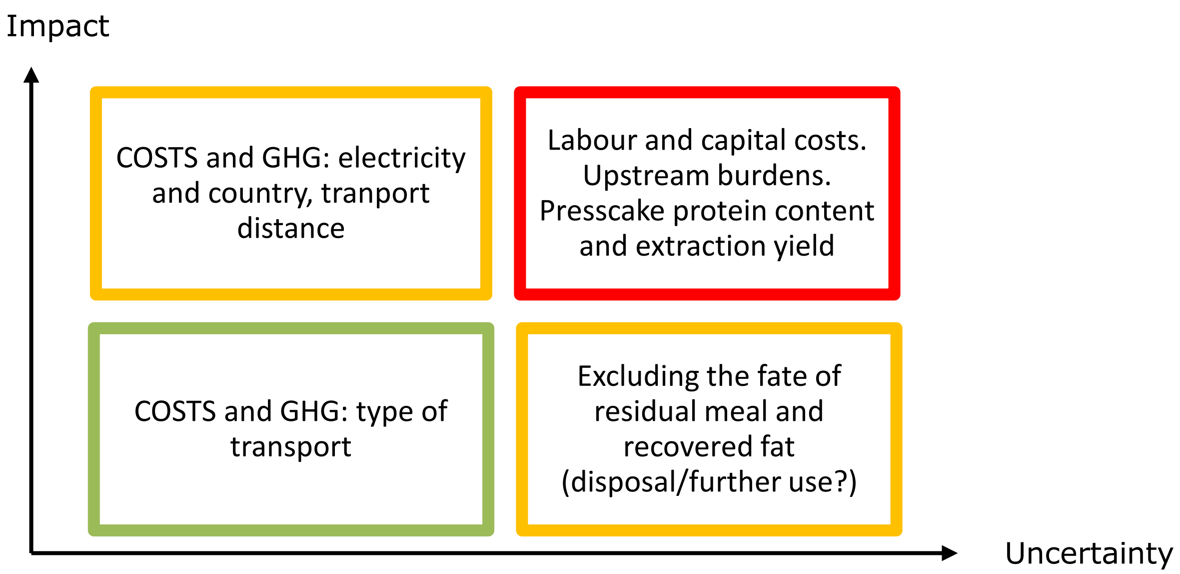


Table 76 Adjustable model parameters for protein isolate using 1 tonne of rapeseed press cake

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transports of rapeseed press cake to processing plant (Rigid truck, 20-26 t, Euro 4, 50% LF)	100	km	A pre-selection of transport options is provided, distances can be set freely.
Heat used	1140	kWh/tonne press cake	Mostly all in the spray drying stage
Total electricity use for processing	200	kWh/tonne press cake	
Fuel used for generating heat	Light fuel oil		A pre-selection of fuels is provided (biogas, natural gas, hard coal, wood chips from forest, EU-average heat)
Labour and capital costs	0	EURO	Set by the user
Upstream burden	0	%	Determined by economic allocation based on user provided information.

Figure 89 assessment of critical parameters for protein isolate using 1 tonne of rapeseed press cake



7.4.4 Energy recovery from rapeseed press cake by incineration

For incineration of oilseed press cake the desolventising and toasting process requirements for animal feed grade meal may not be justified. However, information is not available to estimate how energy demand for desolventisation and uneccessary toasting stages may be alter for this non-feed application. Instead zero desolventising energy use but also not solvent conten has been assumed within the processing boundary. Here the press cake is from a mechanical oil extraction process which recovers less oil from the press cake than a solvent process. Therefore with **different boundaries/ composition**, the press cake sideflow used for energy recovery inventory is not the same sideflow as the press cake sideflow for animal feed.

Figure 90 Heat from burning rapeseed press cake pellets

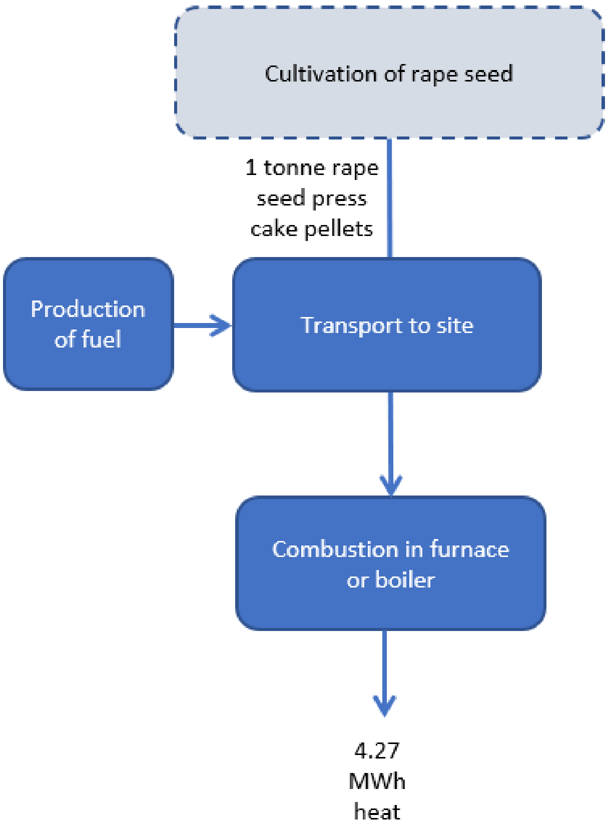


Figure 90 illustrates the processes that are considered in the calculation of GHG emissions and costs for producing energy out of the rape seed press cake. The environmental impact and cost from the upstream processes (dotted line) are included if the producer receives payment for the press cake.

The rapeseed press cake pellets (9% moisture content) are transported to the site by truck. Regarding the use of fuel, electricity and heat, the GHG calculation covers the emissions of producing the fuel and combustion in the truck, as well as emissions from production of heat and energy. The cost takes into account the price of electricity, and fuel for transport and heat.

The rapeseed press cake is assumed to be used to produce heat with a boiler efficiency of 80%. In this valorisation option 4.3 MWh net heat is produced. The energy is compared to average European heat generation and also heat from wood chips from forest biomass.

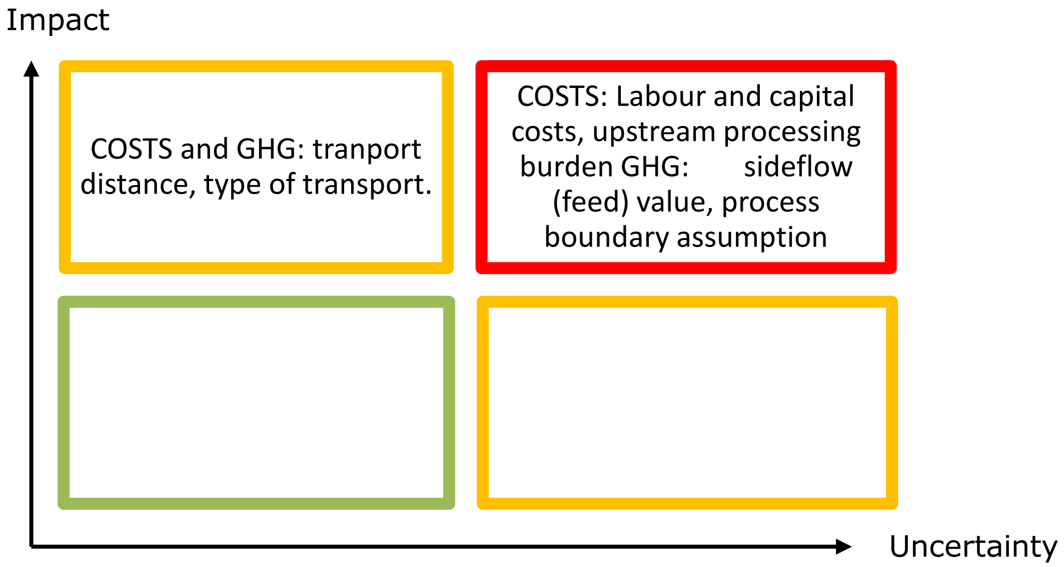
Parameter being modelled are provided in Table 77 Adjustable model parameters for furnace heat obtained from 1 tonne of rapeseed press-cake pellets Table 77 and the assessment of critical parameters are provided in Figure 89.

Table 77 Adjustable model parameters for furnace heat obtained from 1 tonne of rapeseed press-cake pellets

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transports of the rapeseed cake to the incineration plant Truck with semi-trailer Euro 4 26-34 tonne, 90% LF	100	km	A pre-selection of transport options is provided, distances can be set freely.
Heat (pellet mill)	5	kWh	
Electricity (pellet mill)	12	kWh	
Labour and capital costs	0	EURO	Set by the user
Upstream burden*	0	%	Determined by economic allocation based on user provided information.

*For the of rapeseed, 1.54 tonnes of oilseed rape dried to trading moisture is assumed to estimate the total upstream burden of agricultural production for economic allocation required in the tool. This is based on the removal of approximately 75 % of the rapeseed's oil content entering the presses with a moisture content of ~8%. Here the value of the rapemeal is considered to be zero by default, (no accessible feed or altenative markets) but users may wish to change this.

Figure 91 assessment of critical parameters for incineration and energy production from rapeseed press-cake pellets



7.4.5 Rapeseed press cake used as landspread.

Figure 92 Rapeseed press cake used as landspread

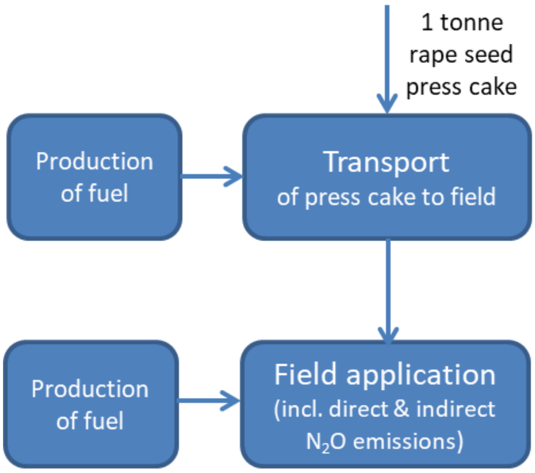


Figure 92 illustrates the processes that are considered in the calculation of GHG emissions and costs of this option for handling rapeseed press cake. The system starts with transport of the press cake to the field by truck. In this scenario it is assumed that the rape seed press cake has no economic value, and therefore the side flow does is not attributed any environmental impact or cost from upstream processes (cultivation of rape seed to the oil producer).

The rape seed press cake is spread by use of tractor onto the field. The climate impact of direct and indirect emissions of nitrous oxide (N_2O) are included in calculations.

This model is based on a rapeseed press cake solids content of 88,8%. Note that the DM content will vary depending oil-pressing process and de-solventising may be required. This has not been included in the boundary.

Regarding the use of truck and tractor, the GHG calculation covers the emissions of producing the fuel and combustion in the truck/tractor. The cost takes into account the price of the fuel.

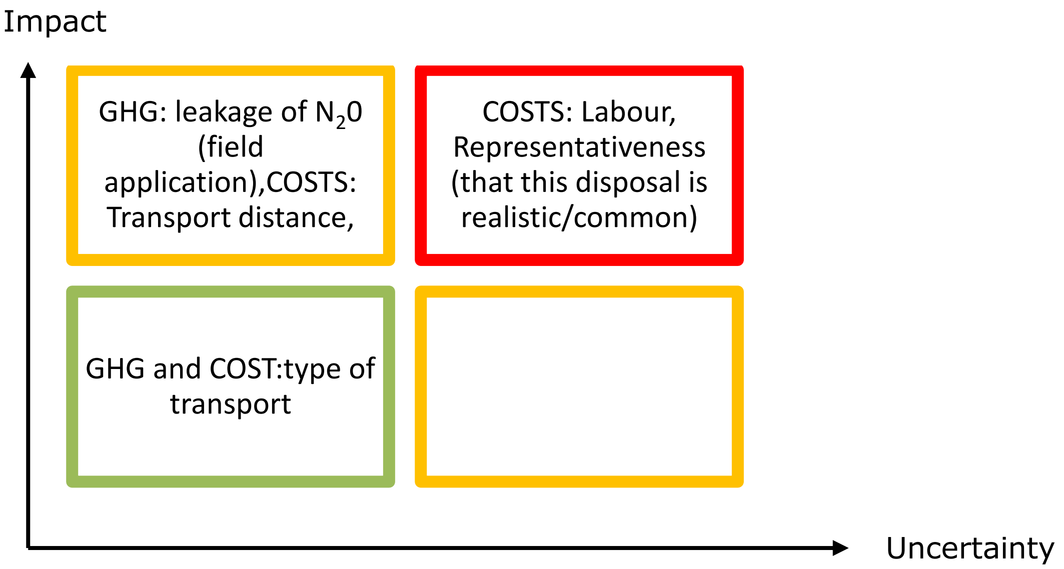
In this valorisation option, no product is produced, and hence no comparison products are shown in the result figures.

Parameter being modelled are provided in Table 78 and the assessment of critical parameters are provided in Figure 93

Table 78 Adjustable model parameters for landspread of rapeseed press cake

Parameter	Default value		Comments
Country	EU		Determines energy mix and cost
Transports to the field (tractor single trailer 50% Load Fraction (LF)	20	km	A pre-selection of transport options is provided, distances can be set freely.
Labour and capital costs	0	EURO	Set by the user

Figure 93 Assessment of critical parameters for landspread of rapeseed press cake



8 Annex 8 Orange pomace

List of abbreviations

dm	Dry matter
FCOJ	Frozen concentrated orange juice
ME	Metabolisable Energy (animal feed)
WHE	Waste heat evaporator

8.1 Background

8.1.1 Rationale

Citrus processing by-products have been identified as one of twenty food chain side flow categories considered suitable for valorisation by Refresh deliverable 6.1 and 6.9.

Citrus pomace may include peel, rag, seeds, and any surplus pulp that isn't used in juice production or other processed food products. Industry sources that design and supply fruit processing technology suggest that most larger citrus processing plants also utilise feed mills employing processes to recover further by-products (Tetra Pak 2018).

8.1.2 Scope

The supply of fresh citrus fruits in the EU-28 totals 12 Million tonnes annually. Around 1.8 Million tonnes (15%) are processed annually, with oranges constituting over 65% by weight, from which orange juice is the dominant product (Table 79, US FAS 2017).

Although most waste citrus will arise from domestic fresh fruit consumption it is mixed with current municipal domestic and catering putrescible wastes. Retail waste is reported to be relatively small per site[156] (e.g. Mattson et al 2018). The scope of valorisation opportunities we identify in this report has been restricted to orange pomace, an unpreventable sideflow, primarily from orange juice processing.

[156] 1.8 and 1.6 tonnes for oranges and lemons per year, respectively from large supermarket sites in Sweden which is 0.9% and 2.1% of the total supplied retail quantities, respectively. Assuming this is the case for most EU retailers, specific recovery of citrus fruits from retail sites are unlikely to be economic, though further detailed study would be needed to make this assertion for any spoilage at supplier wholesale or retail regional distribution centres in other EU member states.

Table 79 EU-28 annual citrus fruit supply and fate, Source: US FAS (2017)

a) Oranges

Oranges ('000 T)	2015/16	2016/17	2017/18*
Production	6,241	6,012	6,258
Import	972	980	990
Export	319	300	295
Fresh Dom Cons.	5,608	5,377	5,631
For Processing	**1,286**	**1,315**	**1,322**
Juice Production (normalised to 65° Brix) [157]	99.7	101.9	102.5

b) Lemons/Limes

Lemons/Limes ('000 T)	2015/16	2016/17	2017/18*
Production	1,269	1,523	1,515
Import	557	450	500
Export	68	75	80
Fresh Dom Cons.	1,532	1,599	1,650
For Processing	**226**	**299**	**285**
Juice Production	n/a	n/a	n/a

c) Tangerines/Mandarins

Tangerines/ Mandarins ('000 T)	2015/16	2016/17	2017/18*
Production	3,076	3,231	3,432
Import	422	430	450
Export	250	240	250
Fresh Dom Cons.	2,976	3,063	2,905
For Processing	**272**	**358**	**269**
Juice Production	n/a	n/a	n/a

d) Total

All citrus ('000 T)	2015/16	2016/17	2017/18*
Gross supply (net of export)	11,900	12,011	12,062
Fresh domestic consumption	10,116	10,039	10,186
Processing	**1,784**	**1,972**	**1,876**

[157] This figure has been standardised to 65° Brix for reporting traded commodities such as frozen concentrated orange juice (FCOJ). Fresh orange juice is typically 9 to 12 Brix sugar concentration (Tetra Pak 2018), so this figure is around 6 times the concentration of fresh juice equivalents. So 100 kt of 65 Brix, is around 600kt in fresh orange juice equivalents, which aligns broadly with the estimates of 45% (almost 1:1) of pomace production from whole processed fruit outlined above.

