Ricardo Energy & Environment

Whisky by-products in renewable energy

Report for ClimateXChange
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Executive summary

Background

The production of whisky yields two significant by-products, namely:

(1) **draff**, which is the soaked grains from the first stage of production; and
(2) **pot ale**, which is the liquid residue from the first distillation stage at malt distilleries.

These whisky by-products can provide a high protein animal feed in three different formats:

(1) **draff** (unprocessed beyond rudimentary drying) as a direct feed;
(2) **pot ale syrup**, made by evaporating the pot ale; or
(3) **dark grains**, a combination of (1) and (2) following a further, intensive drying process.

The same by-products can also be used to produce renewable energy. The recent expansion in this use has prompted questions about the relative carbon footprints of using whisky by-products for animal feed and renewable energy.

Approach

Using life cycle assessment, this study compared three different ways of using the by-products, those being to produce either simple animal feeds (draff and pot ale syrup), dark grains or renewable energy. Following feedback from policy and industry stakeholders, two further scenarios were assessed, in which draff alone was used as a direct animal feed or for renewable energy. This also approximates what happens in grain distilleries, where no pot ale is produced.

Each scenario starts with 1,000 t of Draff, and 3,300 t of Pot Ale if included, and does not include any burdens from the whisky distillation process.

Findings

The study found that all scenarios have a positive benefit, reducing climate change impacts. This is because greenhouse gas emissions are offset by avoiding the production of energy, animal feeds and/or fertilisers by other means. The results indicate that it is the offset energy that is the determining factor between the scenarios.

In the three scenarios studying both draff and pot ale, the renewable energy scenario delivers the greatest benefit. As well as offsetting the need to produce energy by conventional means, there are no energy-intensive drying processes required.

In contrast, there is negligible difference between the two draff-only scenarios, as the offset energy is largely balanced by the avoidance of alternative feed production.

The renewable energy scenarios assume that the heat produced offsets the need to burn natural gas. However, many remote distilleries are not connected to the gas grid, and tend to use heavy fuel oil (HFO) for their heating requirements. Under these circumstances, there was a significant benefit in using the draff for renewable energy rather than as an animal feed.

High-level results (Global Warming Potential)

Scenario	Draff & Pot Ale	Draff only	Draff only (HFO)
Renewable Energy	**-312 t CO_2 eq**	**-187 t CO_2 eq**	**-264 t CO_2 eq**
Simple Animal Feeds	**-217 t CO_2 eq**	**-177 t CO_2 eq**	**-177 t CO_2 eq**
Dark Grains	**-72 t CO_2 eq**	**n/a**	**n/a**

It must be stressed that this report only considers the impact of the different outcomes on global warming potential. With the life cycle inventory compiled, it would not be too difficult to extend the impact assessment to consider additional environmental criteria, and the accompanying model has been designed to facilitate this. Another scenario that could be explored is the anaerobic digestion of draff, which was not examined in this study.

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Appendices

1 Introduction

On behalf of the Scottish Government, ClimateXChange (CXC) commissioned Ricardo Energy and Environment (Ricardo) to deliver a Life Cycle Assessment (LCA) of the greenhouse gas (GHG) emissions associated with the use of whisky distillery by-products for renewable energy or animal feed. This reports on the findings of that study.

The rest of this section provides further background and context for the study, including, at the end of the section, a glossary of acronyms. Section 1 presents the critical decisions about the goal and scope of the LCA. Section 2 describes the LCA model that has been developed, which leads on to discussions about the life cycle inventory in the study and the subsequent impact assessment. Results are presented in Section 3, with details of the sensitivity analysis performed.

1.1 The Scottish Whisky Industry

Whisky is one of Scotland's major products and remains one of the country's most famous and economically significant exports. The Scotch Whisky Association (SWA) states that there were 115 distilleries licenced to produce Scotch whisky in early 2015[1]. Distilleries are located across the country with a few areas of high density, most notably Islay and Speyside.

Use of distillery by-products as an animal feed is important to Scottish cattle farmers as it provides a low-cost feed; they can also be spread to land, as a source of fertiliser. It is anticipated that the whisky sector will continue to expand overall production, both through commissioning of new distilleries and the expansion of existing sites. Based on previous production figures published by the SWA, it is not unreasonable to assume that production could increase by 5% in each of the next two years. Since 2013, some 14 new distilleries have started production and around eight are set to open this year, with many more at various stages of planning and development[2]. This will increase the amount of by-products being produced.

With this growth in the distillery sector and no growth experienced in the agricultural sector, the expectation is that there is a strong need to explore new uses, beyond existing feed and fertiliser markets, for the by-products to support this growth. One of the main considerations is the fact that for many distilleries the amount of draff and pot ale produced exceeds the capacity of the local farms to use it, especially in summer when there is less need for supplementary cattle feed.

In 2006, the SWA published a GHG LCA[3] for the whisky sector on a cradle-to-glass basis. The current study is an important step to advance the understanding of the carbon emissions for whisky by-products in Scotland, which are of great interest to the whisky and agricultural sectors.

1.2 Whisky Production

Distilling whisky involves the production of a number of by-products:

- **Draff** is the industry name for the wet (moisture content ~80%) grains which are no longer useful in the production of alcohol. This material is rich in protein, carbohydrates and fibre.
- **Pot Ale** is the liquid residue from the first distillation stage, and has about the same alcohol content as beer (hence the name). It contains protein from the yeast and grain, as well as copper in the case of malt distilleries using copper stills.
- **Spent Lees** are the liquid residue from the second distillation stage in malt distilleries; it is similar in properties to pot ale, but more dilute.
- **Washings** are, as the name suggests, the result of washing the stills and flushing the lines between batches.

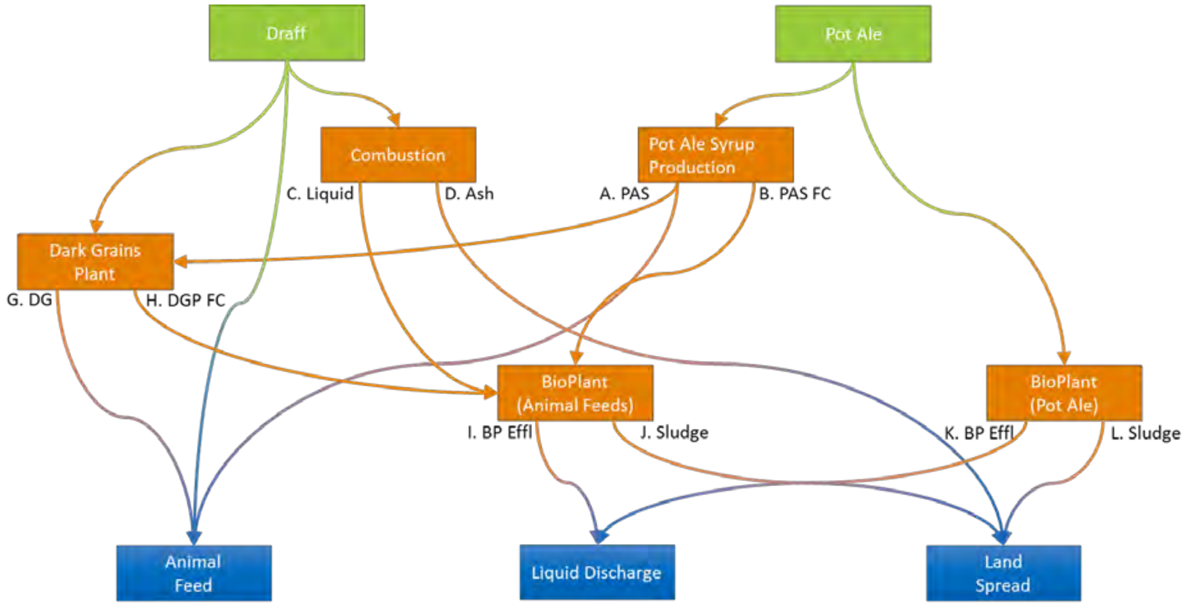
Spent lees and washings are very dilute solutions, which are typically handled in a traditional water treatment works, or directly discharged to sewer, river or sea. As such, they are not of relevance in this study.