8.1.3 Information on potential and actual quantities

It is important to note that orange juice imported for EU consumption is around six times the domestic EU production of orange juice. 90% of orange juice imports were processed from fruit in Brazil. So, the majority of pomace sideflows from juice consumed within the EU remains outside the EU. Domestic production of oranges is concentrated in Eastern Spain and Italy representing 80% of the EU's annual orange production, with smaller contributions from Greece, Portugal, and Cyprus.

Typically, juice constitutes around 50% of the wet weight of an orange, depending on the variety and seasonal conditions. A proportion of the fruit's pulp is retained and added back into juice products. Therefore, assuming a sideflow equivalent to 45% (Braddock1999) of the 1.3 M tonnes of processed oranges, (Table 79a) the total potential pomace from orange juice processing *across Europe* approximates to under 600,000 tonnes per year.

8.1.4 Site volumes

With regards to opportunities for valorisation, absolute site quantities and distances from processing facilities may determine investment potential related to economies of scale. Limited data is available on the structure of the orange juice processing industry across the EU[158]. However, Spain, with the largest processing capacity in the EU, processed 730,000 tonnes or oranges in 2015 with 20 processing plants,[159]. The largest plant is reported to process 170,000 tonnes, so although a level average of 36,500 tonnes per plant is also reported from this source, the distribution of the remaining 540,000 tonnes through the other 19 processing plants has not been substantiated.

Assuming 45% of processed fruit weight becomes fresh pomace, the large processor produces around 75,000 metric tonnes of pomace over a 4-6 month harvesting season. The level average capacity indicates approximately 16,500 tonnes over the same period, however this will vary, since the actual plant size distribution is not reported.

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[158] The European Fruit Juice Association (AIJN) were contacted as part of this research but the trade body does not publicly publish information on its members capacity.

[159] Felici, José. Agriconsa (Agricultura y Conservas, S.A). Data from Presentation : *Citrus Production and Processing In Spain.* International Citrus and Beverage Conference, Clearwater, Florida September 2015.

8.2 Current valorisation options

Markets for valorised citrus by-products are already commercially established in Europe (i.e. TRL of 9). Table 80 shows a summary of these. Quantitative information regarding these markets is not readily available, e.g. in nutraceutical or health product markets relating to flavonoids.

Table 80 Current valorisation options identified (TRL 9) for citrus peel and pulp

Product	Current applications	Reference	Data availability/ Contacts
Dried animal feed	Flaked or pelleted, citrus peel /pulp/molasses, for dairy or beef cattle feed.	Tetrapak (2018), Vincent Corp (2011) Braddock (1999)	Feed mill mass balance Braddock (1999) and processing energy data Vincent Corp (2011)
Pectin	Gelling agent for food manufacturing	IPPA[160], Shan (2016), Braddock (1999)	Dr. Hans-Ulrich Endress IPPA General Secretary.
Dried/candied peel	Food ingredients (e.g. conserves and baked goods)	Braddock (1999)	n/a
Peel cloud	Used largely in the soft drinks industry as an additive for altering beverage product appearance	Tetrapak (2018), GEA (2014)	GEA Westphalia
Citrus essential oils	Flavourings, perfumery, and chemicals	Braddock (1999)	n/a
d-Limonene	Solvent, degreasing agent, flavouring, adhesives (resins).	Braddock (1999), Shan (2016)	Braddock (1999)
Citrus fibre	'Clean label' substitute for existing food manufacturing applications (gelling /emulsifiers/texturising agents)	Various products (e.g. Citri-fi® by Fiberstar Inc, a US company)	Process description (Braddock 1999), Patents by Fiberstar Inc, Cargill, IPPA.
Flavonoids Hesperidin & Naringen	Nutraceutical or health products Naringen (from grapefruit) is used as a bittering agent or sweetener.	n/a	n/a

[160] International Pectin Producers Association Wesite. Accessed Jan 2018.

8.2.1 Citrus feed mills

According to Crawshaw (2001): much of citrus pomace from processing is dried and exported around the world. It is easier to transport, manage and can be stored all year round. It also has a higher nutritive value than fresh pulp. The US citrus growing region of Florida is where the commercial development of citrus feed mills originated. Some mills process more than 50 tonnes of citrus pulp into dried cattle feed per hour. The level of investment in feed mill operations and product valorisation differs depending on the volume of material available.

The US model has been adopted by one juice processing plant in Eastern Spain. This has been established by a consortium of 60 fresh citrus producers, reportedly controlling 60% of Spanish production[161]. Industry sources[162] suggest the company have invested in a feed mill drying 50 tonnes peel per hour for processing into fed *pellets and* using waste heat driven evaporators for extraction of higher value essential oils and *d*-limonene.

Smaller mills can invest in simpler, dryer only, systems, with lower initial capital investment, but higher operating (fuel) costs. Whereas at larger scales, businesses may gain returns suitable for greater capital investment in energy efficient processing that maximise revenue by mixing dried citrus cattle feed pellets with sugar rich molasses from the condensed press liquor, improving the energy value of the feed, in addition to recovering higher value citrus oils.

8.2.2 *d*-Limonene and citrus oils

d-Limonene is a significant constituent of citrus peel oils and has been recovered as a citrus by-product for over 75 years. Various commercial methods have been established for its recovery (Braddock 1999). Citrus oil typically constitutes 3 to 5% of pomace peel with *d*-limonene, its major constituent. Both citrus and mineral based d-limonene is used for a range of industrial and commercial purposes. It is widely known as a solvent for degreasing and cleaning as well as for its distinctive fragrance and flavouring in cosmetic and food grade formulations.

Since citrus oil is mostly insoluble in water, most recovery is associated with handling and extraction from 'frit', the processing residue containing an oil-water emulsion with some solids. Various approaches are established in the Juice processing industry which already integrate oil collection as part of the juicing operation. Some machinery scarifies or pierces citrus fruits' outer peel immediately prior to juice extraction, and others during, or after from pulp processing[163,164,165].

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[161] Reported on the Zuvamesa website, but also food industry websites . Accessed Jan 2018.
[162] Vincent Corporation website, supplied presses to Zuvamesa peel processing site. Accessed Jan 2018.
[163] Such as the Brown Oil Extraction (BOE) process machinery, manufactured and distributed by Brown International Corporation, LLC. Accessed Jan 2018.
[164] e.g. the FMC process, - details can be found on the ASME website.
[165] The 'Italian' process: An example of this machinery, is sold by fruit process engineering company Idelicato. Accessed Jan 2018.

Typically, oil is separated from frit and water by centrifugation, either in two stages, respectively. One tonne of fruit can yield 200-300 litres of emulsion to the first centrifuge and then 3-6 litres of concentrated oil to the second 'polisher' centrifuge (Tetra Pak 2018). More recently, a single stage process has been developed with a reduction in process energy (Nuria 2014). However, the uptake of this process is uncertain, so may not be within scope (TRL 9 process).

In these *cold pressed* peel oil recovery processes, a controlled volume of water is used to obtain the optimum quantity for extraction. Essence oil, containing >90% d-limonene in addition to other aroma compounds may also be recovered from concentrated orange juice process for blending back into juice products (Tetrapak 2018). In these processes citrus oil and d-limonene may not strictly follow the *'less is better'* rule which Davis et al 2016 use to define sideflows. When employed, these processes, rather, constitute an integral part of the citrus fruit processing operation.

However, citrus peels left after cold pressing are more aligned with sideflow definitions, where low value, bulk quantities of by-products are concerned. Extraction of *d*-limonene is conducted as part of bulk dry ruminant feed processing operations[166]. Larger feed mills have invested in waste heat evaporators to produce multiple co-products alongside animal feed. One of these is *d*-Limonene. Whether citrus processing already includes peel oil removal (intentional or not), will subsequently affect the quantity of *d*-Limonene available for further extraction at a feed mill.

8.2.3 Pectin and pectin pomace

85% of commercial pectin production is reported to utilise citrus peel, with apple pomace constituting 14%[167], and the remaining fraction is sourced from minor sources such as beet pulp. Orange peel is used but constitutes only 13% the citrus peel source, which is dominated by lemons and lime, (Ciriminna et al 2016 – sources not stated).

Pectin production in Europe is dominated by a few suppliers where, according to a key industry source, processes are quite different from company to company[167]. In addition, industry sources suggest only 1-2% of orange peel is dried for pectin production, the majority is used for animal feed, (Sørensen 2015). This contrasts with the smaller quantities of lemon and lime harvested, of which >80% peel is reportedly washed and dried prior to pectin extraction and processing (Sørensen 2015). A more consistent and greater commercial pectin yield (May 1990, Braddock 1999), may explain the preference for lime and lemon peel over orange peel. Rapid deterioration in peel quality for pectin extraction[168] as well as spoilage and transport costs typically requires peel processing to be located at, or very near, to fruit

[166] An example of this within Europe is the Zuvamesa feed mill in Puerto de Sagunto, Spain, processing oranges and clementines.

[167] Pers Comm March 2017 Prof Hans-Ulrich Endress. IPPA Secretary General and Herbstrieth and Fox R&D Director.

[168] Commercial pectin processors report a reduction in pectin peel quality of 3% per hour residence time from juice extraction to washing/drying and also 1.2% loss of functionality per month from start of the harvest season (Sørensen 2015).

processors. It is important to emphasise that some of the major pectin producers in Europe are based in countries that do not grow citrus fruit commercially such as Denmark and Germany. These processors rely on imported dried pectin pomace from regions where citrus is grown at scale. An international market for dried pomace also allows for continuity of supply in pectin processing throughout the year.

8.2.4 Citrus fibre

Certain dietary fibres may be extracted from the internal structure of the citrus fruits internal pulp (internal walls or vesicles) as well as the peel albedo or flavedo. A proportion can be processed into food and cosmetic grade products with functional properties relating to a balance of soluble and insoluble fibres[169]. The market for these products may be related to a commercial perception that consumer preference is for so called 'clean label' ingredients[170]; essentially those that appear to be natural or traditional. In addition, there is market potential for their use in replacing less healthy ingredients such as fats in baked goods, with water retaining properties of fibre used to retain texture and stability.

In the past softer orange pulp, the source for some citrus fibre products[171], has been considered a by-product used to recover sugars and solubles for 'adding back' to orange juice or for cattle feed (Crawshaw 2004). However, pulp is now a premium product, and more is processed for sale as floating pulp for addition to juice (Tetra Pak 2018). Therefore, it is difficult to determine if pulp fibre is truly within scope as a sideflow (the less is better) or whether it will be diverted from existing use as a component in orange juice, the driving product.

In addition, though patent applications from large companies with interests in citrus processing can be found for the extraction of citrus fibre[172] processes that are employed at commercial scale are proprietary and no publications were identified with suitable process data.

8.2.5 Alcohol

References can be found for Citrotecno, a Spanish feed mill processing 150,000 tonnes of citrus waste, in conjunction with a European LIFE+ project, 'Citrofuel' [173], attempting to pilot the use of molasses, the sugars concentrated from pulp press liquor, for ethanol production. The goal, to derive anhydrous ethanol for transport fuel, however, was completed at pilot scale (producing 38,000 litres), but the predicted laboratory yields were not achieved, and the project was unable to

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[169] For example Citri-fi® has applications in meat, bakery, beverages, sauces and dressings, prepared foods, dairy, soups, fruits and vegetables and pet foods. Accessed Jan 2018.

[170] E.g. Large suppliers such as Danisco/Dupont reports this as important in its consumer research.

[171] See Cargill's Patent No.US 7,629,010 B2 Accessed Jan 2018.

[172] For example Cargill's patent application and related citations Accessed Jan 2018.

[173] http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=LIFE09_ENV_ES_000433_LAYMAN.pdf Accessed Jan 2018.

demonstrate economic viability at scale. Having reportedly invested 20 Million Euros in its feed mill valorisation facilities in 2009, Citrotecno ceased trading as a business in 2013.

The production as a higher value potable alcohol may be more economically viable than processing into fuels or platform chemical for other bio-based products. In addition, rather than a single feedstock source, vegetable and fruit sideflows may be a potential co-feed for multiple feedstock to ethanol production when co-fermented with more sugar dense materials[174]. However, evidence of existing commercial examples has not been identified.

8.2.6 Anaerobic digestion

Fruit processors may divert fruit peel and pulp as a co-feedstock for anaerobic digestion (AD) to generate energy. This is likely where producers can access local AD plant capacity but cannot justify investment in drying facilities for the quantities produced or are not co-located with third party feed mills or pectin peel processors.

[174] Personal Communication with Robert E. Eickelberger, Vice President Business Operations, and CEO and president, Philip W. Madson, Katzen International Inc. indicated that there may be potential for peel waste and associated sugars (molasses) to be used for ethanol production in multi-feedstock plants, similar to Agrana, in Austria.

8.3 Technical description of process inventories

8.3.1 Sideflow transport

Due to the cost of transporting wet peel and its potential for rapid spoilage (fermenting), it's likely that feed mills will be co-located or sited very near to juice processing plants. Therefore, the transport step is omitted from the inventory and process flow in this report, assuming peel bins are co-located at juice processing sites, and material is moved on site by screw conveyers, elevators, and very short distances by trucks. Transport fuel use is therefore omitted from the inventory and is assumed to be negligible.

However, if a spreadsheet model is based on this inventory an option should be included to allow a transport step to be added should any users wish to see the effect on the overall results. The haulage vehicle assumed should be a large capacity (>29 tonne) tipper truck or similar.

8.3.2 Large feed mill with d-limonene recovery

All feed mill processes will vary depending on the variation in feed mill size and scale. A large-scale feed mill processing over 50 tonnes of citrus pulp per hour with d-Limonene recovery is characterised in Figure 94. The valorisation inventory and following description is based on mass balance reported by Braddock (1999), assuming a moisture of 65% after screw pressing. This is author reports that this is the established method for large citrus feed mill and processing plant operation in the US.

Citrus peel and pulp is typically shredded or hammer milled. A press aid, quick lime or calcium oxide (CaO), is added in 0.3-0.5% (w/w) of the wet infeed to a reaction screw conveyor (which is assumed to contribute minimally to the overall process energy consumption). This allows the quick lime to react with the peel reducing acidity and de-esterifying pectin which allows water formerly bound by pectin to be pressed out. Two stage screw pressing with a lower and then higher torque press is typical of feed mills[175]. The reduction in moisture prior to drying, is key to the economic viability of the process.

The press cake is then typically dried in a direct fired single pass rotary dryer. Citrus feed mills utilise the dryer exhaust to drive the waste heat evaporators (WHE) used to concentrate press liquor or molasses. A proportion of press liquor (molasses), concentrated in the evaporator stage, is mixed with the press cake from the first press to diffuse more dissolved solids into the peel. This raises dissolved solids, reducing the net moisture further, prior to the second pressing[175]. The condensate from vapour in the first effect of the evaporator is collected and *d*-Limonene is separated from the emulsion by allowing it to float to the surface for decanting.

[175] http://www.vincentcorp.com/content/double-pressing-basics Accessed Jan 2018.

Figure 94 Model process flow for 1 tonne of orange pomace processed in a large (~50 tonne/hour) citrus feed mill with *d*-Limonene recovery.

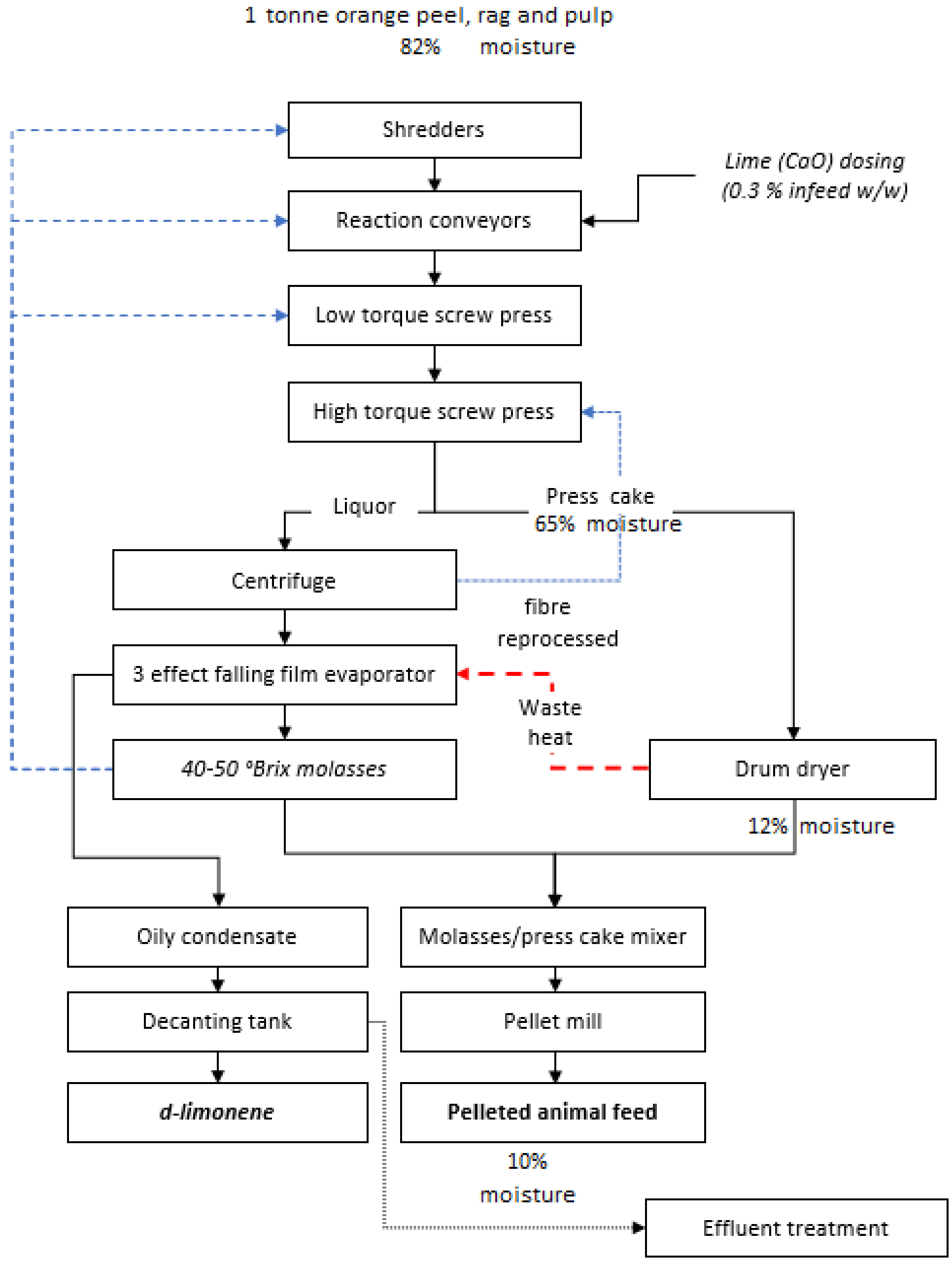


Table 81 Model inventory for processing 1 tonne wet orange pomace in a large (50 tonnes/hr) citrus feed mill.

INVENTORY				
Shredding & double pressing				
In	Wet citrus pulp	1	tonne	82% Moisture
	Transport	-	km	Assumed mill is on or near processor site (see 8.3)
	Shredding electricity	2.6	kWh	Rotary shredder (no data for citrus hammer milling machinery) †
	Press electricity	3.0	kWh	Based on actual screw press specifications†
	Lime (CaO)	3.0	kg	0.3% w/w dosing/ reaction conveyor energy assumed negligible
	Conveyance	-	kWh	Energy use from site material handling is assumed negligible
Out	Press cake	350	kg	
	Press liquor	653	kg	Assumed all CaO is in pressate as calcium hydroxide in solution
Drum dryer (single pass)				
In	Press cake	*350*	*kg*	
	Molasses 40°B	117	kg	Net of that returned to aid reaction & presses (>90% moisture)
	Natural Gas	976	MJ	Drying fuel estimated from dryer performance in Braddock (1999)
Out	Dried feed material	205	kg	
	(Moisture removed	*262*	*kg)*	
Waste Heat Evaporator				
In	Press liquor	653	kg	
	Waste heat from drum drier	-		Assumed the dryer exhaust meets the evaporator load with
	(sole source of heat)			No additional heat source required.
Out	Molasses 40°B	117	kg	DM content not known but reported 70-73% (Crawshaw 2001)
	Heated moisture (evaporated)	281	kg	
	d-limonene (decanted)	2.5	kg	
	Decanting process	-	kWh	Assumed gravity separation in tanks and negligible energy use
Pelleting				
In	Dried press cake & molasses	205	kg	12 % moisture
	Electricity	1.6	kWh	Industry reference, pers. comm Hans Boonen , Product Manager Van Aarsen Machinefabriek B.V.
Out	Pelleted feed	200	kg	10% moisture
	Moisture	5	kg	
	Solids losses	0.1	kg	
				†Source : Vincent Corporation Web site

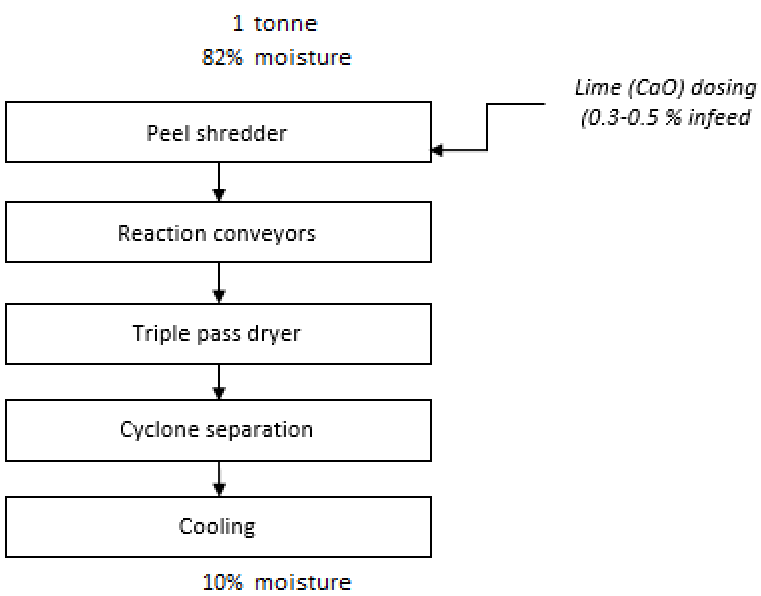
Comparable products

Citrus pomace can be used as a cereals substitute in cattle feed due to its high energy content and good digestibility (Heuze et al 2018). Pelleted with molasses the ME is uncertain since the diffusion of sugar content from molasses though the pomace fibre is not known exactly. Citrus molasses has been reported to contain 11.3 MJ ME per kg dm and dried citrus pulp alone has been reported to be comparable to feed barley (Heuze et al 2018). So, comparable products on a dry basis are assumed to be feed barley based on the equivalent ME content (12.4 MJ ME kg dm).

8.3.3 Small feed mill (citrus feed only)

At the smaller scale of processing, (<10 tonne/hour) citrus pulp and peel from fruit juice processors may be simply dried as an animal feed. This has a lower investment cost than large feed mills but a much higher specific operating cost. The dryer performance and process is based on fuel consumption of a single commercial example of a dryer designed for this application[176]. The fuel consumption is based on this systems in US orange growing region. Differences in climate may affect extrapolation of drying performance to plants in Mainland Europe. Fortunately, relative humidity and temperature profiles in Florida and Eastern Spain are not dissimilar. Therefore, the same figures are assumed to be applicable in the EU's key orange growing and processing region.

Figure 95 Model process flow for 1 tonne of orange pomace in a small scale (<10 tonne/hour) feed mill[176].



Energy demand of conveyers and post drying processes such as cyclone separation and rotary cooling drum are excluded from the inventory based on their minor contribution compared to energy required in the drying stage. These are assumed to be <1kWh given the mechanical duty of the physical processes (cyclone, cooling fans and rotary are likely to require relatively small duty electrical motors).

[176] A more detailed description can be found on the website of the Vincent Corporation, Tampa Bay, Florida, USA.

Table 82 Model inventory for processing 1 tonne wet orange pomace for a smaller (<10 tonnes/hr) citrus feed mill (based on information from Vincent Corp.[176]).

INVENTORY				
Shredding				
In				
	Wet citrus pulp	1	tonne	>80% moisture
	Electricity	3.25	kWh	
	Lime (CaO)	3	kg	
Out				
	Peel/pulp	1000	kg	*Assuming minor losses*
Reaction conveyer				
	Electricity	-		*Conveyer & liming doser - driven by small motors - assumed negligible*
Dryer				
In				
	Heating fuel (gas)	77	m^3	Based on equivalent to *'85 gallons per dried short ton' performance* as a benchmark reported for this citrus dryer
	Electricity	-	kWh	Cyclone separation, cooling drum and fan *motors duty assumed relatively minor so omitted*
Out				
Dried peel		200	kg	*10-12% moisture*

Comparable products

Citrus pomace can be used as a cereals replacement for cattle. Without added molasses, on a dry matter basis the energy content is around 13.5 MJ ME. So, the quantity of feed wheat or barley based on the equivalent dry matter ME content (13.1 and 12.4 MJ ME) would crudely be comparable products.

8.3.4 Pectin pomace

Where orange pomace has a suitable pectin content it can be appropriately processed to sell as a commodity to pectin manufacturers, commanding a higher price than citrus animal feed. The model process flow from pomace processing to pectin manufacture is shown in Figure 96. Due to commercial restrictions it is not possible to obtain typical processing data for pectin manufacturing from citrus pectin pomace[177]. This makes it difficult to derive a representative high level or typical process model for orange pomace pectin. LCA inventories have been collated for the International Pectin Processors Association (IPPA)[178] but are not in the public domain.

Although drying can incur yield penalties over fresh peel, (Crandall et al 1978), and there are plants that produce pectin from fresh pomace[179], the benefit of storage and transport cost allows fruit pomace processors access to the growing international market demand for pectin pomace feedstock.

Therefore, the product process boundary of the inventory model ends at the drying of orange pomace suitable for sale into the pectin pomace market.

To obtain pectin yields and qualities required by the industry processors dry pectin pomace requires controlled processing conditions which increases the GHG burden compared processing citrus pulps for animal feed.

The key processes are:

1. Washing peel to remove unwanted solids such as sugars

2. A controlled maximum temperature drying process

These are required to reduce browning during drying which affects the pectin quality. The dewatering aids such as calcium oxide (CaO), used in feed mills to free bound water, cannot be added since its purpose is to reduce the desired binding properties of pectin. In addition, the higher moisture content (85-90%) means press cake adheres to dryer surfaces. To avoid risk of degrading or burning pectin pomace, drying temperatures are lower in pectin pomace dryers compared to bulk citrus dryers used for animal feeds.

The data on material and energy flows have been taken from a mass balance model provided by the Vincent Corporation[180]. The model is based on the Corporation's experience in installing and commissioning pectin peel processing lines.

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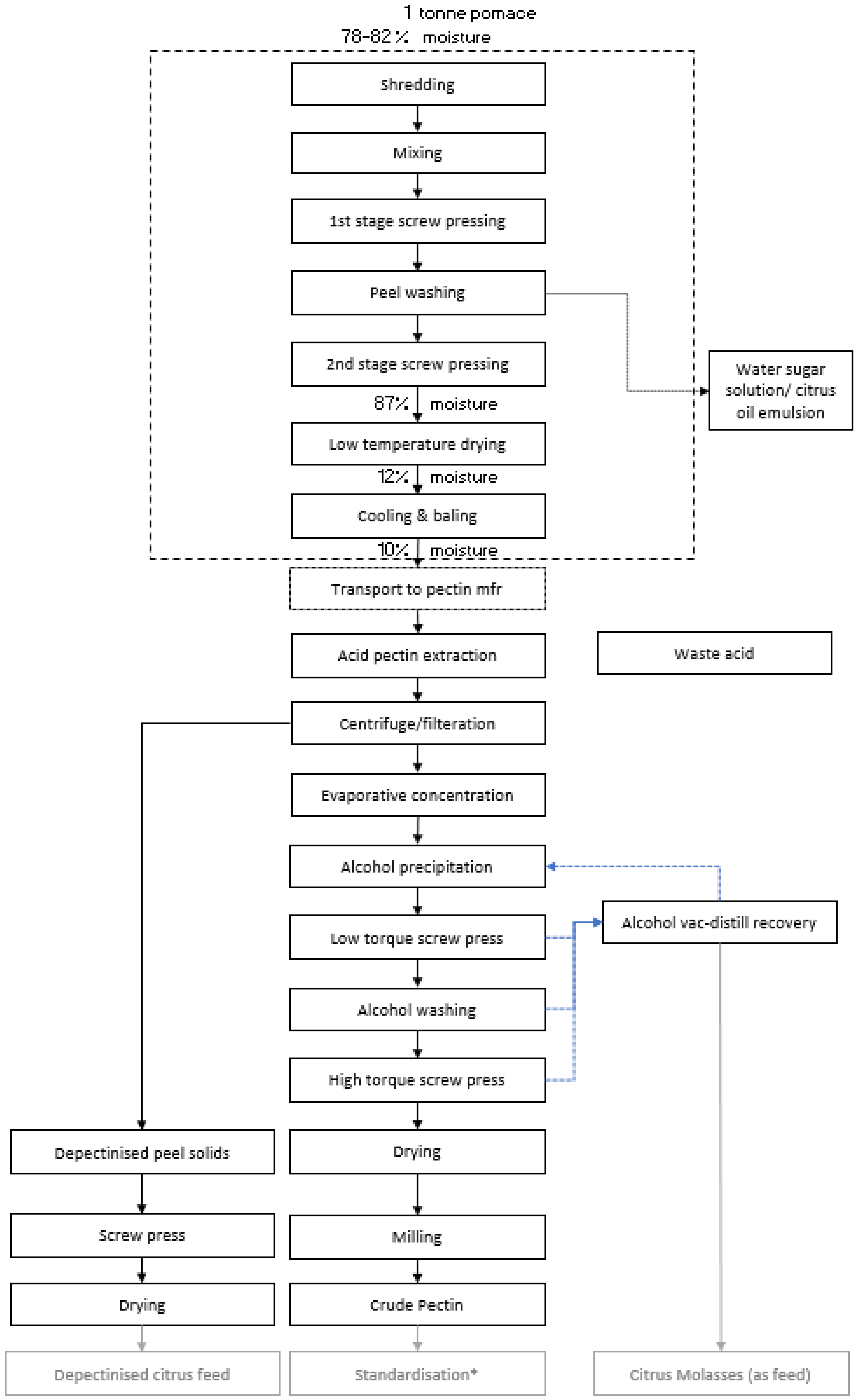
[177] As outlined in earlier sections the pectin production processes are proprietary and may be quite different from company to company. Pers Comm March 2017 Prof Hans-Ulrich Endress. IPPA Secretary General and Herbstrieth and Fox R&D Director.
[178] Lifecycle assessment inventories have been collated by consultants c/o International Pectin Producers Association (IPPA) which represents its 8 members. However, this is confidential (ibid).
[179] E.g. a plant in Matazza, Sicily (Cargill Pectin Italy Srl), is reported to process fresh citrus pomace into pectin.
[180] Model supplied by Bob Johnston Senior Engineer, Vincent Corporation, Tampa Bay, Florida. US. Personal Communication February 2018.