[1] Scotch Whisky Association, available at - http://www.scotch-whisky.org.uk/what-we-do/facts-figures/
[2] http://www.scotch-whisky.org.uk/news-publications/publications/documents/swa-annual-review-2016-17/#.WVZWcITysnQ
[3] The Life Cycle Assessment of Scotch Whisky, available at http://www.scotch-whisky.org.uk/media/12908/lifecycleassessment.pdf [accessed 26/Apr/2017]

This leaves draff and pot ale. Pot ale is traditionally concentrated to produce **Pot Ale Syrup** (PAS), a liquid that can either be fed directly to animals, or combined with draff (which is also an animal feed in its own right) and further concentrated to produce **Distillers'** or **Whisky Dark Grains** (DDG, WDG), a solid animal feed. More recently, distillers have been using the two materials as renewable energy sources, using biomass combustion (for the draff) and anaerobic digestion (for the pot ale). These different options for the two materials are presented schematically in Figure 1.

We are also aware of work by, for example, Celtic Renewables to develop biofuels from draff and pot ale, but have chosen for now to exclude this from the modelling, as such work is still in development.

Figure 1: Potential Fates of Whisky By-Products



FC = Foul Condensate

1.3 Market Context

1.3.1 Introduction

Previous research has indicated that the whisky sector in Scotland has significant potential for strong growth. For example, the *Sector Study on Beer, Whisky and Fish* indicated that confidence in the whisky sector remains high with a growth rate estimated at 2.1% over the period to 2018[4]. The *Distillery Feed By-Products Briefing*, published in 2012, also indicated growth in the sector, identifying that investment was expected to increase distillation capacity by around 33 million litres per annum (lpa), which in turn could generate around 27,000 tonnes (dry) of additional by-product (draff and pot ale syrup) per annum by 2014[5].

In discussing the distillery sector, it is important to recognise the reality that, due to their bio-chemical nature and high volumes, by-products cannot be stored for any length of time. As such, the accumulation of by-products poses a risk to the production process and they need to be removed from site. This study focusses on the associated merits of the possible fates.

The supply and demand of whisky by-products for different markets is not straightforward and there are a number of drivers and factors that affect this, most notably economics, geography and seasonality. Possible fates include historical uses for by-products, such as animal feed in the agriculture sector, and newer markets that use the by-products as feedstock for renewable heat and energy generation.

[4] http://www.zerowastescotland.org.uk/sites/default/files/ZWS645%20Beer%20Whisky%20Fish%20Report_0.pdf
[5] https://www.sruc.ac.uk/download/downloads/id/1057/distillery_feed_by-products_briefing

1.3.2 Context for the Whisky Sector

There are a number of different drivers that are relevant for the whisky sector as it produces increasing amounts of by-products such as draff and pot ale. The sector is focused on taking sustainability and circular economy considerations into account. For example, the Scotch Whisky Association's Environmental Strategy Refresh in 2016[6] covers four main themes:

- reducing energy use and greenhouse gas emissions
- responsible water use
- embracing a 'circular economy' in its supply chain
- sustainable land use

A key target within the sustainability strategy is the reduction of energy use and associated greenhouse gas emissions. Reducing energy use and greenhouse gas emissions has had a number of implications on the availability of by-products:

- Energy supplies and the type of fuel used is changing, with a move away from heavy fuel oil where possible. In recent years, two gas pipeline projects have been completed in Speyside to provide a number of distilleries in the area with a natural gas supply for the first time[7]. This will help reduce their greenhouse gas emissions through the replacement of fuel oil, which was delivered by road transport. The latest pipeline, completed in April 2016, provides seasonal gas, with the aim of a year-round supply being provided going forward.
- The use of by-products such as draff and pot ale for renewable heat and energy generation via combustion in biomass plants and as an input in anaerobic digestion plants is now a key market for utilising the by-products. This is also used to help shift away from other fuels, such as fuel oil and reduce greenhouse gas emissions. In addition, it provides economic benefits by offsetting the need to use other fuels and other energy sources to generate heat.
- There are a number of incentives to promote low carbon electricity generation that are relevant to the use of whisky by-products. For example, anaerobic digestion (AD) plants may have benefited from incentives under the Feed in Tariff (FIT) and also the Renewable Heat Incentive (RHI). Combustion plants may have received incentives from the RHI, depending on the feedstock the plants under this scheme use, and also the Renewable Obligation (RO) scheme.
- Changes in these incentives will in some instances remove or lessen these drivers. For example, the RO scheme is now closed to new generating capacity[8] and reductions in the FIT for new schemes seeking accreditation have also been introduced[9].
- Feedstock changes relevant to the RHI and FIT are also being proposed. The proposed change indicates that if more than 50% of biogas generated is from sources other than waste or residues a proportion of the output would not be eligible under the incentive schemes, reducing payment to the operator. This change could see increases in demand for waste and residues as operators seek feedstock that will maximise their eligibility under the incentive schemes. Depending on how whisky by-products are classified, this could greatly increase their demand as a bioenergy feedstock.
- Distilleries will need to consider changes to incentives in future years as this may affect the viability of certain routes by-products are used.
- Many of the biomass and AD plants provide on-site renewable generation of heat and energy utilising feedstocks generated by the individual distillery. However, there are off-site plants with larger capacity, notably the CoRDe plant in Speyside[10], which receives feedstock from a number of different distilleries within the area.
- Having large off-site renewable generation plants or large off-site AD plants drawing on feedstock from different distilleries could affect the supply available to other by-product markets in the area.

[6] http://www.scotch-whisky.org.uk/news-publications/publications/documents/environmental-strategy-refresh/#.WVIkxuvycs
[7] http://www.fulcrum.co.uk/news/news/2016/fulcrum-completes-40m-gas-pipeline-project-for-speyside-distilleries-ahead-of-schedule/
[8] https://www.ofgem.gov.uk/environmental-programmes/ro/about-ro/ro-closure
[9] https://www.ofgem.gov.uk/environmental-programmes/fit/fit-tariff-rates and https://www.ofgem.gov.uk/publications-and-updates/feed-tariff-fit-generation-export-payment-rate-table-1-april-30-june-2017
[10] http://www.aet-biomass.com/en-GB/Home/References/Biomass-Fired-Plants/Rothes-CoRDe.aspx

The drivers outlined above not only address sustainability aspects, but will also help the sector to mitigate against wider business issues such as security in supply and fluctuations in energy prices.

1.3.2.1 Other considerations

Aside from the sustainability drivers, the increasing quantities of by-products mean the following factors are also important:

- In addition to more established markets for by-products, such as animal feed and feedstock for renewable generation, alternative, newly developing markets need to be considered as quantities of by-products increase. Circular economy opportunities to turn by-products into higher value products have been investigated and developed. For example, in recent years the use of pot ale to make biodiesel has been undertaken.[11] Research by Horizon Proteins is also under way to explore the opportunity to extract protein from pot ale.[12]
- Increasing quantities of by-products mean alternative markets need to be considered as traditional ways of dealing with them reach saturation. An example is land saturation, where there are limits to the amount of by-products that can be spread and this needs to be managed.
- Although overall there would appear to be sufficient amounts of by-products to meet demand, additional factors such as seasonality and geography make the market context more complicated.
    - Seasonality of animal feed requirements may mean demand at certain times for the year is low. This highlights the fluctuating market demands and highlights issues associated with transportation costs and storage.
    - Geographical aspects of supply and demand are also important. For example, as noted above, a large off-site combustion plant taking by-products from various distilleries within a geographical area may affect supply for other markets within that area. Geographical aspects and proximity of supply and demand to each other will also be influenced by viable transport distances, which may vary depending on the end market and the value of by-products to that market.