Figure 96 Model process flow for 1 tonne of orange pomace into pectin peel



*Pectin quality varies with fruit and processing. Sugars may be added to standardise to a typical 150 grade pectin. The dotted modelling boundary is shown for the product: dried pectin peel at processors gate.

Table 83 A model inventory for processing 1 tonne wet orange peel into dried pectin pomace.

INVENTORY				
Transport	Orange pomace	Assume negligible		Due to rapid spoilage typical practice is to dry pectin peel locally/onsite.
Shredding				To improve washing out oils etc.
In	Orange pomace	1	tonne	82% moisture
	Electricity	4.1	kWh	Motors driving shredders
Out	Shredded pomace	1000	kg	5mm pieces (dry) preferable for pectin extraction process – assumed no losses
Mixing				
In	Orange pomace	1000	kg	82% moisture
	Press liquor and screen water	3540	kg	Recirculation of 2nd press liquor and static screened wash stage water to mixing tanks
	Pumping duties	No data	kWh	Infeed pumps from press liquor and static screens, outfeed of mixture to first press
Out	Mixed pomace/liquor	4540	kg	96% moisture
1st stage screw press				
In	Mixed peel	4540	kg	
	Electricity	12.4	kWh	Based on low range throughput of widely used industry screw press (Vincent Corp)
Out	Press liquor	3090	kg	To effluent
	Pressed pomace	1045	kg	92% moisture
Washing stages				
In	Water	2750	kg	(1.25 - 3 kg water/ kg peel - net input - to 3-4 horizontal counter flow wash tanks recirculating wash water
	Electricity	No data	kWh	Recirculation pumps (assumed low contribution)
	Citric or other acid	-	kg	Final wash water adjusted to pH 4 recommended (assumed low contribution)
Out	Screened pectin pomace	1018	kg	92% moisture
2nd stage screw press				
In	Washed pomace	1018	kg	92% moisture
	Electricity	3.0	kWh	
Out	Press liquor	356	kg	(recirculated to intermediary washing stage)
	Pressed pomace	662	kg	87 % moisture though this may vary
Peel dryer				
In	Heat (natural gas)	2360	MJ	Based on direct fired pectin dryer fuel consumption performance indicated by Industry sources.
	Electricity	-	kWh	Fan duties, cyclone extract
	Press cake	662	kg	87 % moisture
Out	Dried pectin pomace	98	kg	Dried to 12% - additional moisture loss in reel cooler is assumed to result in a final moisture of 10%
Cooling & Baling				
In	Electricity		kWh	Ambient air cooling - fan motor consumption is assumed to be negligible relative to dryer energy
Out	50kg bales of pectin pomace	96	kg	10% moisture or less for transportation to pectin producers

Comparable products

Pectin yields are dependent on the initial peel quality, which also relates to the fruit harvest month and the time between juice extraction and processing (Sørensen 2015). Orange, lemon or lime pomace produce different yields and quality of pectin. After standardising to a 150 grade pectin (a typical commercial standard for its gelling function), Rouse & Crandall 1978, report a maximum pectin extraction yield of around 8% of fresh orange peel weight, whereas the more commonly used lemon pomace yielded 11% pectin.

These yields are similar to the general rule of 2-3lb (0.9-1.4kg) of 150 grade pectin per box of unspecified citrus fruit (Braddock 1999)[181] . Though on a peel only basis, applying this general rule, the yield would be greater, and probably more representative those of lime and lemon peel.

For the purposes of comparing outputs, with average pectin pomace, a conservative mid-interval pectin yield, standardised to 150 grade pectin quality, of 8% of fresh orange pomace is assumed.

Therefore, 1 kg of dried orange pectin pomace is assumed to be equivalent to 0.7 kg of average pectin pomace[182].

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[181] A US box is 40.8kg of fruit. Assuming 45% of box weight is citrus pomace (peel rag and core) for pectin extraction. Braddocks figures indicate a 150 grade pectin yield between 5% and 7.7% on a fresh pomace basis or 7.4 to 11.4% on a peel only (30% box weight) basis.
[182]Assuming quotient of an 8% orange pomace 150 grade pectin yield and a 150 grade average market pectin yield of 11% dominated by lemon and lime pectin pomace.

9 Annex 9 Abattoir by-products: Carcass fats and proteinaceous matter

List of abbreviations

ABP	Animal by-products
Cat 3 ABP	Category 3 animal by-products from slaughterhouses or abattoirs are fit for human consumption at the point of slaughter, but are not intended for human consumption typically for commercial/cultural reasons.
Cat 2 ABP	Category 2 animal by-products from slaughterhouses or abattoirs are materials which are considered high risk requiring approved treatment and then are limited for use as combustion fuels or approved disposal.
Cat 1 ABP	Category 1 animal by-products from slaughterhouses or abattoirs include specified risk materials (partly dependent on country's disease control status), body parts that pose a disease risk, parts of infected animals or animals suspected of being infected of diseases transmissible to humans or animals. Cat 1 ABP's are the highest risk and requiring approved tightly controlled treatment and disposal.
CFPM	Carcass fats and proteinaceous matter (which is not an established term but has been used in this report for convenience)
MBM	Meat and bone meal (MBM) is an industry reference for animal proteins that are processed from animal by-products not fit for human consumption at the point of animal slaughter. These are meals rendered from Cat 1 or Cat 2 animal by-products that cannot be used as a feed ingredient in any circumstances. It is to be distinguished clearly from Cat 3 ABP meals which are classified as PAP's.
PAP	Processed animal protein, restricted to materials classed as Cat 3 ABP
TME	Tallow methyl ester (biodiesel made with animal fats)

9.1 Background

9.1.1 Rationale

Proteinaceous and fatty carcass materials from abattoirs slaughtering livestock for meat, have been identified as one of twenty food chain side flow categories considered suitable for valorisation by Refresh deliverable 6.9[183].

A Refresh sideflow is defined by Davis et al (2017) as a material flow leaving the food supply chain that the stakeholder generating it wants to minimise. This aspect can be less clear where abattoirs or meat processors have integrated facilities with rendering operations on site allowing further processing of carcass material sideflows into established commodities (EC 2005). With non-integrated facilities, historically third-party renderers have paid abattoirs for various raw materials and this is still an essential revenue stream for the slaughtering industry in some Member States[184].

However, since the BSE outbreak, the regulatory environment in the EU has changed, and this has also impacted the way these materials are required to be treated. Therefore, it is important to introduce this regulatory background and define more clearly where CFPM fits the sideflow definition that infers the stakeholder 'the less is better' for these materials.

9.1.2 Regulatory restrictions

There have been significant restrictions placed on the uses of meat industry by-products, with implications for valorisation. Market access to proteinaceous material or fat, therefore, depends on its status as either food grade material or its risk category if declared as an animal by-product. The former is defined legally by meat hygiene regulations where producers can and wish to send it as food grade processing. The latter is determined by TSE[185] and animal by-product regulations.

Across the EU animal by-products are categorised into three levels of risk depending on the parts of the animal they contain, the health status of the slaughtered animal, and the controlled risk status of the country the animal has been reared and/or slaughtered in. Processors are required, or can choose (in certain circumstances for Category 3 risk materials), to consign materials that are food grade, at the point of slaughter, as animal by-products (ABP). Once declared as an ABP this cannot be reversed. Processing routes prevent ABP's, by law, from re-entering the food processing chain. Consigning food grade abattoir sideflows to ABP 3, 2 or even 1 processing routes, may depend on its commercial (and cultural)

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[183] http://eu-refresh.org/sites/default/files/D6_9_Waste_Streams_Final.pdf

[184] Historically, non-meat products such as fatty tissues, bones, hides or skins and eviscera etc have been utilised as a valued commodities for food, feed and other uses. In the UK an industry name given to such sideflows is 'the 5th quarter' since, after the cost of processing, livestock quarters sold for meat returned a low margin, so the sale of these protein rich 'by-products' typically constituted most of an abattoirs operating profit (EBLEX 2014).

value balanced against costs, (e.g. transport and processing), but also perceived risks and operational practices of the processors (EBLEX 2014).

The processing requirements and restrictions on the use of products derived from animal by-products from each risk category are controlled by regulations. Additional restrictions on end use may also be made in each individual Member State via cultural practice, widely adopted standards or even National regulations. However, the following briefly introduces the key aspects:

Feed bans

In 2001 EU regulatory restrictions prohibited any animal protein being fed to ruminants and preventing the use of any kind of processed animal proteins in feeds for farmed animals including horses and goats and pigs kept as pets[185]. There are exceptions to this rule for certain (e.g. dog and cat) pet foods and animals bred only for producing fur. There have since been derogations made to this rule where risks are considered low for certain animal feeds processed from some animal by-products (products such as plasma, separated from non-ruminant blood in approved processes).

Low risk by-products

Materials consigned as low risk proteinaceous animal by-products[186] are legally required to be processed by breaking into a maximum particle size and exposing to a combination of temperatures and pressures over specified time periods. These are classed as processed animal proteins (PAP's). Due to TSE related feed restrictions in the EU, only since 2013 PAP's of non-ruminant origin can be used as a feed in aquaculture for farmed fish and invertebrates. Recently industry report that the EU are considering proposals to further lift restrictions to allow porcine PAP to be fed to poultry and poultry PAP to be fed to pigs[187]

Hydrolysed proteins

Since 2005 restriction on feeding proteins derived, by hydrolysis, from non-ruminant animals or from ruminant hides and skins have been lifted[188]. These are still subject to conditions of treatment and use set by the animal by-products regulations. According to UK guidance, 2010 TSE regulations permits hydrolysed proteins from non-ruminant sources and ruminant hides and skin to be used as feed for ruminant and non-ruminant farm animals.

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[185] EC 999/2001 laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies (OJ L 147, 31.5.2001), Herein the '*European 2001 TSE regulations*'.

[186] Under the EU Animal By-product (ABP) regulations low risk is defined as (Category 3) animal by-products not intended, but fit for human consumption at the point of slaughter.

[187] *The case for feeding pigmeal to chickens*. Article in Industy Magazine Poultry Business. June 2017. Also Pers Comm, Jane Brindle, Group Technical Manager, Leogroup Ltd.

[188] From 1st September 2005, the European 2001 TSE regulations were relaxed by ammendments (EC 1292/2005) to hydrolysed proteins derived from non-ruminants to be used as an intraspecies feed source for poultry and pigs.

High risk by-products

Higher risk animal by-products are defined in detail in legislation[189], but mostly are materials that are from, or include specified parts of, slaughtered animals that have not been approved as fit and healthy or have an unknown or confirmed risk of carrying transmissible disease and/or where Members States have a declared risk status. Due to their designated greater transmissible disease risk these are prohibited from the classification of processed animal proteins (PAP). In some member states meat and bone meal (MBM) is the name given to rendered proteinaceous materials that has been designated as higher risk animal by-products. Materials declared high risk requires specified sterilisation or rendering methods and its use is restricted to disposal by incineration or controlled higher temperature combustion. For this reason, MBM may be used as a furnace fuel, in high temperature cement kilns as a secondary fuel, also contributing to the pre-calcining process[190]. High risk fats, can through approved processing be converted into biodiesel fuel.

Direct combustion

Tallow can also be burnt directly by renderers. For some Member States this practice had been restricted by the costs of compliance with new requirements of the Waste Incineration Directive[191]. Regulations now specifically cover animal fat or tallow combustion, (EU No 142/2011 as amended). Since these amendments to the ABP Regulations, most EU regulators do not require tallow combustion to be in accordance with the former WID criteria.

However, across the EU, permits are currently inconsistent, and some aspects of the former WID criteria are still specified by some Regulators, e.g. the requirement to continuously monitor some emissions to air[192]. In the UK, most animal fats used for combustion fuel are Cat 1 or 2 ABP's[192] (see also Alberici et al 2014). This is largely because these receive more support through policy incentives in the UK (Renewable Transport Fuel Obligation and Renewable Obligation Certificates). Even so, declines in the use of tallow as a process fuel in the UK, Germany and France have been related to the lower price of natural gas, making more tallow available for biodiesel production which is also supported by enhanced incentives such as the Renewable Transport Fuel Obligation in the UK, (Alberici et al 2014). However, Figure 98 indicates that at least around 50,000 tonnes of Cat 3 mixed species fats are still used for combustion across 21 Member States.

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[189] Defined in Articles 8 and 9 of regulation (EC) 1069/2009 in conjunction with corresponding implementing Regulation (EC) 142/2011.

[190] VDZ industry report, accessed online Dec 2017 https://www.vdz-online.de/fileadmin/gruppen/vdz/3LiteraturRecherche/TB12-15/VDZ-Taetigkeitsbericht_2012-2015.pdf

[191] Saria UK archived website article, published 2008, accessed March 2018.

[192] Adrian Kesterson, FABRA - pers comm, Mar-2018.

9.1.3 Scope

The processing of edible fats removed from carcasses at abattoirs and meat processing plants, is well established. Edible cutting fat, back fat, and leaf fat co-products of meat production have specific wet melting processes preferentially applied for these (Woodgate and Van der Veen 2014). This *first fat* processing is a viable source of driving revenue and can be excluded from the scope of the side flow definition. The fats and proteinaceous matter that are considered *within scope* are those which are taken from the carcass remaining after the key driving co-products are removed.

Typically, fat processing or rendering may be integrated with the abattoir and occur on the same site or under the same operational control (EC 2005). It may also take place on other sites controlled by separate operators or dedicated renderers, involving an additional transport step.

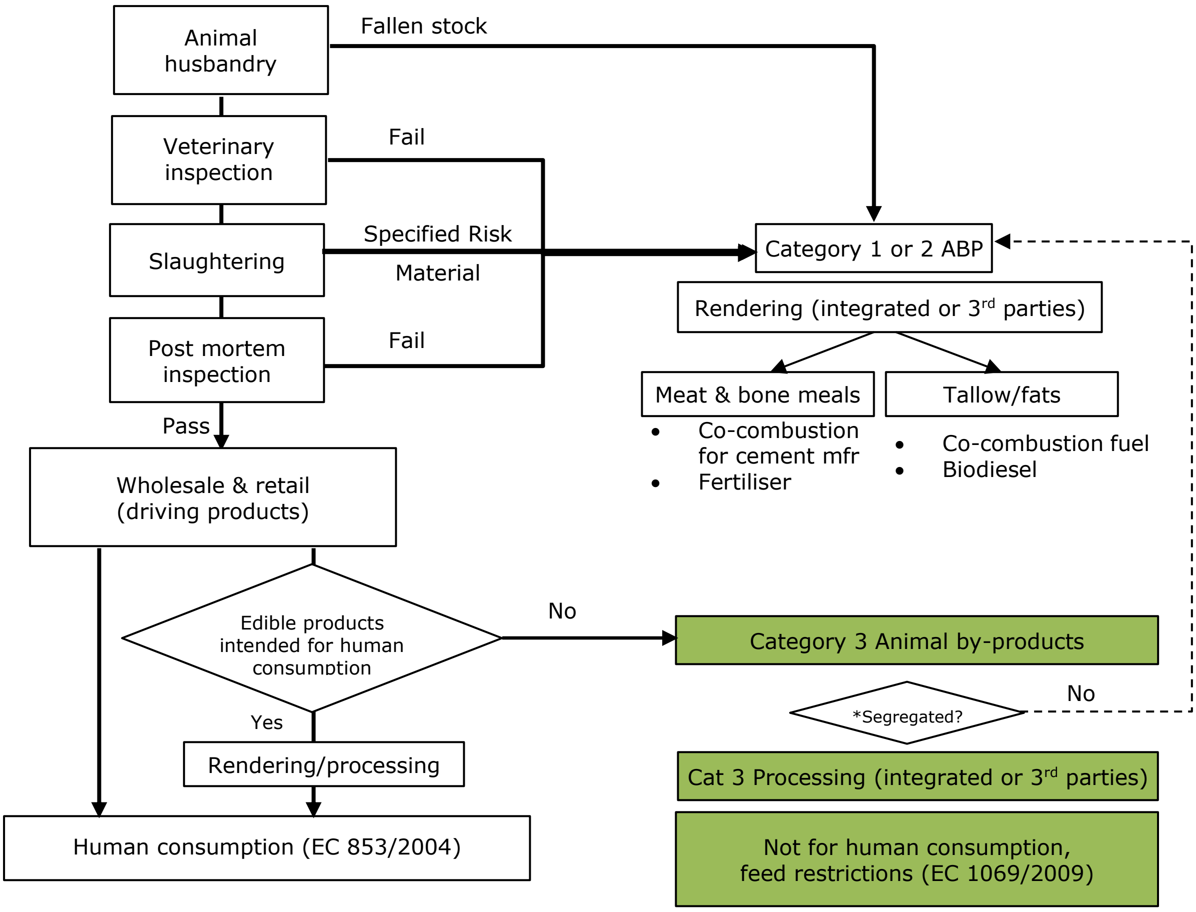
From healthy animals, proteinaceous and fatty carcass materials deemed fit for human consumption can be sent by slaughterhouses or meat cutting plants for processing as either material suitable for further use in the food chain or declared as a category 3 low risk animal by-product. It may then be permitted for use in a variety of controlled ways, though with clear restrictions on its use as an animal feed.

Given the regulatory restrictions for higher risk materials outlined in the previous sections, only carcass materials that are deemed fit for human consumption at the point of slaughter are included in the scope of modelling valorisation inventories, (green shaded areas in Figure 97).

The original description from Moates et al 2016 refers to a waste stream that is *Proteinaceous matter incl. Category 3 material from slaughter plus carcass fat.* From here this category 3 animal by-product sideflow is referred to as carcass fats and proteinaceous matter (CFPM*)*

Therefore, depending on the producer’s circumstances, it is assumed that these sideflows could have been used in food products at the point of separation but, instead, have been declared as category 3 animal by-products. Once declared as an animal by-product, a sideflow is prohibited from re-entering the food production chain (e.g. edible tallow, lard, or fats).

Figure 97 Schematic indicating how fats and proteinaceous side streams relate to animal by-product categories (green indicates sideflow scope)



Co-products for food manufacturing

- Carcase recovered meat
- Blood
- Offals
- Cheek meat
- Bones for edible products
- Sinews
- Membranes

Further processed into food components

- Raw fat and greaves - cooking lard and oils
- Bones - gelatine and collagen
- Hide splits - gelatine and collagen
- Intestines (pig/sheep) - edible casings
- Stomachs - tripe
- Hooves - beef heels

Fats

- Combustion fuel
- Pet food
- Oleochemicals: Tallow methyl ester biodiesel, soaps, detergents, cosmetics, pharmaceuticals, plastics etc.

Processed Animal Protein (PAP) meal

- Pet food
- Aquaculture protein feed
- Bonemeal fertiliser
- Feed minerals

Others

- Hydrolysed proteins (pharmaceutical)
- Collagen, gelatin (pharmaceutical)

**NB. Clear separation of ABP categories are required. Any risk of mixing low risk (cat 3) animal by-products with higher risk animal by-products (cat 1 or 2) will always be classified as the highest risk category component and required to be treated accordingly. In addition, any risk of mixing proteinaceous materials, especially from ruminants, with fats will prevent valorisation options for terrestrial farm animal feed.*

9.1.4 Information on potential and actual quantities

European level statistics are collected by the trade body EFPRA. The high-level data are shown in Figure 98 and Figure 99. However, the underlying data is confidential and cannot be shared[193]. For some categories, annual percentage changes (black font), indicates the volatility of the market for some of these sideflows and co-products. For example, the volume of edible tallow and lard processed for food use appears to drop by 31% between 2016 and 2017.

Site volumes

An industry survey conducted in the UK indicates that site level data quality is poor. The quantity of materials sent from processors as various categories of by-products reported by abattoirs differed to the figures reported from renderers receipts (EBLEX 2014).

The study also reports anecdotal evidence that smaller processors are more likely to send food grade fats for processing into non-food products than larger processors (EBLEX 2014). Segregation of ABP streams is also an important determinant of valorisation potential.

If abattoirs mix low risk (cat 3) fats with higher risk by-products they will always require classification as the highest risk component, preventing potential valorisation routes as animal feed. Anecdotal evidence also suggests that UK abattoirs send ABP Cat 3 materials for ABP Cat 1 rendering, (EBLEX 2014), thus restricting any further use to energy recovery through co-combustion or biofuels.

Also, for multispecies abattoirs the TSE regulations' strict requirement for prevention of any ruminant protein in animal feed means that without adequate separation of non-ruminant slaughtering from ruminants the potential for use in feed will also be reduced. However, PAP is not banned from the pet food market, which is a dominant user and Category 3 fats are also currently used for animal feed (Figure 99).

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[193]A request was made to (and rejected by) Dirk Dobbelaere, European Fat Processors and Renderers Association (EFPRA), on the grounds of confidentiality. Personal Communication June 2017.

Figure 98 Uses of edible and category 3 animal by-product fats (2016) from an industry survey of representatives in 21 Member States (Dobbelaere 2017)

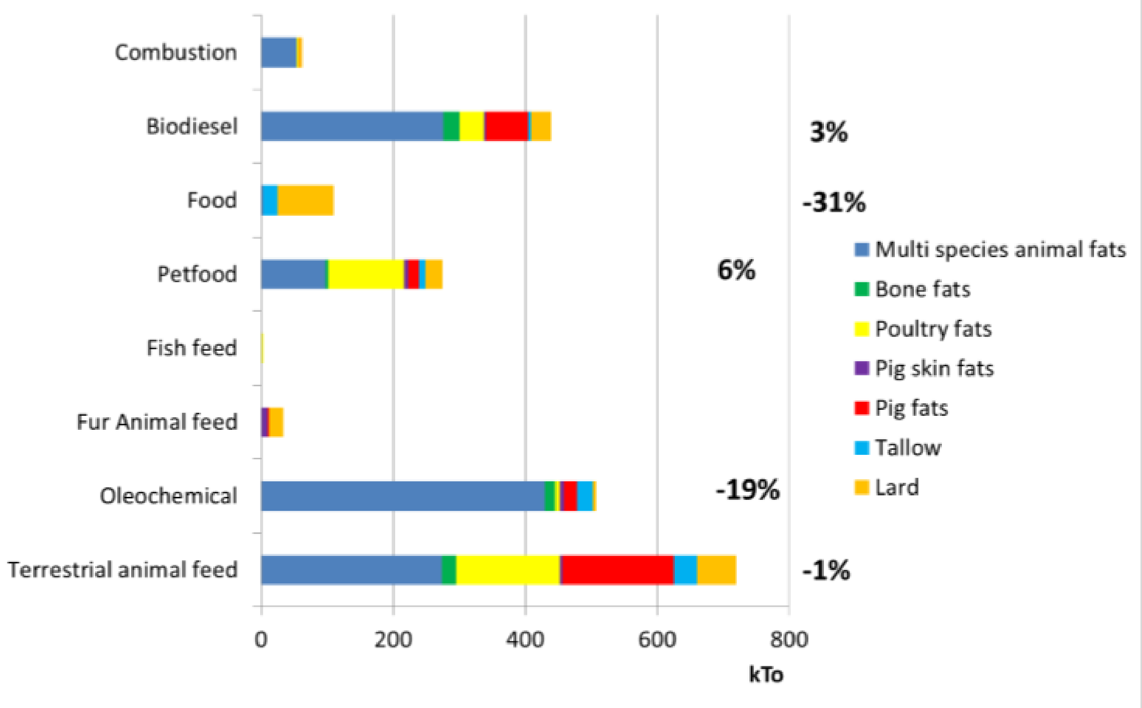
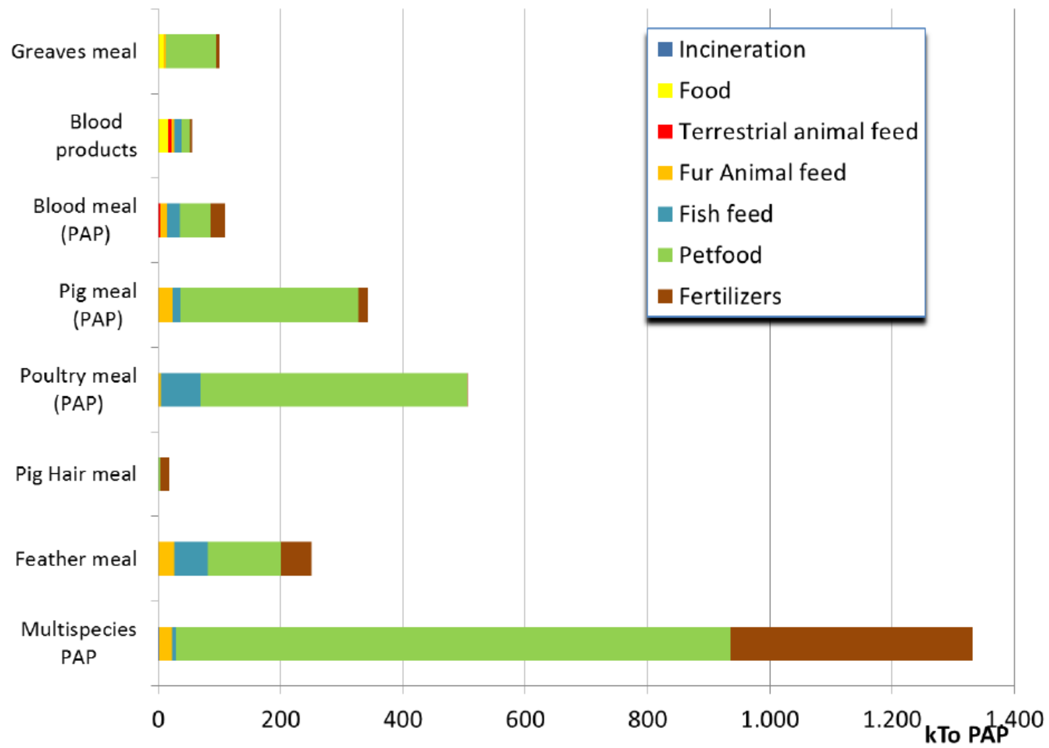


Figure 99 Uses of edible and category 3 proteinaceous animal by-products (2016) from an industry survey of representatives in 21 Member States (Dobbelaere 2017)



9.2 Current valorisation options

Valorisation routes for rendered fats and proteinaceous meals from slaughtered livestock are already established commercially in Europe (i.e. at a TRL of 9). Table 84 shows a summary of the main product markets for these fats and protein meals.

Higher quality food grade fat processing is achieved by lower temperatures characterised by wet rendering systems,and may be associated with fat specifically trimmed from carcasses by meat cutting plants as meat co-products (Woodgate and Van der Veen 2014). For the purposes of this high-level model, this fat source is not considered to be a clear sideflow process based on the 'less is better' criteria set out by Davis et al (2016). The sideflow scope is therefore restricted to processing of left over carcass materials (after meat cutting and fat trimming).

Table 84 Current valorisation options (TRL 9) for food and category 3 ABP

Product	EU estimates†
Edible (rendered) fats for baking	100,000 t
Rendered fats for Terrestrial animal feed	700,000 t
Rendered fats for pet foods	300,000 t
Oleochemicals (soap, detergents etc)	~500,000 t
Biodiesel (TME)	Cat 3 ~400,000 t (Cat 1&2 500,000 t)
Pet food (multi-species PAP)	EU 2 Million tonnes, (¾ PAP)
Fish feed (Poultry and Pig PAP only)	85,000 t (excluding blood meal)
Fertiliser PAP	EU 700,000 tonnes, >50% is multi-species PAP

† Approximated figures taken from charts presented by Dobbelaere 2017.

9.3 Technical description of process inventories

9.3.1 Permitted animal feed (and pet food) ingredients

Figure 100 shows the modelled process flow representing the conversion of edible carcass sideflow from abattoirs or meat cutting plants into rendered fat and proteinaceous matter. This involves breaking up materials and disc drying and then pressing fats. Though, sterilisation is shown as a separate processing step, disc dryers can be used to satisfy the sterilisation conditions required[194].

There is considerable variation between processes, and species-specific processing methods make it difficult to characterise a generic multispecies fat rendering processes across Europe. This is also reflected in the respective energy required[195]. Therefore, this model is reflective only of one example processing route of many, and a representative or *generic* process model is not possible. The inventory is also adapted from US rendering process data for cattle carcasses. However, it is assumed to satisfy EU ABP regulations processing energy requirements and the energy figures adapted to 1 tonne of ABP are broadly comparable to those reported from a UK survey of ABP renderers (Ramirez 2012).

[194] E.g. proicessing equipement is able to satisfy minimum Cat 3 ABP processing requirements, specified by Department for Environment, Food & Rural Affairs and Animal and Plant Health Agency website. Accessed Feb 2018.

[195] Pers. Comm Adrian Kesterson, FABRA UK, technical author for updating IPPC BAT submission. See also EC 2005.

Figure 100 Model process for CFPM rendered as animal feeds

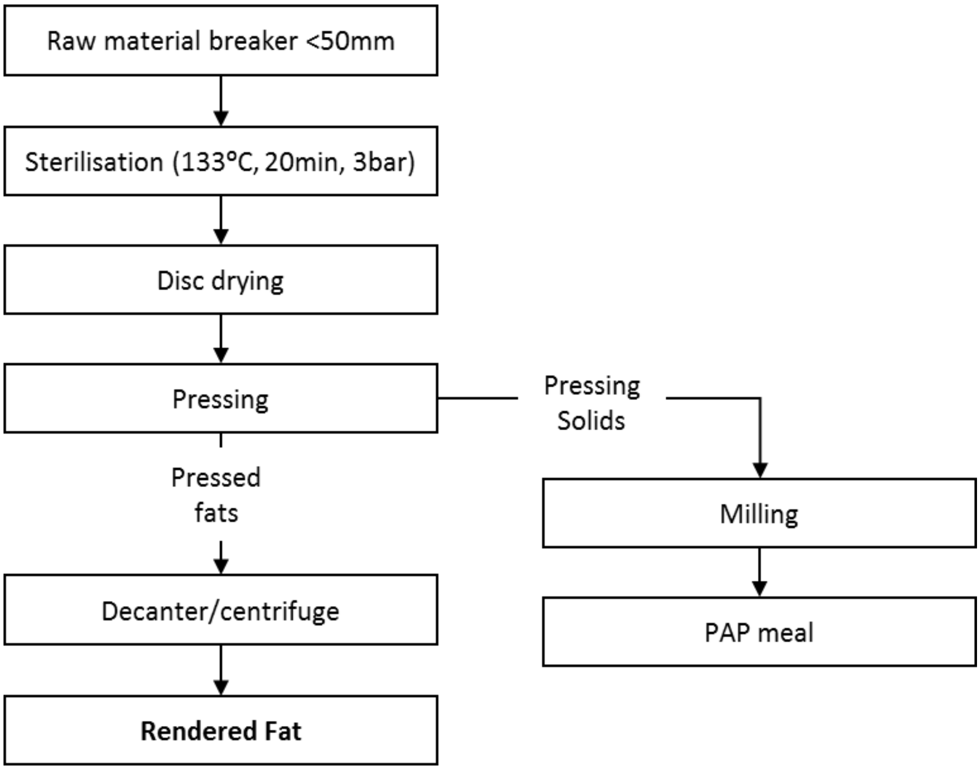


Table 85 Model inventory for processing 1 tonne of CFPM into animal feed products

Inventory			
Inputs*			
Fat and proteinaceous animal by-products	1	t	
Thermal energy	2120	MJ	
Electric energy	82	kWh	
Heat recovery exported	0	MJ	No data
Transport by lorry to rendering site	0	t km	Assume Integrated plant
Outputs*			
Rendered fat	**282**	**kg**	
Processed Animal Proteins (PAP)	**228**	**kg**	
Cooking vapours	490	kg	
Transport to feed and pet food plant	variable	km	82 t.km is inventory default *

*Adapted from Dufour and Irribarren (2012).