1.3.3 Context for Farmers & the Animal Feed Sector

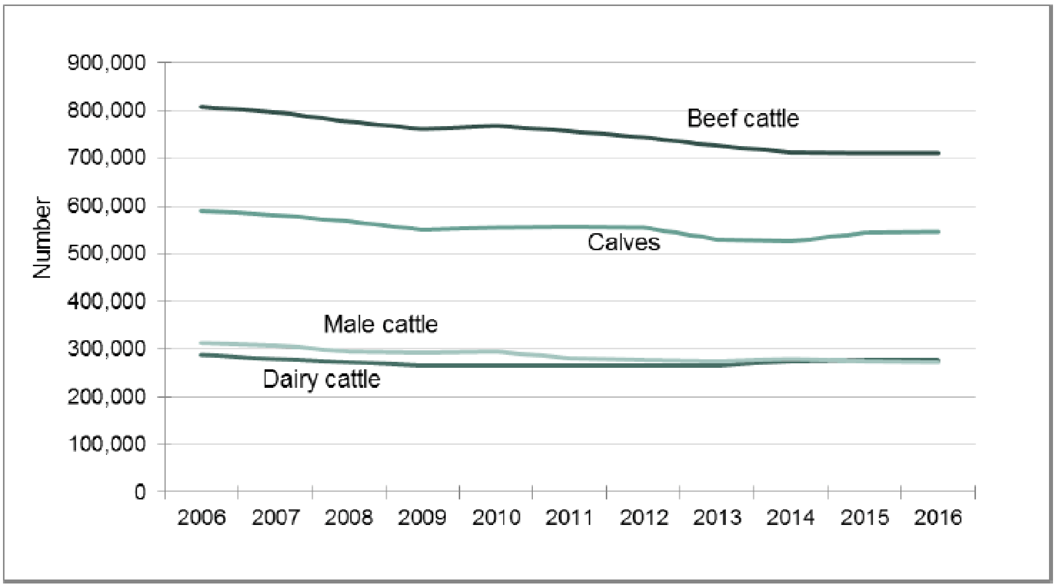
Historically, farmers have used by-products from whisky production for animal feed. There are a number of factors that act as drivers for the market for the use of whisky by-products as animal feed:

- The use of by-products from distilleries in close proximity is important for animal feed otherwise transportation costs can become prohibitive due to the weight of the by-products and the remote nature of some farms, such as those located on the islands.
- There are alternative animal feeds to the use of whisky by-products. This includes for example soya, which can be imported. However high transportation costs and fluctuating prices mean this is not necessarily viable – or, at least, can be significantly more costly.
- Low margins mean increases in costs, such as those outlined in the points above, could have significant impact on the farming sector.
- By-products from bioethanol production can also be used for animal feed (or as a biofuel). Previous research[13] indicated that development in the bioethanol industry in the UK could lead to an increased supply of by-products suitable for animal feed. However, demand from plants such as the one in Teesside has been much lower than originally anticipated[14], which means the level of by-products is lower than previously thought.
- Demand is seasonal, and as noted above this can result in disparities between supply and demand at certain times of the year, which is further affected by lifetime and storage factors.

[11] http://www.celtic-renewables.com/news/latest-news/scottish-distillery-first-to-produce-fuel-from-whisky-residues
http://uk.reuters.com/article/us-biofuel-whisky-idUKKCN0RZ12420151005
https://thinkprogress.org/how-whisky-makers-could-soon-be-providing-a-superior-biofuel-49db7730860d
[12] http://www.horizonproteins.com/
[13] http://www.zerowastescotland.org.uk/sites/default/files/ZWS645%20Beer%20Whisky%20Fish%20Report_0.pdf and
https://www.sruc.ac.uk/download/downloads/id/1057/distillery_feed_by-products_briefing
[14] https://www.ft.com/content/188ac0fe-f76d-11e6-9516-2d969e0d3b65?mhq5j=e3

- Demand for by-products such as animal feed can fluctuate. For example, it may depend on the success of some fodder crops, but also changes in cattle numbers. Figure 2 shows that overall cattle numbers have decreased, in particular over the period 2010-2014, although since then changes have been limited[15].

Figure 2: Dairy & beef herd trends, 2006 to 2016



Source: http://www.gov.scot/Topics/Statistics/Browse/Agriculture-Fisheries/agritopics/Cattle

1.3.4 Summary and recent discussions between sectors

The increasing quantities of whisky by-products (as a result of increased whisky production) has meant that new markets (bioenergy, for example) have been explored and developed for the use of this material in addition to historical uses such as animal feed. Although overall there should be sufficient supply to meet demand, other factors such as geography, seasonality, economics, new markets and changing demand mean that the dynamics between supply and demand are not straightforward, as highlighted by the different drivers explored above.

The recent meeting between the Scottish Tenant Farmers Association and the Scotch Whisky Association[16] highlights the issue of these different drivers and factors. The outcome from these discussions is that dialogue between the sectors is to continue, including across the supply chain to provide a wider understanding of the seasonal and geographical variations in availability of supply of by-products and the demand from livestock producers.

[15] http://www.gov.scot/Topics/Statistics/Browse/Agriculture-Fisheries/agritopics/Cattle
[16] http://www.tfascotland.org.uk/whisky-dialogue-to-continue/ and https://scotchwhisky.com/magazine/latest-news/13876/swa-meets-farmers-over-animal-feed-shortage/

1.4 Glossary of Acronyms in this report

The table below explains the acronyms used in this report

Table 1: Table of Acronyms

AD	Anaerobic Digestion	kt	kilo-tonne (one thousand tonnes)
AF	Animal Feed	LCA	Life Cycle Assessment
BEIS	UK Government Department for Business, Energy and Industrial Strategy	LCI	Life Cycle Inventory
CO2	Carbon Dioxide	LCIA	Life Cycle Impact Assessment
CXC	ClimateXChange	MJ	Mega-Joule (one million joules)
DDG	Distillers' Dark Grains	Mt	Mega-tonne (one million tonnes)
DECC	Department for Energy and Climate Change	NPK	Nitrogen Phosphorous Kalium (Potassium)
DG	Dark Grains	PAS	Pot Ale Syrup
DM	Dry Matter	QA	Quality Assurance
FC	Foul Condensate	RHI	Renewable Heat Incentive
FIT	Feed-In Tariff	RO	Renewable Obligation(s)
GHG	GreenHouse Gas	SWA	Scotch Whisky Association
GWP	Global Warming Potential	tkm	tonne-kilometre (a unit of freight movement)
IPCC	Intergovernmental Panel on Climate Change	UK	United Kingdom
ISO	International Standards Organisation	WDG	Whisky Dark Grains

The primary goal of this study is to determine the relative global warming potential impacts of using Scottish whisky by-products as animal feed (either draff and pot ale syrup, or whisky dark grains) or as renewable energy feedstock. A secondary goal is to understand the principle drivers for the headline results, in order to determine their sensitivity to underlying assumptions and uncertainties.

1.5 System Boundary

The system boundary defines what will be included in and excluded from the scope of study. Results from LCA studies can be influenced by selecting favourable system boundaries. Instead, the boundaries should be set to reflect the goal of the study, and sometimes taking into account the availability of data to perform the study. The system boundary for this study is formally defined under the series of headings below.

1.5.1 Life cycle stages

The chosen system boundary for this study starts at the point of arising of the draff and pot ale. These two materials have a very low value to the distilleries, in comparison to the whisky itself. Therefore, it is reasonable to ascribe all the effort (and hence environmental burden) associated with making the whisky (and its by-products) to the whisky itself. This means that the by-products can be considered to arise "burden free". This is also appropriate because the goal of the study is to compare their fates, and including their manufacturing burden would not influence the overall direction of the results.

The study follows the two by-products through the series of operations that take place until they are either consumed for energy production (including the fates of the combustion products), are spread to land for their fertilising benefits or are fed to animals for their nutritional benefits.

Where fertilisers and animal feeds are produced, the environmental benefits of these outputs are modelled by an LCA technique called “system expansion”. The model looks at the value provided by the products and determines how much conventional fertiliser or animal feed would be required to deliver the same benefit. The scenarios are then credited with offsetting (or saving) the environmental impacts that would have been incurred in producing those alternatives.

1.5.2 Temporal

There is no temporal boundary; all impacts are considered regardless of timing. As is usual in LCA, global warming impacts are measured over a 100-year period, i.e. using IPCC GWP_{100} values. Therefore, any emissions of biogenic carbon dioxide (notably from the combustion of the draff) are considered to be within the natural carbon cycle, and discounted from the calculations.

1.5.3 Geographical

There is no geographic boundary; all impacts are considered regardless of physical location. Standard UK grid emissions and impact factors are used for all consumption of electricity.

1.6 Functional Unit

The functional unit provides the basis for the comparison within the LCA, defining what materials or service will be studied. In this instance, it was agreed that an appropriate functional unit would be 1,000 tonnes of draff and its equivalent output in pot ale (3,300 tonnes)[17].

This provides a common baseline against which to compare the scenarios.

1.7 Data Sources

Obtaining reasonable data for an LCA is absolutely critical, and is usually the determining factor for a project’s quality and also for the effort required to complete the work. LCA practitioners prefer to use primary data where possible, direct from the systems being studied, and only revert to secondary data (from literature) when required. The balance of primary and secondary data is often dictated by the budget and timescale of the study.