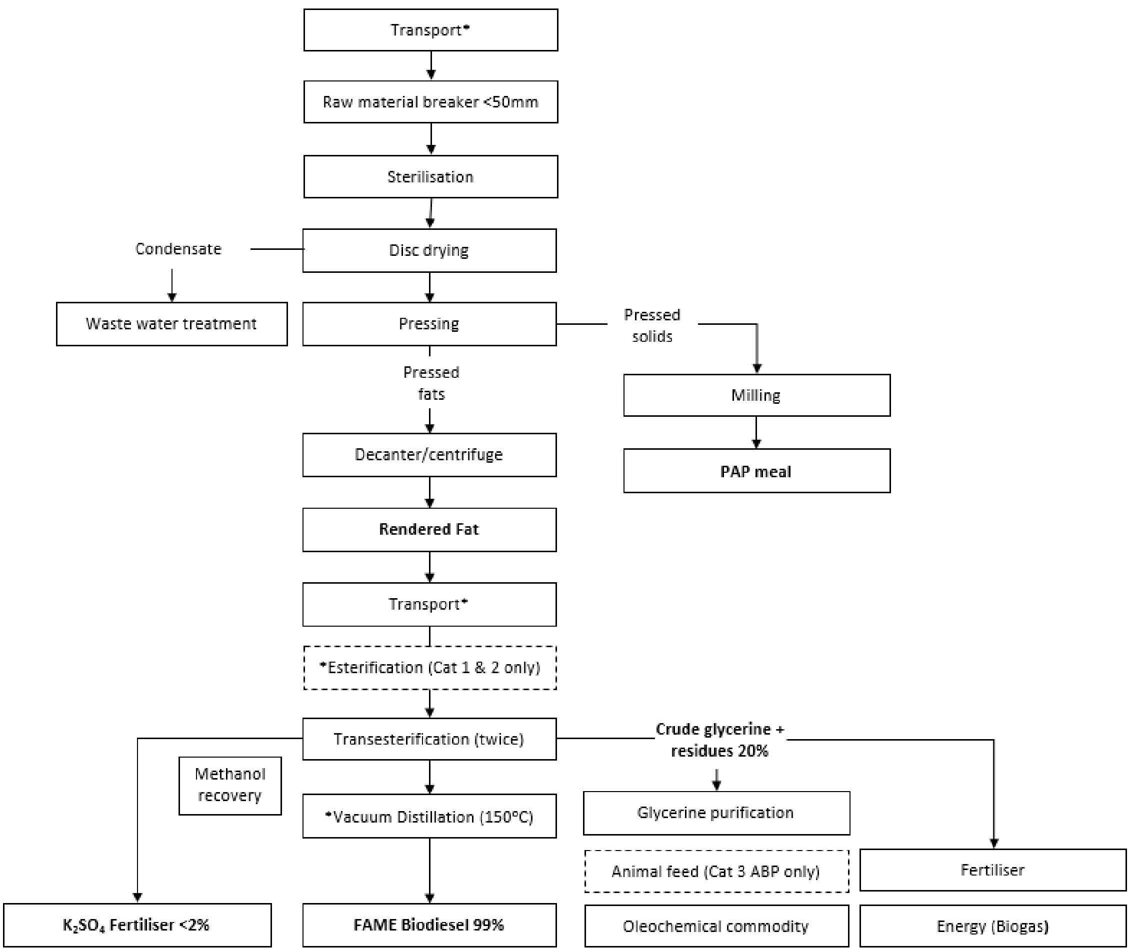
Transport has not been included since this is a user variable. A default for the tool scaled from Dufour and Irribarren is around 160 km (80 t.km), for transport of fats to biofuel processors, which appears to be based on US data. Data for EU countries are not available for comparison.

The sideflow PAP from animal fat processing, is assumed to be sold to pet food processors in the market for multispecies PAP. This is the most common route shown in Figure 99, which fits with the inventory relating to cattle CFPM processing which are prohibited from animal feed but may be used in certain approved pet food production processes, (EBLEX 2014[196]).

9.3.2 Tallow Methyl Ester (TME) Biodiesel

The process description for TME production from processed carcass fats is characterised in Figure 101. Aggregated process energy and yields (Table 86) have been adapted from Dufour and Irribarren (2012) which are derived from a US study by Lopez et al (2010). Co-products of transesterification are crude glycerol and potassium sulphate, both of which can be used for fertiliser. Glycerine can also be used as a feedstock in the oleochemical industry, or in animal feed where only category 3 ABP fats are used as the feedstock.

Figure 101 Model process for rendered CFPM into biodiesel



196 See also https://www.gov.uk/guidance/using-animal-by-products-to-make-pet-food

Table 86 Model inventory for 1 tonne of CFPM into biodiesel.

Inventory			
***Inputs**			
Fat and proteinaceous animal by-products	1	t	
Thermal energy	2120	MJ	
Electric energy	82	kWh	
Transport by lorry to rendering site	0	t km	Integrated site
***Outputs**			
Rendered fat	282	kg	
Meat & bone meal/Processed Animal Proteins (MBM /PAP)	228	kg	
Cooking vapours	490	kg	
Transport to biodiesel plant	variable	t km	User entry in model
***Inputs**			
Tallow feedstock	282	kg	
Methanol	31	kg	Assumed 100% recovered
Water	20	kg	
Sodium hydroxide	1	kg	
Sodium methoxide	3	kg	
Hydrogen chloride	2	kg	
Thermal energy (esterification)	49	MJ	
Electric energy (esterification)	8	kWh	
Thermal energy (transesterification)	482	MJ	
Electric energy (transesterification)	8	kWh	
***Outputs**			
Biodiesel	278	kg	
Crude glycerine	32	kg	
Salts to landfill	3	kg	
Hazardous liquid waste	6	kg	
Transport of biodiesel	variable	t.km	User entry in model

*Adapted from Dufour and Irribarren (2012).

9.3.3 Solid toilet soap

Soap is still a major surfactant and it use provides a dominant market for long chain fatty acids from tallow. Another major long chain fatty acid source used in soap manufacture is Palm oil. Figure 102 shows the model processing chain for soap originating from CFPM and the model inventory (Table 87).

A ratio of 80:20 mix of long chain to short chain fatty acids is approximated for the model, where tallow makes up all 80% of the long chain fats. The most common source for the remaining 20% short chain fats is assumed to be coconut oil. Palm kernel oil competes with coconut oil, however. The process assumptions, in addition to aggregated energy data, is based on the inventory published by Postlethwaite (1995) and represents a continuous soap making process typically used by a larger industry producer[197], as opposed to batch processing.

Glycerine as a co-product

There are two major differences in soap processing systems based on whether glycerine produced in the saponification process is extracted or not[198]. Glycerine is commonly included in toilet soap as a humectant and for its emulsifying properties.

Postlethwaite states that *all the glycerine co-product is used elsewhere,* suggesting a glycerine extraction process resulting in none present in the final soap product. However, a glycerine extraction process is not reported in Postlethwaite's soap production inventory. Neither is any allocation procedure documented relating to glycerine yet co-product allocation is clearly included in the tallow production stages. It appears that glycerine removal is not actually accounted for in the inventory, indicating the wet soap, prior to drying, retains glycerine in its composition.

Supporting this argument, a mass balance basic saponification calculation (Spitz 2009) from the inventory of raw materials published by Postlethwaite shows glycerine would make up almost 9% of the 1000 kg soap functional unit with a similar final product moisture of 12%. Therefore, a 1000 kg yield could be obtained only by *including* the glycerine reaction product. This is broadly similar to the base case solid soap product environmental footprint, which also includes a glycerine content, albeit 6% (Escamilla et al 2012). A further argument for assuming glycerine is not used elsewhere is that its commodity value has since fallen because of its increased production as a co-product of the biodiesel industry in the last 15 years. Therefore, in using material inventory data from Postlethwaite (1995), a glycerine reaction product is assumed to be retained, making 8.7% of the final soap product by weight.

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[197] The author was a physical chemist employed by Unilever in the surfactanrts and personal product sectors, also chaired SETAC-Europe LCA steering committee, therefore the inventory is considered to be from a respectable industry source, and from mature technology representative of todays processes.

[198] SWING or SAGE acronyms are used for Soap With INcluded Glycerine or Soap After Glycerine Extraction, respectively, (Spitz 2009).

Energy use assumptions

Aggregated energy data for the saponification, washing and drying stages of base soap manufacturing is reported to be the same for different fat sources (Postlethwaite 1995). A similar total energy figure is published in more recent technical review of product environmental footprints for the sector, (Escamilla et al 2012)[199]. The split between electricity and heat required in soap manufacture is not given in Postlethwaite (1995) but is assumed from the split given by Escamilla et al 2012 to be 2% electricity to 98% heat. Soap processing technology is mature and, though there have been some innovations[200] the overall efficiencies from Postlethwaite (1995) are assumed to be broadly representative of today's range of installed technologies.

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[199] Due to data being unavailable from industry, the JRC relies on a commercial LCA dataset that is derived from a study of the European surfactants industry published in 1995 by European LCI Surfactant Study Group set up ECOSOL – European Council on Studies on LAB/LAS a sector group of the European Chemical Industry Council (CEFIC) and represents the European producers of Linear Alkylbenzene and Alkylsulphonates (LAB/LAS).

[200] Soap production plant design and fabrication in Europe have been led by companies such as Mazzoni and Binnachi which supplied production lines for processes orginally patented by Palmolive-Colgate and Lever Brothers. These companies are still supplying industry today, Mazzoni claiming a 60% market share of soap processing technology sales. Though the company report recent advances in the last 10 years in continuous soap processing, the key process for saponification of animal fat based soap with glycerine extraction in a mature market is assumed to be represent that reported by Posthlethwaite 1995.

Figure 102 Model process for rendered CFPM into soap

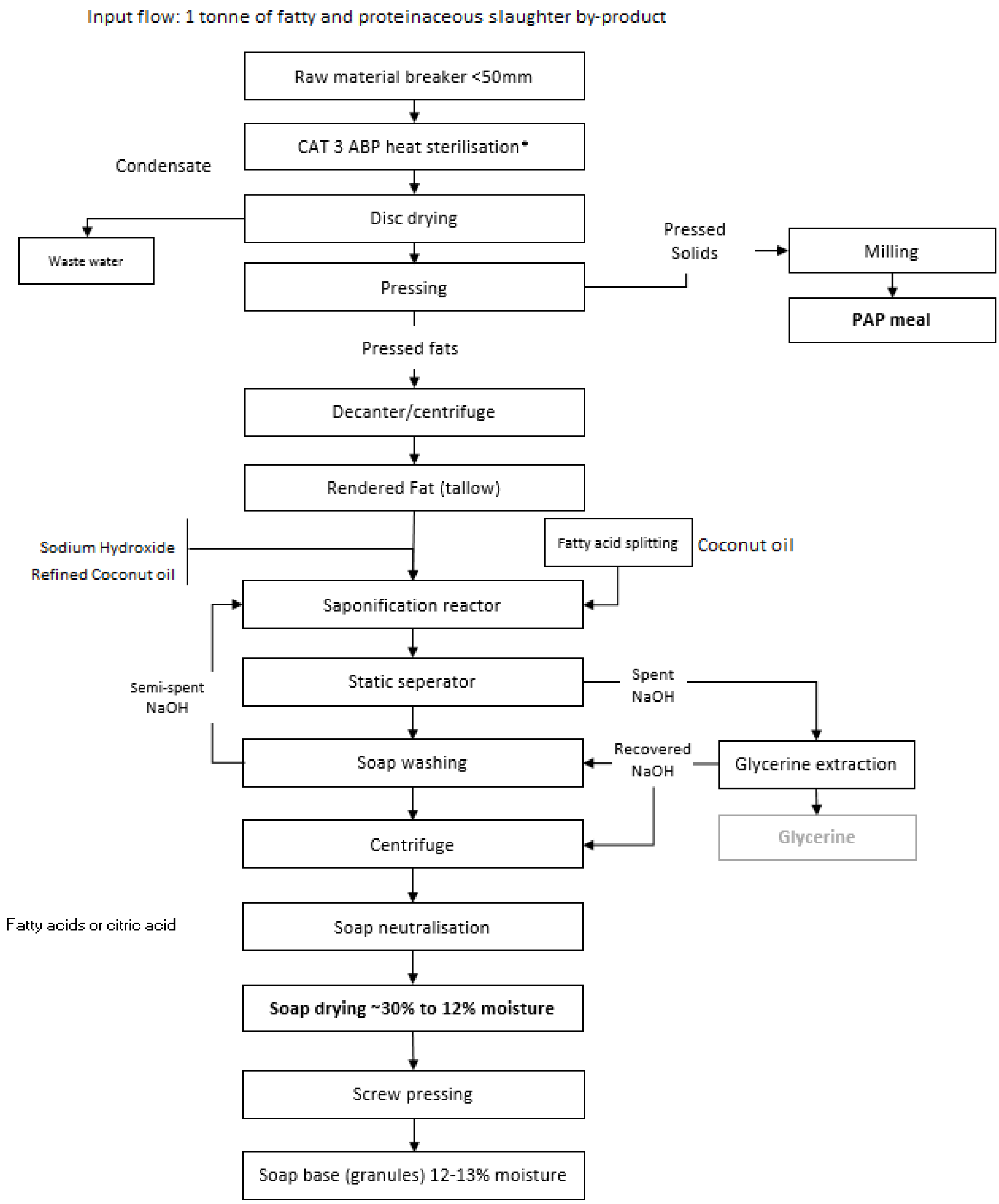

Table 87 Model inventory for processing 1 tonne of rendered CFPM into soap

Inventory					
Rendering					
	Inputs				
		Fat and proteinaceous animal by-products	1	t	
		Heat	2120	MJ	Reported values range between 1,350-3,550 MJ /tonne infeed (Ramirez 2012, Dufour and Irribarren)
		Electricity	82	kWh	
		Transport by lorry to rendering site	0	t km	Integrated site
	Outputs				
		Heat recovery exported	0	MJ	Assumed any heat recovery is used entirely onsite (hot water sanitation)
		Rendered fat	282	kg	
		Meat & bone meal/Processed Animal Proteins (MBM /PAP)	228	kg	
		Cooking vapours	490	kg	See 'Heat recovery exported'
		Transport to base soap manufacturer	Variable	t km	User entry in model
Soap manufacture					
	Inputs	Electricity	8	kWh	Aggregated across processes (Postlethwaite 1995, Escamilla et al 2012)
		Heat (assumed Natural Gas)	1800	MJ	
		Tallow	282	kg	
		Coconut oil	70	kg	(For 18% assumed for short chain triglyceride, 2% for FA required)
		Fatty acids	-	kg	Neutralisation stage - may also be citric acids (Spitz 2009)
		Sodium Hydroxide	53	kg	Assuming NaOH added in 50% initial solution (w/v)
		Water in NaOH solution for reaction	53	kg	Initial NaOH solution
		Wash water incorporated into wet soap	173	kg	30% moisture for pumping, then spray drying
	Outputs	**Dried soap granules**	**419**	**kg**	Approx. 12% moisture (including glycerine)
		Glycerine	**40**	**kg**	Assumed 8.5-9% w/w of final products (soap 80%) and left in soap

*Adapted from Dufour and Irribarren (2012).

10 Annex 10 Potato processing by-products

List of abbreviations

NREU	Non-renewable energy use
PLA	Polylactic acid
$kgCO_2eq$	Kilograms of carbon dioxide equivalent
GHG	Greenhouse gas

10.1 Background

10.1.1 Rationale

Processed potato products have been identified as one of twenty foods for which a processing waste, or *sideflow*, has been considered suitable for valorisation by Refresh deliverable 6.9[201]. A Refresh sideflow is defined by Davis et al (2017) as material flows leaving the food supply chain that the stakeholder generating it wants to minimise. The aim of this report is to produce model inventories for commercially demonstrated valorisation routes (meeting EU TRL 9 status).