For these reasons, Ricardo is particularly grateful to the sector for providing us with typical operational data, including indicative mass balances for each of the key operations, associated energy consumption and production data, and information concerning the nutrient content (NPK values) of the various materials spread to land.

This information was supplemented by literature information on the nutritional value of the by-product animal feeds, as well as their alternatives. Ricardo used generic data concerning the construction of the process plants (the so-called capital burdens), in the expectation that these would not be critical. Transport distances and modes were estimated and discussed at the stakeholder meeting held on 7th July. Following minor adjustments, stakeholders agreed that the estimates were appropriate.

[17] It is acknowledged that this output ratio varies between distilleries. The chosen ratio is based on Robin Crawshaw, Co-Product Feeds: Animal Feeds from the food and drinks industries, Nottingham University Press 2001, 98

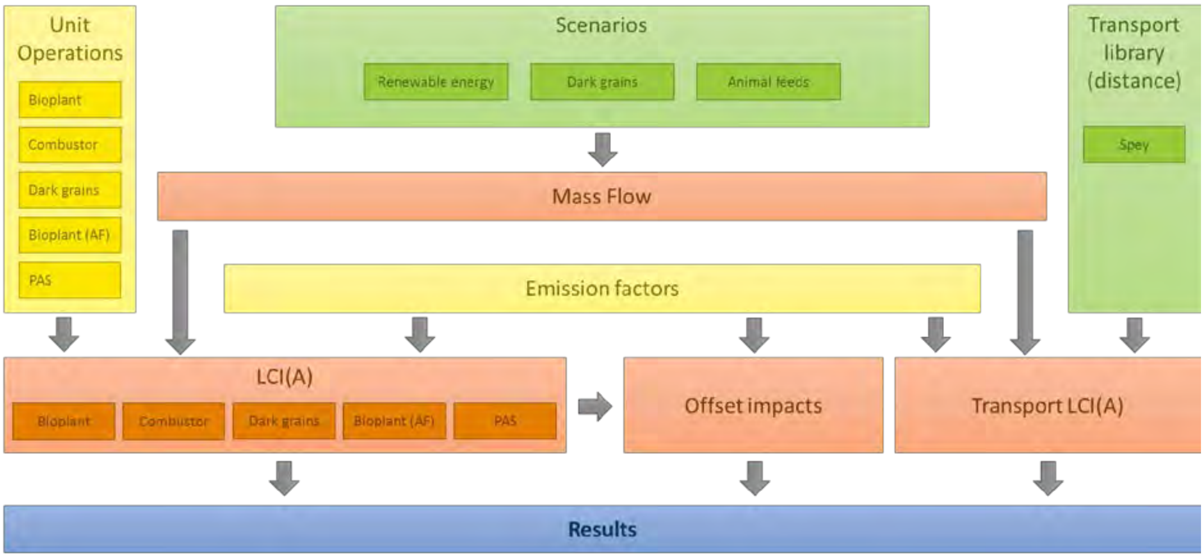
2 The LCA Model

The second stage of an LCA, as defined by ISO, is to compile the life cycle inventory. Before discussing this, and the impact assessment stage that follows, it makes sense to discuss the LCA model in Microsoft Excel® that was developed to hold these datasets, perform the calculations and assist with the subsequent interpretation.

2.1 Model Design

Figure 3 below illustrates the LCA model design and how data flow through it. Sections in green represent user input, yellow sections land external data, orange sections perform calculations and the blue section presents the results.

Figure 3: Model design schematic



The user chooses which scenario to model: should materials be sent to generate renewable energy, provide animal feed (draff and pot ale syrup) or produce dark grain animal feeds? This information is passed to the Mass Flow sheet, which takes the functional unit arisings of draff and pot ale, and uses the scenario choice to allocate the correct mass input to each dedicated LCI(A) sheet.

These life cycle inventories (LCIs) take information from the relevant Unit Operation data sheet, and scale it to match the incoming materials provided by the Mass Flow. Additionally, the LCI pulls in emission factor information for each entry in the inventory to calculate the impact assessment (LCIA). Information about volumes of end fate materials (animal feeds and landspread) is then passed on to the Offsets impacts sheet, which calculates how much animal feed / fertiliser has been displaced and, thereby, the impact that has been offset.

Separately, the user can select which transport scenario to use for the modelling, defining the distances between unit operations and the mode(s) of transport between them. This reflects the fact that distilleries in the Highlands and Islands will require quite different transport arrangements to move their materials between the different facilities in comparison to those in Speyside. For now, the model just holds data for a Speyside model, but the facility exists to add different transport scenarios, to investigate how these impact the results.

The transport scenario information is passed to the Transport LCI(A) sheet, which combines the mode and distance information (km) with mass information from the Mass Flow sheet (t) to calculate the tkm per transport mode. The Transport LCI(A) then uses emission factor information per transport mode to calculate an impact assessment.

Finally, the three outputs (from the LCI(A)s, the Offset impacts and the Transport LCI(A)) are then combined in the results table.

2.1.1 Intellectual Property

As agreed in our contract, the intellectual property in the LCA model rests with Ricardo, but we have granted the client a perpetual, non-exclusive, non-assignable, royalty free licence to use the model for its internal business operations.

2.2 The Life Cycle Inventory

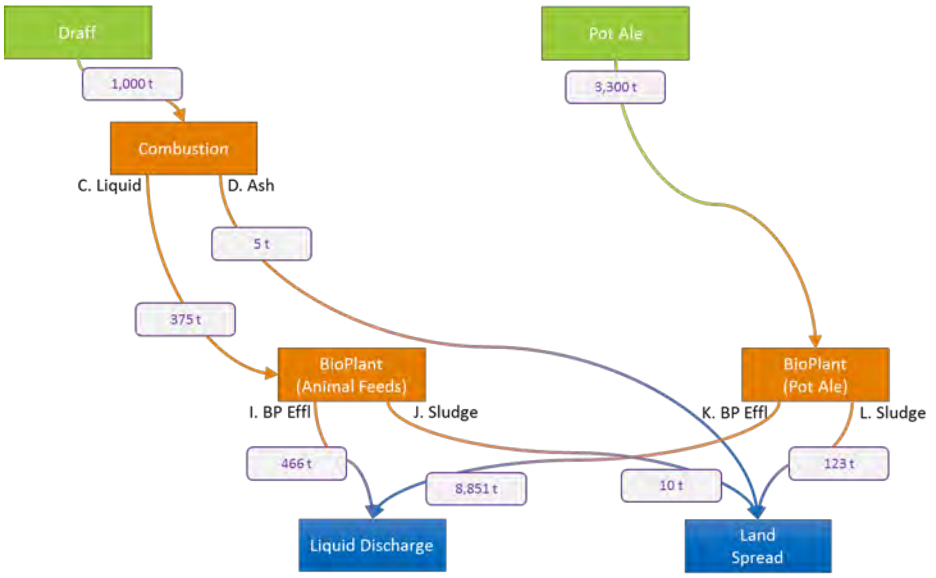
For this project, the life cycle inventory was compiled on a series of sheets, one for each of the unit operations in the model (namely the draff combustor, the pot ale syrup plant, the dark grains plant, the pot ale bioplant and the animal feeds bioplant[18]). The datasets include:

- the capital burdens associated with the construction of the facilities;
- a mass balance over a certain time period, detailing all the material inputs and outputs;
- all the energy inputs and outputs (identity and amount);
- all the by-products and wastes, with their management fate (recycled, landfilled, etc.); and
- all relevant emissions to land, water and air.

The mass flows through the different unit operations for the three scenarios studied are presented in the series of diagrams in Figure 4.

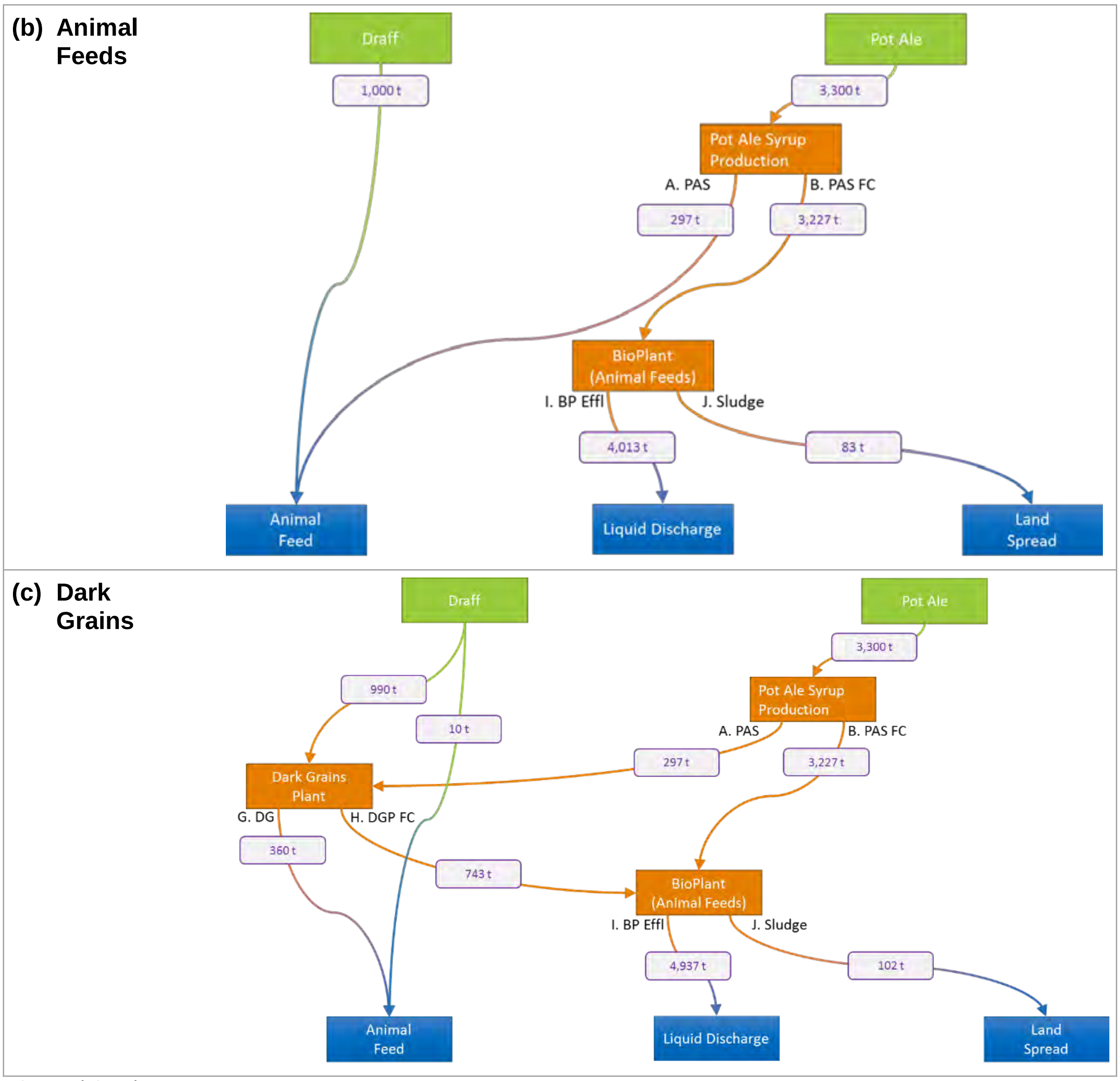
Figure 4: Schematic Diagrams of the Three Scenarios, with Mass Flow Data

(a) Renewable Energy



[18] We chose to model separately the digestion of pot ale (in the pot ale bioplant) and the digestion of all other liquid wastes (in the animal feed bioplant) because of the significant difference in "strength" of these two materials.

Figure 5 cont: Schematic Diagrams of the Three Scenarios, with Mass Flow Data



FC= Foul Condensate

The principal inventories described above were supplemented in the model with a series of other datasets, detailed in the sections below.

2.2.1 Speyside transport scenario

The model is provided with an estimation of transport requirements for typical distilleries located in Speyside (other scenarios can be added). These estimates were agreed by stakeholders to be appropriate. The data used are presented in the table below.

Table 2: Transport Distances (in km) used in Model (Speyside scenario)

From	To	Bulk Tanker	Articulated Lorry	Tractor and Trailer	Pipe (pumped)	Pipe (gravity)
Draff	Dark Grains Plant		15			
Draff	Combustor		15			
Draff	AF Draff		15			
Pot Ale	PAS production	15				
Pot Ale	Bioplant	15				
Pot Ale	Land spread	10				
Dark Grains Animal Feed	AF DG		240			
Dark Grains Plant Liquor	Liquid discharge	25				
Dark Grains Plant Liquor	Bioplant (AF)	25				
Combustion Foul Liquor	Liquid discharge	25				
Combustion Foul Liquor	Bioplant (AF)	25				
Combustion Ash	Land spread			10		
Pot Ale Syrup	Dark Grains Plant					0.1
Pot Ale Syrup	AF PAS		40			
PAS Foul Condensate	Bioplant (AF)	25				
PAS Foul Condensate	Liquid discharge	25				
AD Plant Effluent	Bioplant				0.2	
AD Plant Effluent	Liquid discharge					0.5
AD Plant Bio-Solid	Land spread			10		
BioPlant AF Effluent	Liquid discharge				25	
BioPlant AF Sludge	Land spread			10		
BioPlant Effluent	Liquid discharge				1	
BioPlant Sludge	Land spread			10		

2.2.2 Nutritional values of animal feeds

In order to perform the system expansion to account for using whisky by-products as animal feeds, it is necessary to estimate their nutritional benefits and that of the traditional alternatives. It was decided that an appropriate pair of metrics for nutritional value are Metabolisable Energy and Crude Protein (on a dry matter basis). The values for the three animal by-products, and their alternatives (rape meal, soy bean meal and silage) are provided in the tables below. Using simultaneous equations, it is then a simple step to determine the equivalent amounts of the traditional feedstocks required to deliver the same nutritional benefits as a tonne of each of the by-products (last two columns). Soy bean meal was added as part of sensitivity analysis following a stakeholder meeting. Its use is assumed to be an alternative to rape meal.

Table 3: Animal Feed Nutritional Values – Rape meal scenario[19]

Animal Feed	Metabolisable Energy	Crude Protein	Dry Matter		Rape	Silage
Units:	MJ/kg DM	g/kg DM	g/kg		t/t	t/t
Draff	11.1	200	230		0.065	0.729
Pot Ale Syrup	14.5	360	450		0.360	1.035
Dark Grains	12.2	265	900		0.456	2.379
Rape Meal	12.0	400	900		1	0
Silage	10.6	130	240		0	1
Soy Bean Meal	13.3	530	890		-	-

Table 4: Animal Feed Nutritional Values – Soy bean meal scenario[19]

Animal Feed	Metabolisable Energy	Crude Protein	Dry Matter		Soy	Silage
Units:	MJ/kg DM	g/kg DM	g/kg		t/t	t/t
Draff	11.1	200	230		0.045	0.794
Pot Ale Syrup	14.5	360	450		0.251	1.397
Dark Grains	12.2	265	900		0.318	2.836
Rape Meal	12.0	400	900		-	-
Silage	10.6	130	240		0	1
Soy Bean Meal	13.3	530	890		1	0

2.2.3 Nutrient values of land-spreading

In an analogous assessment, the nutrient value of the various materials that are spread to land were transcribed to equivalent levels of traditional fertilisers by comparing their Nitrogen, Phosphorous and Potassium contents (NPK values). The table below shows how data on dry matter content and NPK content were combined to yield tonne-per-tonne equivalents data for the landspread materials and their fertiliser alternatives.

Table 5: Landspreading Nutrient Values

				Fertiliser:	Ammonium Nitrate	Triple Super-phosphate	Potassium Chloride
				Basis:	as N	as P_2O_5	as K_2O
				Ratio:	1	0.2183	0.4149
Material	DM	N	P	K	Ammonium Nitrate	Triple Super-phosphate	Potassium Chloride
Units:	g/kg	g/kg DM			t/t	t/t	t/t
Pot Ale	40	46.08	20	22	0.0018	0.0037	0.0021
Combustion Ash	396	28.3	65.2	3.5	0.0112	0.1183	0.0033
AD Bio-Solid	21	100	42.9	4.8	0.0021	0.0041	0.0002
BioPlant Sludge	19	100	26.3	10.5	0.0019	0.0023	0.0005

2.3 The Life Cycle Impact Assessment

As mentioned above, the LCI(A) sheets not only compile inventories of the material and energy flows associated with each process, they also apply emission factors to determine the environmental impact of each individual flow. The emission factors are brought in from the LCIA Categories sheet. This is

[19] Principle source: https://www.fas.scot/pdf/farm-management-handbook-livestock/

designed to be able to hold emission factors for many environmental indicators, but is only populated for now with GWP_{100} factors, as requested by ClimateXChange.