10.1.2 Scope

Sideflows from potato processing can be distinguished broadly between two different sectors: potatoes grown principally as food products, and potatoes grown for starch production. Starch potato processing is considered outside of the scope of REFRESH *food* sideflow valorisation.

Food sideflows here focusses on those from principally potatoes grown and processed exclusively for food items. Examples are chips (fries), crisps, canned, fresh, frozen, or dehydrated for pre-prepared meals, or their components. In the potato industry these edible varieties are called 'ware' potatoes. The processed food potato market in the EU is worth €9.4 Billion, just over 1 % of the overall value of EU food and beverage industry output (Eurostat 2017).

In the dedicated potato starch processing sector, although native or modified potato starches are used in various food and drink products, foods are not exclusively the driving market. Potato starch is commonly used in wider industrial applications[202]. It also has differing sideflows to food potato products. Considerable quantities of potato starch by-products such as fibre, proteins and concentrated potato fruit juice already have established markets for animal feed and use as fertilisers and are less likely to be treated as waste[203].

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[201] http://eu-refresh.org/sites/default/files/D6_9_Waste_Streams_Final.pdf

[202] Potato starch makes up around 13% of the 11 million tonnes of starch produced by the EU processors (maize and wheat starch dominate). Only approximately 60% of commercial starch production in Europe is used by the food and drinks sector. Almost a third is sold primarily to the paper and corrugating industry, with the remainder for pharmaceutical and other non-food uses. Source: Starch Europe Website accessed Jan 2018.

[203] https://www.starch.eu/starch/#coproducts

10.1.3 Information on potential and actual quantities

Potato processing in the EU is concentrated mainly in Belgium, France, Germany, Italy, the Netherlands, and the United Kingdom. The quantities of different sideflows from ware potato processing industries depend on the processing technologies, which are related to the various driving products. Processing products are diverse with specialisms observed for some Member States (Table 88). However, due to confidentiality, Eurostat cannot publish production data for these categories for each Member state and the respective processing losses cannot be estimated for each in MS. Studies indicate a large range in processing loss sideflows, between 9% and 35% of the original potato, with 19% average (n=5) for which 14% is due to peeling alone (Willersinn et al 2015). Partly the variation is attributed to product type, but also depends greatly on the quality and size 'calibration' of the crop.

Table 88 EU-28's sold production by groups of processed potatoes products in 2015, and leading producers across the EU (Source: Eurostat).

Processed potato products	EU 28 Total Sold Quantity tonnes	Lead MS producer (share%)
Frozen potatoes, uncooked or cooked in steam/water	538,800	Italy (62%)
Frozen potatoes, prepared or preserved (including potatoes cooked or partly cooked in oil)	4,956,400	Netherlands (34%)
Dried whole potatoes (cut or sliced)	3,600	Germany (74%)
Dried potato flour, meal, flakes, granules, and pellets	439,200	Germany (51%)
Preserved potato flour, meal, or flakes (not dried or frozen)	89,200	No information
Potatoes prepared or preserved as crisps	2,000,000	UK (21%)
Potato starch (excluded from scope)	1,190,600	No information

10.1.4 Site volumes

Without carrying out representative surveys of the size structure of potato processing companies it is not possible estimate the quantities of different sideflows produced at sites across the EU. Environmental operating permits for UK sites were requested from regulators. However, these did not provide suitable information that can be used to estimate plant processing capacities[204]. Information from processing technology manufacturers and trade sources has been sought instead. Their technology capacities and knowledge gives some indication of the range of production capacity of sites that can invest in this technology.

Peeling operations

The theoretical minimum quantity of peel that can be removed is approximately 2-3% of the mass of a typical sized whole potato. For medium and large processors, anecdotal evidence from industry and regulatory sources suggests potato peeling operations can be broadly split into mechanical abrasive peeling or steam peeling technology (EC JRC 2017); mechanised knife peeling may be used when a variety of products are processed, or where smaller processing capacities are concerned. Knife peeling may also be used in conjunction with abrasive peeling. Chemical peeling using caustic solutions, though once common, is now much less so[205].

Steam peeling

Steam peeling is commonly applied in chips/French fries processing plants in continuous processes. Steam peeling losses of 5-6% of the potato mass are reported by industry sources[206]. In addition to skin some of the flesh of the potato is also removed. The starch content is partially gelatinised by the heat. Typically, it is used as an animal feed co-product (Crawshaw 2001, EC JRC 2017). Odenburg, a company based in Dublin, Ireland, supplied peeling equipment to a significant share of European fries producers for many years. The company, now owned by Tomra (Norway), produces processing lines with capacities ranging from 1 – 65 tonnes per hour. Other articles published in the commercial press have used examples of 30 tonnes per hour, which are assumed to represent typical medium to large potato processors. Assuming 6,000 operational hours per year and 5% losses from peeling with 80 - 90% recovery indicates over 7 – 8 kilo tonnes of peel per year per site.

Abrasive and mechanised peeling

Potato crisp processors commonly use abrasive peeling. A higher proportion of peel waste arises from abrasive mechanised peeling compared to steam peeling. In

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[204] Freedom of information requests were made to public authorities to obtain site level IPC permits for UK factories, which require in principal some data on site waste, water and energy consumption for performance monitoring. This information was left blank from the permit documents, and it is likely this information has been withheld for reasons of commercial sensitivity.

[205] Potato Business Website: Accessed April 2018

[206] Marijke Bellemans, TOMRA Sorting Solutions, article published online, Freshplaza, web journal of fresh produce industry. Publication date: 7/8/2014 accessed

addition, waste arisings may include potato meal (from rejected potatoes). An average of 35 - 40% loss from the fresh weight potato infeed has been indicated by one industry source[207] and 10-30% from another source.

Abrasive peeling is used by the largest crisp manufacturers in the UK processing in excess 800 tonnes of potatoes per day, whereas medium sized crisp processors may process 100-200 tonnes a day. So, site arisings could vary from <10 tonnes per day to over 300 tonnes per day at the largest plants.

Cutting and slicing processes

Starchy processing water from cutting and slicing fries, chips or crisps is a side flow that is processed by larger companies to recover starch from and reduce effluent processing loads. The recoverable starch from slicing operations varies depending on the final products. Industry sources indicate starch, up to 2% by weight, of processed potato's, can be recovered from slicing water, reducing to <0.5%[208] for straight cut French fries. The crisp market is also diversifying, and some UK manufacturers have started to use dry slicing operations to purposely avoid starch loss from potato crisp products, perceived as an integral part of the product texture[209].

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[207] Huw Thomas, MSE Hiller, Personal Communication March 2018
[208] Huw Thomas MSE Hiller, Personal Communication March 2018
[209] E.g Kettle Foods, UK.

10.2 Current valorisation options

10.2.1 Animal feed

Industry sources indicate that peel and recovered starch from the processing of food potato products are most commonly used as animal feeds in the UK [210] (EC JRC 2017). Uncooked peels and raw rejected whole potatoes, and trimmed parts from crisp manufacturers may have a high fibre but relatively low energy content which restricts its use as a feed to ruminant livestock at certain life stages. In addition, uncooked, the starch fraction is less digestible to non-ruminants such as pigs, and contain anti-nutritional factors which impair protein digestion (Crawshaw 2001).

Peeling processes that employ steam, typically applied by chip (fries, not crisps) processors, makes the starch and peel fractions of the side streams, (steam peel), more palatable and improves the rate of digestion for livestock including non-ruminants such as pigs (Crawshaw 2001). In general, abrasion peeling causes higher product losses than steam peeling, 20-30% compared to <15 % respectively (EC JRC 2017). Even accounting for this yield difference, as can be seen from Table 88, the much larger volume of potato chips produced suggests that steam peel represents the larger sideflow from ware potato processing in the EU. Therefore, peel processing sideflow in its most common form is likely to be dominated by the animal feed industry.

10.2.2 Waste water starch recovery.

Starch can be recovered from waste water and sold and further refined for a variety of purposes, or, subject to feed safety requirements, used as a crude starch feed cake for livestock rearing.

10.2.3 Starch based packaging

Conventional starch can be used as a feedstock for biodegradable packaging and packing fillers[211]. Few examples have been found where recovered potato starch is being explicitly used in Europe. However, examples have been found where recovered starch has been marketed as a more 'eco-friendly' alternative than starch processed from dedicated starch crops or fossil-based equivalents by companies outside of the EU[212].

10.2.4 Anaerobic digestion

Anaerobic digestion has been employed in commercial potato processing sites where high starch loads in the waste water can be treated by bacteria's metabolic

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[210] Robin Crawshaw personal communication Nov 2017.
[211] E.g http://www.greenlightpackaging.com/about-green-light/ accessed Jan 2018
[212] E.g. https://earthpac.co.nz/our-environment/ accessed Jan 2018

processes to generate biogas for combustion in heat and power generating engines[213].

10.3 Technical description of process inventories

10.3.1 Animal feed (abraded peel and trimmings)

The processes assumed for mechanical peel recovery utilised as an animal feed are based on an example used at a large UK crisp processing site. The raw peel and trimmings are typically transferred in process water to a large silo or sump tank. The resulting slurry is pumped via a screen to a filter press which mechanically removes over 70% of the mass of sideflow as press water which includes solids as fines. The pumping process is not considered additional, (it would exist with or without recovery), and therefore its electricity consumption is excluded from the inventory.

Based on industry sources the remaining filtrate fraction is assumed to be < 30% and approximately 30% solids. This can be transported to farms as a fibrous low energy forage at this stage, (with no addition of recovered starch). However, the addition of recovered starch may improve the value received from feed merchants but also reduce processors effluent costs. Starch can be recovered from process water via centrifuge or hydrocyclones. Centrifuges are used in the basic model following the industry example (Figure 103). The result is a ruminant feed stuff with 30-35% solids.

[213] McCains, an international potato products company, have employed this in its UK processing division

Figure 103 Model of mechanical peel dewatering and starch recovery for feed

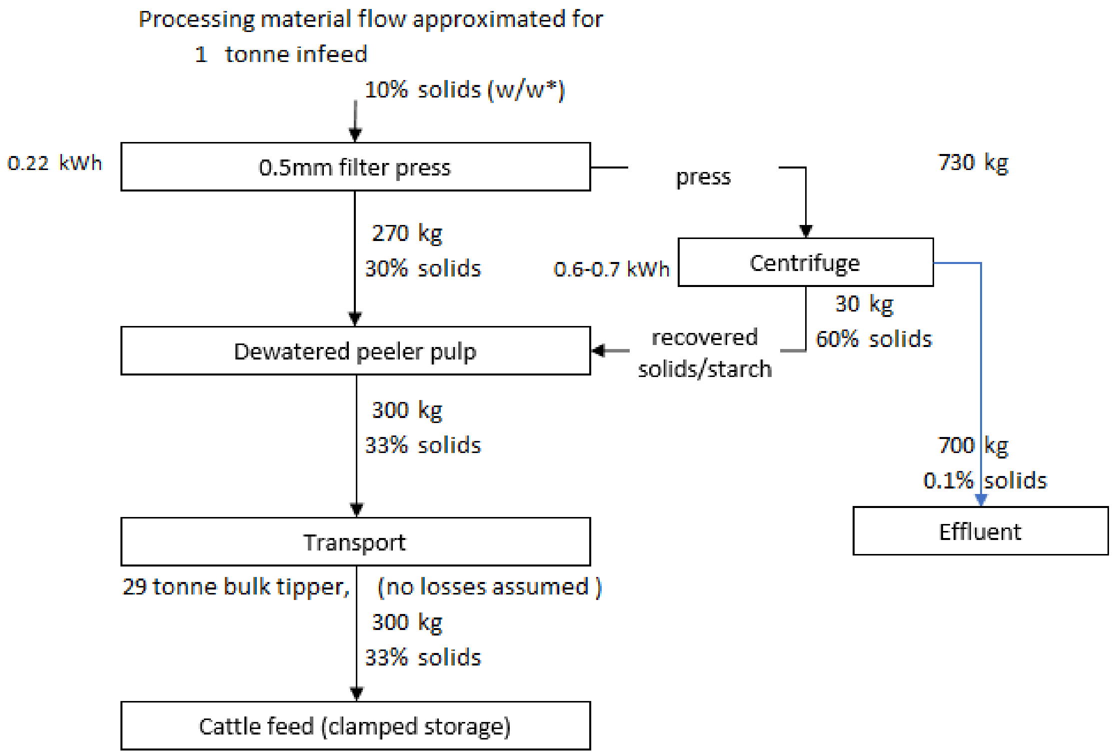

Table 89 Model inventory for mechanical potato peel recovery for feed.

INVENTORY	Value	Units	*Notes*
Filter press			
Input			
Mechanical peel at processor site	1,000	kg	*90% moisture*
Electricity	*0.22*	kWh	
Output			
Pressed peeler pulp	270	kg	
Press water	730	kg	*Sent to centrifuge for recovery of fines*
Centrifuge			
Input			
Press water	270	kg	
Electricity	0.7	kWh	
Output			
Recovered fines (starchy solids)	*30*	kg	*60% solids*
Effluent treatment plant/sewerage	700		*0.1% solids*
Final combined output			
Pressed peel and recovered starch	*300*	kg	*33% solids*
Transport			
29 tonne bulk tipper	50	km	*Animal feed merchant to regional farms*

Data is indicative but based on UK potato processing industry applications - personal communication, Huw Thomas, M&SE Hiller March ‘18.

Comparable products

According to Crawshaw (2001) at 32-36% dry matter 2.75 kg of abraded potato ‘peel and trim’ can replace 1 kg of rolled barley. A similar replacement could loosely be applied given similar given similar dry matter contents.

10.3.2 Potato feed (steam peel)

Potato feed and steam peel are terms used in the UK for peel removed thermally by steam, typically employed by potato chip (fries) processors.

Due to the thermal process, the starch in steam peel undergoes a degree of gelatinisation which changes the sideflow properties affecting bound water, but also improves the palatability of the sideflow as a feed. UK feed merchants supply steam peel at 11% dry matter[214], so dewatering is not an exclusive requirement for its use as a feed. In this case, the only process associated with valorisation is a logistical one of bulk transport between source and farms by feed merchants. However, by removing some of the bulk weight of bound and free water the sideflow is cheaper to transport and has an improved nutritive content.

The valorisation approach outlined below is based on a US process which reacts hydrated lime with the steam peel as a press aid which frees bound water during screw pressing[215]. Starch suspended in the press water is recovered using a hydrocyclone. European processor's approaches for steam peel valorisation are proprietary[216] and were not publicly accessible.

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214 https://www.duynie.co.uk/products/potato-peel/1259
215 Vincent Corporation website, accessed March '18.
216 Personal Communication, Erik Van der Been, Valorisation Manager, Lamb Weston BV. Erik has also been unable to respond to a further requests for comments on the applicability of this model as a representative process for European processors.