The factors were calculated in the widely used modelling software SimaPro[20] by applying the ReCiPe Midpoint (H) method to various ecoinvent 2 datasets, representative of the products and processes used within the model. ecoinvent is one of the world's largest and best-recognised repositories of life cycle impacts for products and processes.

The SimaPro calculation determined the emission factors for the various processes in terms of CO_2 eq. The LCIA Categories sheet paired the incoming ecoinvent products and processes information (including the emission factor calculated by SimaPro), with the material flow names used within the model's Unit Operation and LCI(A) sheets. This enabled the impact to be scaled by the amount of each material being modelled in the LCI(A) sheets.

2.4 Quality Assurance

Over the past couple of years, Ricardo has worked with the Modelling Integrity Team in the UK Department for Business, Energy and Industrial Strategy (BEIS, formerly DECC) to apply its new QA standards to a range of our models. In 2016, we chose to adopt the BEIS assessment criteria for our own internal modelling QA procedures, so the methodology is now embedded in all our modelling work.

In this project, Ricardo prepared a QA plan at the start of project, setting out (among other things) the model governance and the checking we would perform to review the calculations and confirm the outputs, and shared it with CXC during the inception meeting. During the project, we periodically reviewed the model against the plan, to confirm the correct direction of travel. A copy of the completed plan is provided in Appendix 1.

On completion of the modelling, the model was audited by an internal specialist (Jamie Warmington from Ricardo's Cross Practice Modelling Group) who had not been involved with the project beforehand. He reviewed the model against BEIS's assessment criteria (as adopted by Ricardo) and produced the QA Log that accompanies the report in Appendix 2.

[20] http://www.simapro.co.uk/

3 Analysis of Results

3.1 Initial Results

The initial top-level results are presented in Table 6. Note that the results are presented in units of t CO_2 eq of climate change *impact*. This means that the most negative numbers (in blue) are preferred, since they represent a net reduction in climate change. Within the accuracy of the model, the results suggest that the renewable energy scenario performs the best and the dark grains scenario performs the worst.

Table 6: Initial top-level results (GWP_{100} in units of t CO_2 eq)

Scenario	Total GWP_{100}
Renewable Energy	**-312**
Animal Feeds	**-217**
Dark Grains	**-72**

The results are further broken down in the tables and figures below, split first by process (Table 7 and Figure 5) and then by life cycle stage (Table 8 and Figure 6). Furthermore, each scenario is plotted twice, once showing the contributions of each phase, which may be both positive and negative, and then (in grey) the net total.

Table 7: GWP_{100} Results, split by Process (in units of t CO_2 eq)

Process	Renewable Energy	Animal Feeds	Dark Grains
Combustor	-185		
PAS production		73	73
Dark Grains Plant			99
Bioplant (AF)	0	2	3
Bioplant	-124		
Animal feed		-291	-245
Fertiliser	-3	-1	-2
Total	**-312**	**-217**	**-72**

Figure 5: GWP_{100} Results, split by Process (in units of t CO_2 eq)

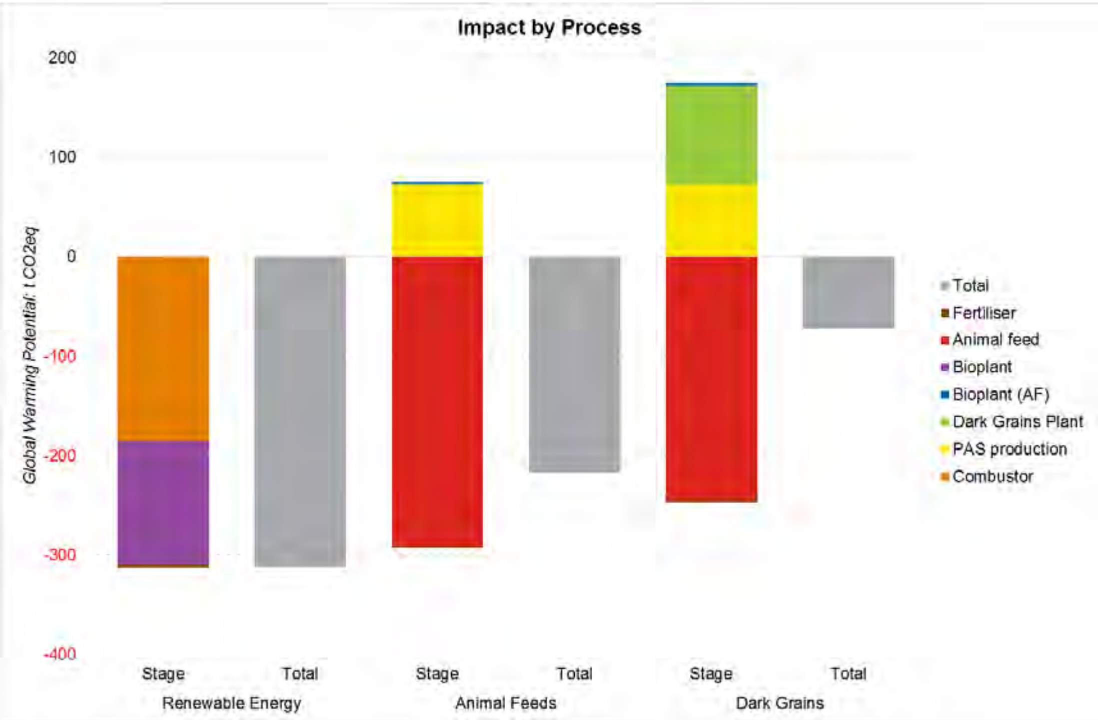
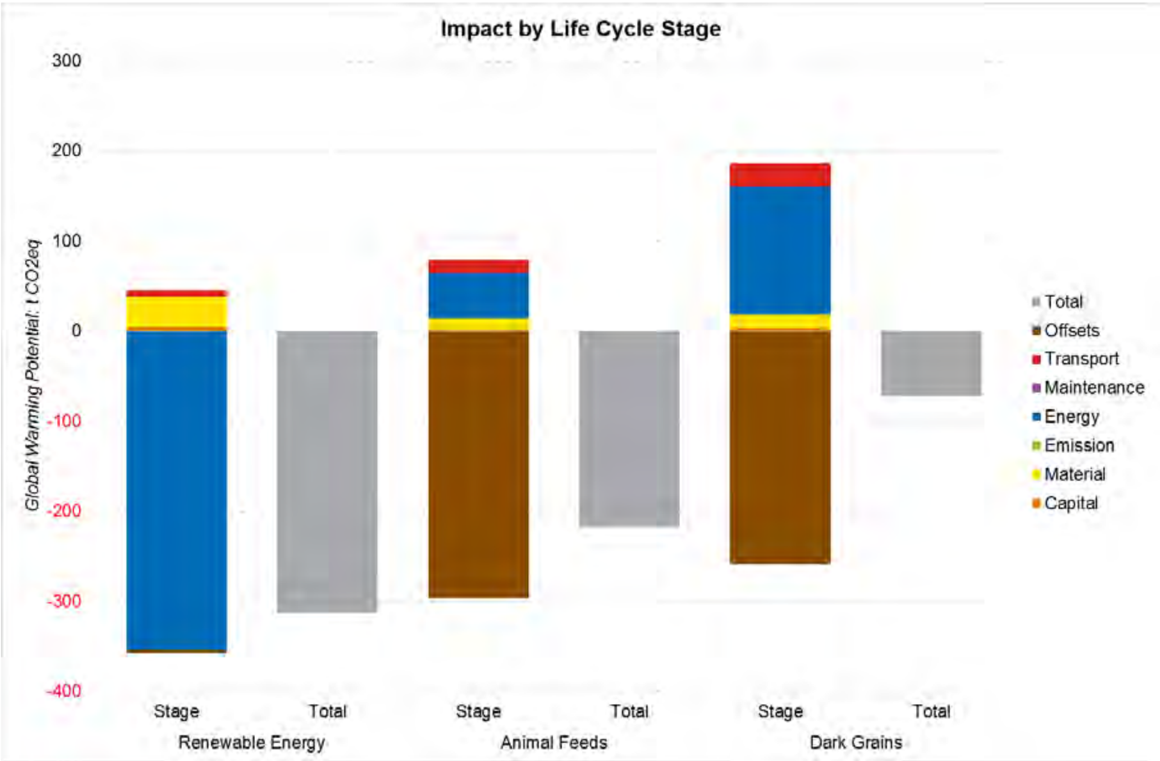


Table 8: GWP_{100} Results, split by Life Cycle Stage (in units of t CO_2 eq)

Life Cycle Stage	Renewable Energy	Animal Feeds	Dark Grains
1-Capital	5	2	3
2-Material	32	13	15
3-Emission			
4-Energy	-354	50	141
5-Maintenance	0	1	1
Transport	7	14	26
Offsets	-4	-296	-258
Total	**-312**	**-217**	**-72**

Figure 6: GWP_{100} Results, split by Life Cycle Stage (in units of t CO_2 eq



Looking first at the results by process, it can be seen that three processes make significant contributions to GWP reductions – the combustor and (pot ale) bioplant in the renewable energy scenario, and the animal feeds in the other scenarios. Fertiliser also makes a reducing contribution, but very minor. In contrast, the PAS production and dark grain plants generate a large climate change burden due to the energy intensive nature of the process.

Turning to the life cycle stages, the animal feed offsets and energy saving of the renewables plants are the major contributors to emissions reductions, whilst energy consumption is the big issue for the dark grains plant. Interestingly, the GWP_{100} benefit of the dark grains offset is smaller than that of the draff and PAS in the animal feed scenario. Despite the higher nutritional value of the dark grains, the smaller volume produced means that the draff and PAS are apparently more favourable (at least, from a carbon perspective).

As is usual, the assumptions used within the processes and their life cycle stages influence the direction of the results and the relative favourability of the scenarios. For that reason, it is important to perform a careful sensitivity analysis of the key drivers.

3.2 Sensitivity Analysis

Following input from Stakeholders, after meeting on 7th July, sensitivity analysis was carried out in key areas. This is described under the headings below.

3.2.1 Animal feed offsets

The initial model only assessed the impact of offsetting a combination of rape meal and silage animal feeds, the exact ratios determined through the offsetting calculations described above. During the stakeholder meeting, it was highlighted that rape meal was not always readily available and that farmers would often substitute soy bean meal instead. Moreover, little soy bean meal is produced in Europe, and it was queried how the higher transport burden of soy bean meal would impact the model.

Consequently, soy bean meal was added to the model as an additional scenario. The offsetting calculations for soy bean are described in section 2.2.2 alongside those for rape meal. The impact of substituting rape meal for soy bean meal does not affect the renewable energy scenario, since this does not offset any animal feeds, however it does impact the animal feed and dark grains scenarios. The results for the soy meal scenario are shown in Table 9 and compared with the rape meal scenarios in Table 10.

Table 9: Initial top-level results using soy meal (GWP_{100} in units of t CO_2 eq)

Scenario	Total GWP_{100}
Renewable Energy	**-312**
Animal Feeds (soy)	**-227**
Dark Grains (soy)	**-81**

Table 10: GWP_{100} Results for Animal Feeds and Dark Grains scenarios, split by Process (in units of t CO_2 eq)

Process	Animal Feeds (Rape)	Dark Grains (Rape)	Animal Feeds (Soy)	Dark Grains (Soy)
Combustor				
PAS production	73	73	73	73
Dark Grains Plant		99		99
Bioplant (AF)	2	3	2	3
Bioplant				
Animal feed	-291	-245	-301	-255
Fertiliser	-1	-2	-1	-2
Total	**-217**	**-72**	**-227**	**-81**

To model the offset impact of soy meal, an existing ecoinvent process for soybean meal production in the USA was used. Appropriate transport burdens for shipping soybean meal to Scotland were then added to this process.

As can see from Table 10, the offset benefits from using soy meal are a little higher than those for rape meal, though the differences do not significantly affect the overall results. Table 3 and Table 4 show that, to deliver the equivalent nutritional content, less soy meal is needed than rape meal, but a little more silage is also required. Accounting for the relative emission factors of the three alternatives, the net result is a small benefit from switching to soy meal, despite the greater transport impact.

3.2.2 Co-firing with wood chips

During the stakeholder meeting, concerns were raised regarding the burden of wood as a co-fuel in the combustor process. Initially, the model only assessed the energy generated through the combustion of draff. However, it was argued that draff will always require a wood co-fuel to enable combustion and that the accompanying forestry impact should be added to the model.

To carry out the sensitivity analysis, data were taken from the AET website[21] to calculate key parameters for the draff combustor if woodchips are co-fired. The model calculates the ratio of woodchips required to co-fire the draff and the subsequent increase in energy output.

The impact of adding a wood-chip co-fuel to the model is a significant benefit to the renewable energy scenario. While the wood-chip itself adds an additional impact of 16.45 t CO_2 eq to the model, it offsets the generation of significantly more heat and grid electricity. Including wood-chip co-firing to the model takes the renewable energy scenario from -312 t CO_2 eq to -540 t CO_2 eq, a benefit increase of 73%.

Wood-chip co-firing has been excluded from the main results as the key focus of this study is how best to use the distillery by-products. Combining the benefit of using wood and draff for renewable energy obscures the benefit received from sending by-products for renewable energy.

[21] http://www.aet-biomass.com/en-GB/Home/References/Biomass-Fired-Plants/Rothes-CoRDe.aspx

3.2.3 Offsetting heavy fuel oil

Another sensitivity highlighted during the stakeholder meeting was which energy source should be off-set within the combustor and bioplant operations. It was stated during the meeting that many of the Speyside distilleries are not on the gas network and are instead using renewable energy to replace heavy fuel oil (HFO) brought in by road.

The model initially used an ecoinvent process for steam from natural gas to calculate the offset impact of generating heat via the combustor and bioplant processes. A sensitivity was built in to the model to replace this process with another ecoinvent process for process steam from HFO. Using HFO to generate heat has a larger climate change impact compared with natural gas and consequently running the model under the HFO option provides a climate change benefit to each scenario. Note the difference between the dark grains scenario is 0.619 t CO_2 eq in favour of offsetting HFO. While each scenario benefits, the gain within the animal feed and dark grains scenarios is negligible in comparison with the renewable energy benefit. The results are shown in Table 11 below.

Table 11: Top level results (GWP_{100} in units of t CO_2 eq) for natural gas and HFO sensitivities

Scenario	Natural gas	HFO
Renewable Energy	**-312**	**-392**
Animal Feeds	**-217**	**-218**
Dark Grains	**-72**	**-72**

4 Conclusions

Each of the three scenarios is found to have a beneficial climate change impact, resulting in a net reduction in GHG emissions.

Three processes make significant contributions to GHG emission reductions – the combustor and (pot ale) bioplant in the renewable energy scenario, and the animal feeds in the other scenarios. These processes are covered by the energy and offsets life cycle stages respectively.

The findings suggest that it is the offset energy which is the determining factor between the scenarios. The emissions from energy in the renewable energy scenario total -354 t CO_2 eq, in comparison with -296 t CO_2 eq from offsets in the animal feeds scenario. Moreover, both the animal feeds and dark grain scenarios are burdened with positive values from their energy consumption.

The sensitivity analysis undertaken in this study demonstrates that the scenarios' GWP impact is influenced by the assumptions made in the model. Switching rape meal for soya bean meal increases the animal feed scenarios' GWP benefits; including woodchip co-firing significantly decreases the GWP impact of the renewable energy scenario; and offsetting heavy fuel oil improves each scenario to varying amounts. However, the overall positioning of the three scenarios is unaffected by changing the sensitivities modelled.

Possible next steps for the work, if CXC is minded to continue the investigations, would include:

- extending the model to consider additional environmental impacts beyond GWP. The model has been designed to facilitate such an extension, but this would be dependent on finding impact factors for all the necessary flows. While the majority are taken from ecoinvent and are therefore straightforward, some other factors would need more research.
- the model could be extended to include a new scenario in which draff is sent to anaerobic digestion.