Figure 104 Model of steam peel dewatering and starch recovery for feed

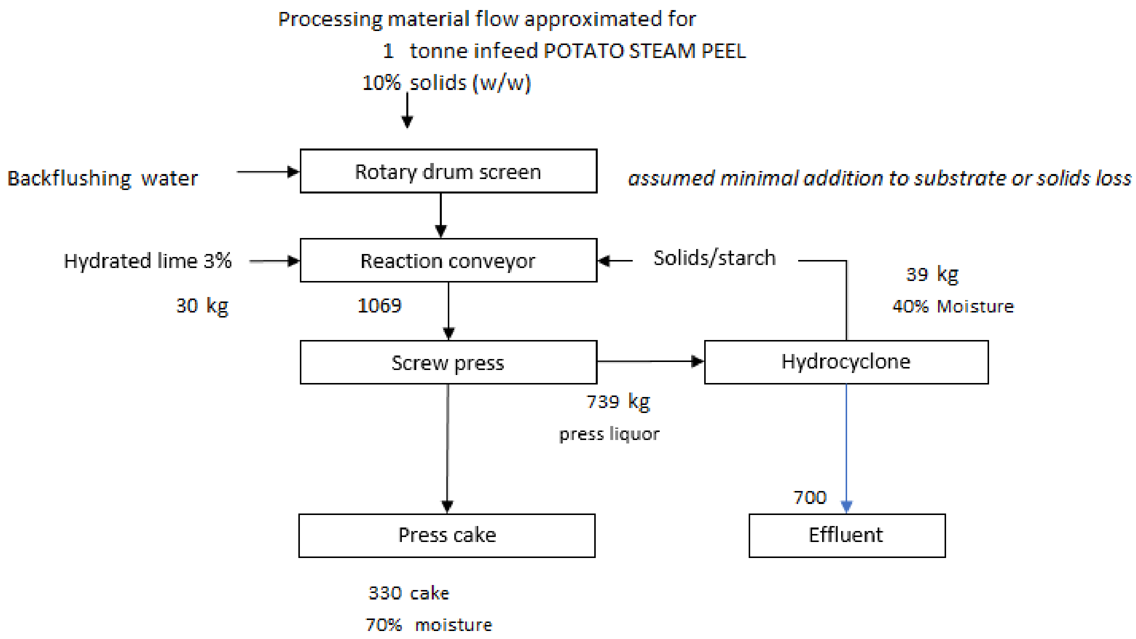


Table 90 Model inventory for potato steam peel recovery for feed

INVENTORY			
Rotary drum screen & reaction conveyor			
Input			
Steam peel at processor site	1,000	kg	*Pumped from processing collection tank via drum screen*
Calcium hydroxide	30	kg	*Hydrated lime is mixed with steam peel to 3% w/w*
Electricity	*no data*	kWh	*Assumed negligible due to likely small motor duties*
Output			
Reacted steam peel	1030	kg	*A fraction of the bound water is freed by reaction with $Ca(OH)_2$*
Screw press			
Input			
Reacted steam peel	1030	kg	
Recovered starch from press water	39	kg	
Electricity		kWh	
Output			
Press water*	739	kg	*3.3% solids*
Dewatered steam peel	330	kg	*70% moisture*
Hydrocyclone starch recovery			
Input			
Press water*	739	kg	*3.3% solids*
Electricity	0.4	kWh	*Based on specific pump duty estimate (Larrson, Sweden)*
Output			
Recovered starch from press water	39	kg	*40% moisture*
Effluent	700	kg	*0.2 % solids*
Final output			
Dewatered steam peel	330	kg	*70% moisture*

**approximated as water density for pump duty estimates.*

Comparable products

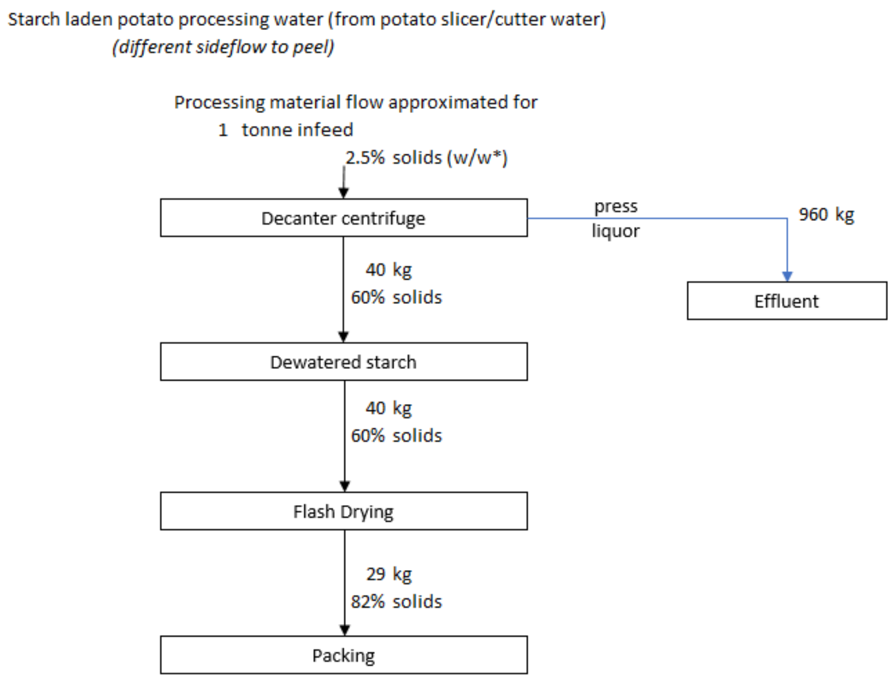
Fed to beef cattle Crawshaw (2001) indicates that 40 kg of steam peel can replace up to 5 kg of cereal grain. For dairy cattle he indicates 25-30 kg steam peel per day can provide the energy equivalent of 3 - 3.5 kg of cereal. Though no references are given on the moisture of the steam peel, the ruminant metabolisable energy (ME) on a dry matter basis is around 12 MJ for steam peel, whereas feed wheat is around 13 MJ and barley somewhat lower. So Crawshaw's replacement ratio of over 8 to 1 suggests, on an energy basis, that this is largely due to differences in moisture content. Using ME equivalents suggests he has based this on steam peel with just over 10% dry matter compared to the cereals 86% dry matter. In the process presented above it has been concentrated to 30% dry matter, so on an energy content basis for ruminants around 2.7 kg of steam peel at 30% dry matter would be comparable to 1kg of feed cereal grain.

10.3.3 Starch - reclaimed from processing water

Starch can be reclaimed from potato processing water and used as an animal feed without addition to peel, or also sold for use in non-feed, industrial or commercial starch markets. Figure 105 shows a basic process for recovering starch from process water associated with potato cutting or slicing machinery.

Broeren et al assumed 2.5% w/w of potato slicer wash water is starch. A UK industry source indicated 100 tonnes of potatoes processed typically produces around 1.8 tonnes (dm) of recoverable starch with a 95% centrifuge recovery[217]. Other industry sources estimate between 1% and 2% of any potatoes sliced will be recovered as starch[218]. Slicing water is assumed to contain approximately 2.5% solids, which are predominantly starch. Using this assumption, the wash water and associated centrifuge energy consumption has been estimated from discussions with an industry decanter centrifuge supplier[217]. The effluent removed is assumed to be processed as for industrial sewerage or by effluent treatment plants with differences in emissions assumed to be negligible to average effluent treatment.

Figure 105 Recovery of starch from slicing/cutting process water



[217] Huw Thomas, MSE Hiller. Personal Communication March 2018.
[218] http://www.centri-force.co.uk/case-studies/starch-recovery/ website accessed April 2018

Table 91 high level inventory for process water starch recovery

INVENTORY				
<u>**Decanter Centrifuge**</u>				
	Input			
	Processing water	1,000	kg	**2.5% starch*
	Electricity	*0.9*	kWh	*0.8-1 kWh/m3**
	Output			
	Starch rich solids (retentate)	40	kg	*60% solids*
	Removed (centrate) effluent	960	kg	*Sent to effluent plant/sewerage*
<u>**Drying**</u>				
	Input			
	Starch rich solids	40	kg	
	Electricity	0.0	kWh	
	Heat	68	MJ	*Gas fired 40% efficiency (Broeren et al 2017)*
	Output			
	Reclaimed starch	*29*	kg	*18% moisture*

*Data estimate: personal communication with Huw Thomas, MSE Miller.

10.3.4 Reclaimed starch based plastic

As outlined in 10.2, reclaimed starch from ware potato processing may be a preferable source for sustainable claims made for packaging compared to processors relying on dedicated starch crop feedstocks.

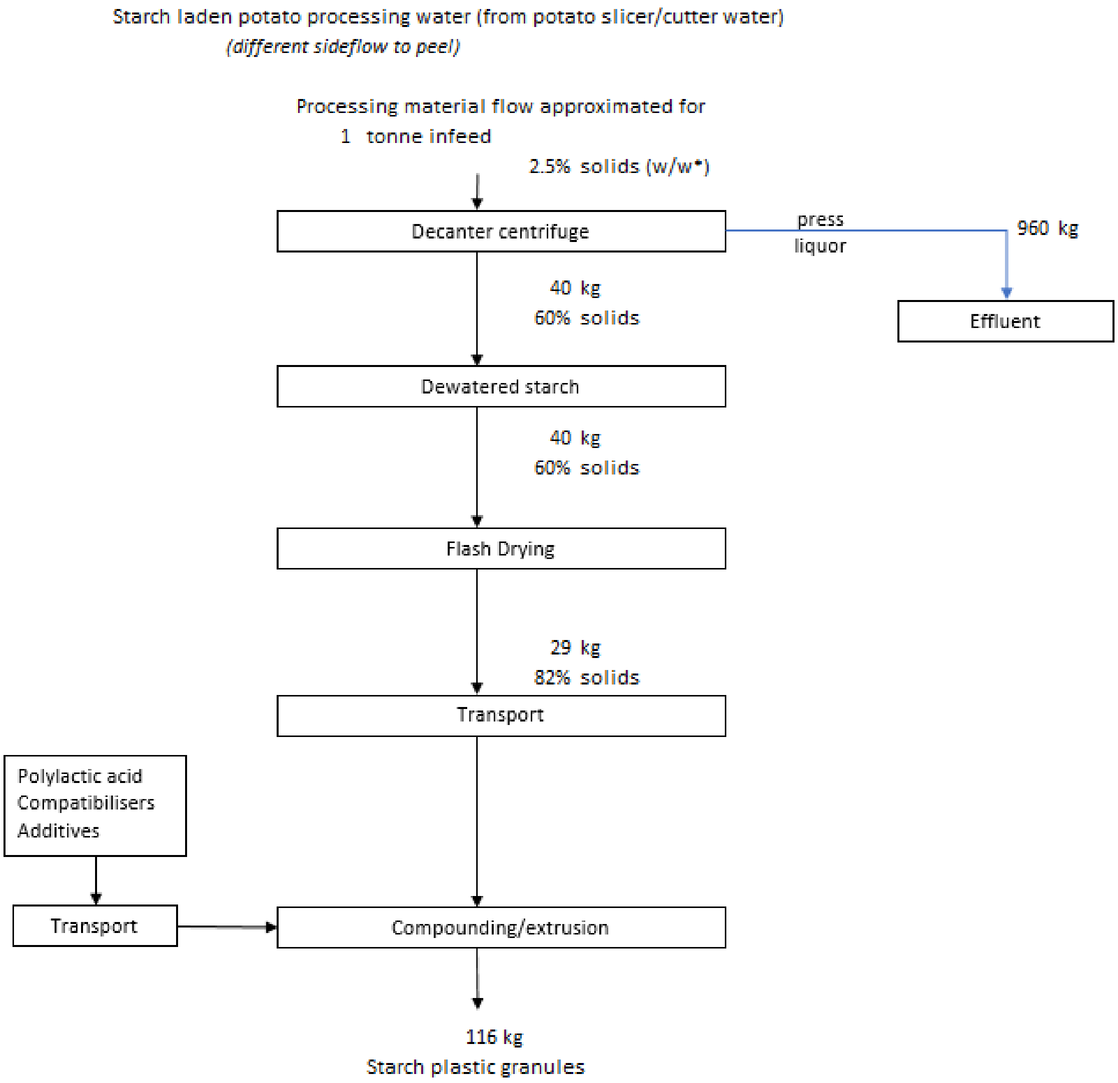
The inventory for the processes before centrifugation is taken from Table 91 in the previous section. After centrifugation, in Figure 106, processes are taken from a recent study published by Broeren et al 2017 for polylactic acid and starch plastic, extruded and compounded in the form of granules, at the factory gate. Broeren et al argue that centrifugation is a waste treatment step and not part of the bioplastics inventory. Though it has been included in Table 92 for this model as a part of the sideflow recovery stage.

The dewatered starch is dried further to 18% moisture content by flash evaporation, using natural gas at an assumed 40% thermal efficiency by Broeren et al 2017. Inventory data for input materials, including their transport, compounding and extrusion processes are not published. Instead a single result for the total global warming potential published by Broeren et al is aggregated for all these processes and inputs using background data appropriate to a Netherlands or European context.

It is important to also note that biogenic carbon in the starch (removed from the atmosphere during potato cultivation) is counted as a negative emission in the authors inventory at the study boundary (factory gate). This is approx. 1.2 kgCO_2 equivalents per kg where starch content is 25% of the polymer. Of the remaining mass 43% and 32% is PLA and compatibliser/ additives respectively. Total biogenic carbon removal to the factory gate is reported at approximately -1.25 kgCO_2 eq per kg and is included in this figure.

This has been used to adjust in the aggregated figure to omit stored biogenic carbon from the scope of this inventory in line with the modelling approaches used in the spreadsheet model. The emissions figure, excluding biogenic credits, presented in Table 92 approximates between 2.4 to 2.5 kgCO_2 equivalents per kg of final product.

Figure 106 Recovered potato processing starch used as a *bio-plastic* feedstock material.



Comparison products

Comparisons can be made with the same kind of polymer using a typical virgin starch crop based. The reductions in GHG for using reclaimed starch compared to virgin potato starch are reported to be minor by Broeren et al, ranging between 1.2–5.2% for all different grades of starch containing plastic modelled. This may largely reflect an additional drying duty for reclaimed starch (40% to 18% moisture compared to 20% to 18%) which makes up for the fossil use for primary crop production and processing of virgin potato starch crops.

Limitations and uncertainties

The study by Broeren et al does not compare key starch crops such as maize (83% of global starch production) with reclaimed starch, yet maize starch appears to be intrinsically included in the production of the PLA fraction of the polymer, which remains unchanged in the comparison.

Interestingly, the same per cent values of reductions (1.2-5.2%) are reported for both non-renewable energy use (NREU) and GHG emissions. This suggests that GHG reductions essentially reflect differences in net fossil energy use. However, Broeren et al report more pronounced reductions (19–41%) in eutrophication potential in changing from virgin starch production to reclaimed starch. Use of nitrate and phosphate causing fertiliser may account for key differences between reclaimed and virgin starch. If so, one would expect to see some evidence of an additional GHG emission reduction due to the absence of nitrogenous fertiliser related nitrous oxide GHG emissions in the inventory for reclaimed starch compared to the reductions in NREU. In addition, demands on land use and related GHG emissions for non-food crops may also be implicated in some instances in land use change (e.g. Searchinger 2008). The nitrous oxide emissions are not reported and the indirect land use change is considered a potential risk, but has not been quantified. This is probably due to the uncertainty associated with doing so, but also it may be considered methodologically inconsistent with the attributional approach taken.

Table 92 Model inventory for 1 tonne of potato effluent processed into bioplastic.

INVENTORY				
Decanter Centrifuge				
	Input			
	Processing water	1,000	kg	*2.5% starch*
	Electricity	*0.9*	kWh	*0.8-1 kWh/m3**
	Output			
	Starch rich solids (retentate)	40	kg	*60% solids*
	(Centrate) effluent	960	kg	*Sent to effluent plant/sewerage*
Drying				
	Input			
	Starch rich solids	40	kg	
	Electricity	0.0	kWh	*No data*
	Heat**	68	MJ	*Gas fired 40% efficiency (Broeren et al 2017)*
	Output			
	Reclaimed starch	*29*	kg	*18% moisture*
Processing into biodegradable plastic**				
	Input			
	Transport (components listed)	No data	t.km	***Reported GHG total = 2.4 -2.5 kgCO_2 eq per kg (excluding biogenic sequestration credit)*
	Reclaimed starch**	*29*	kg	
	Polylactic acid (PLA) (biobased)	50	kg	
	Compatibiliser additive	31	kg	
	Other additives	6	kg	
	Electricity (compounding extrusion)	61	kWh	
	Output			
	Starch PLA plastic *granule feedstock*	116	kg	

*Data is indicative but based on UK potato processing industry applications - personal communication, Huw Thomas, M&SE Hiller

** Based on Broeren et al 2017, (no details are given on compatibiliser and additives components due to commercial confidentiality).

Annex 11 Input data to the FORKLIFT model

This is provided in an additional separate excel file (as supplementary information) on the results section for Deliverable 6.10 of the the REFRESH website.

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