Appendices

Appendix 1: Model QA Plan

Appendix 2: Model QA Log

Appendix 3: Draff only scenarios

Appendix 1 – Model QA Plan

Model QA Activity	Allocated Person	Estimated Date	Actual Date	Comments
Initiate a QA Plan for the workbook	Simon Gandy	10/05/2017	17/05/2017	
Prepare scope and spec document(s)	Sam Hinton	19/06/2017	17/05/2017	See proposal, KO minutes and final report
Establish version control scheme	Sam Hinton	10/05/2017	10/05/2017	Done; this is embedded in Ricardo's Excel template
Complete workbook design & population	Sam Hinton	19/06/2017	03/06/2017	
Prepare user and technical guides, as required	Sam Hinton	19/06/2017	06/07/2017	Simpler user guide will be embedded in model
Review model method with proportionate peer review	Sam Hinton	25/07/2017	16/08/2017	Will be done as part of steering group meeting
Sign-off suitability of input data	Sam Hinton	25/07/2017	22/08/2017	Refer to required QA level for criteria DA1 and DA2. Tackle as part of steering group meeting
Sign-off suitability of input assumptions	Sam Hinton	25/07/2017	22/08/2017	Refer to required QA level for criteria DA3 and S7. Tackle as part of steering group meeting
Perform proportionate formulae audit and VBA check	Jamie Warmington	12/06/2017	01/09/2017	Refer to required QA level for criteria Ve1, Ve3 and S6
Complete QA Log to confirm ready to release	Jamie Warmington	25/07/2017	01/09/2017	This will include completing the tests below; requirements dependent on set QA level
Finalise model ready for release	Sam Hinton	25/07/2017	04/09/2017	

Appendix 2 – QA Log

ID	Worksheet	Log	Likely Error	Potential error	Not Best Practice	Reviewed / Checked	Question	Unchecked	Same As Previous	Total Entries
1	'QA_Contents'	Contents_Log	0	0	0	0	0	41	0	41
2	'QA_Formula'	Formula_Log	0	57	22	1103	0	227	0	1409
3	'QA_Errors'	Errors_Log	0	0	0	0	0	0	0	0
4	'QA_Names'	Names_Log	0	0	0	183	0	1	0	184
5	'QA_Comments'	Comments_Log	0	0	0	0	0	128	0	128
6	'QA_Links'	Links_Log	0	0	0	0	0	0	0	0
7	'QA_References'	References_Log	0	0	0	0	0	43	0	43
8	'QA_Objects'	Objects_Log	0	0	0	49	0	1	0	50
Total			**0**	**57**	**22**	**1335**	**0**	**441**	**0**	**1855**

The QA audit reviewed over 1,100 unique formulae within the model. 57 formulae were flagged for further checking. Two of these formulae consisted of hardcoded figures, but were accompanied by explanatory notes within the relevant sheets and found to function correctly. A further potential issue concerned legacy design that presented abnormal formatting but did not affect the model’s functionality. The remaining 54 related to a redundant table within the model’s LCI(A) sheets; the table did not return any results or interact with the rest of the model and was later deleted from the model.

Appendix 3 – Draff Only Scenarios

Shortly after the main study's completion, CXC commissioned an extension to explore the relative merits of the two possible fates for draff, as a renewable feedstock or an animal feed, disregarding pot ale. The reasoning was that that the animal feed scenario was suffering from the environmental burdens of the large amounts of energy needed to evaporate pot ale to produce an animal feed. The question was therefore raised about how the scenarios might compare if only draff were considered. Focussing on draff by-product is also a reasonable approximation to grain distilleries' by-products, where no pot ale is produced.

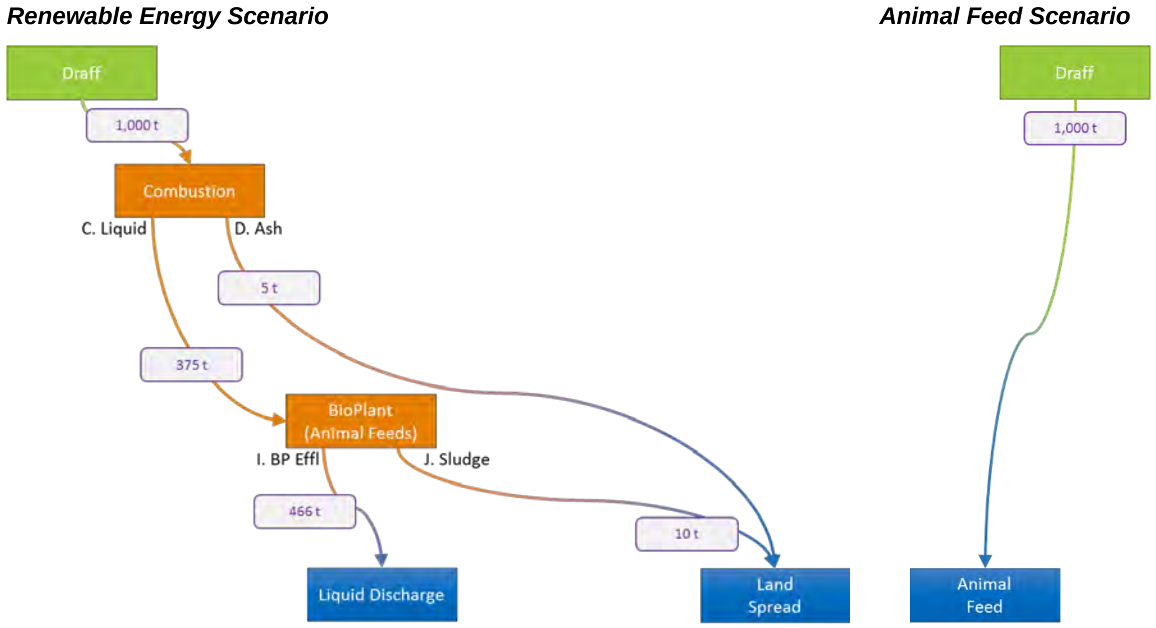
This appendix assesses the impacts of using 1,000 tonnes of draff to generate renewable energy or provide animal feed.

Mass flow

As per the original model, life cycle inventories were compiled on a series of sheets, one per operation. The notable difference within this extension to the study was the absence of pot ale. This changed the flow of materials between the operations; crucially no pot ale is sent to a pot ale syrup plant, and subsequently no draff is sent to a dark grains plant to be combined with pot ale syrup to make dark grains.

The two flows of materials considered in this extension are represented in Figure 7 below.

Figure 7: Mass flow for Draff Only scenarios



Results

The top-level results are presented in Table 12 below. Note there is no Dark Grains scenario as no pot ale is available to make the dark grains. Both scenarios deliver a reduced GWP benefit when compared to the core study, where 3,300 tonnes of pot ale are included. The renewable energy scenario still performs better than the animal feeds scenario, but the margin of difference is now so small (~5%) as to be insignificant within the general accuracy of the modelling.

Table 12: Top level results (GWP_{100} in units of t CO_2 eq)

Scenario	Draff only	Core study
Renewable Energy	**-187**	**-312**
Animal Feeds	**-177**	**-217**

As before, the results are further broken down in the tables below by process and then by life cycle stage. Table 13 shows that the animal feed scenario receives all of its benefit from offsetting traditional animal feed (in this case rape meal). The renewable energy scenario receives the bulk of its benefit from the renewable energy generated via combustion with a very small additional benefit from offsetting fertilisers via the small amount of material sent to land spread.

Table 13: GWP_{100} Results for Draff only, split by Process (in units of t CO_2 eq)

Process	Renewable Energy	Animal Feeds
Combustor	-185	
Bioplant (AF)	0	
Bioplant		
Animal feed		-177
Fertiliser	-2	
Total	**-187**	**-177**

Table 14: GWP_{100} Results for Draff only, split by Life Cycle Stage (in units of t CO_2 eq)

Life Cycle Stage	Renewable Energy	Animal Feeds
1-Capital	4	
2-Material	2	
3-Emission		
4-Energy	-194	
5-Maintenance	0	
Transport	3	2
Offsets	-2	-179
Total	**-187**	**-177**

Sensitivity Analysis

This section applies the sensitivities undertaken in the core study to the draff only extension.

Animal feed offsets

The core study undertook a sensitivity analysis to offset soy bean meal animal feeds instead of rape meal. Table 15 below compares the impacts of the draff only renewable energy scenario, animal feed scenario offsetting rape meal and the animal feed scenario offsetting soy meal. Note the renewable energy scenario does not change as its mass flow does not offset any animal feeds and is unaffected by switching between rape meal and soy meal.

Table 15: Results of animal feed offset sensitivity tests (in units of t CO_2 eq)

Scenario	Draff only
Renewable Energy	**-187**
Animal Feeds (rape meal)	**-177**
Animal Feeds (soy meal)	**-181**

Offsetting soy meal rather than rape meal increases the animal feed scenario's GWP benefit, to within ~3% of that provided by the renewable energy scenario.

Offsetting heavy fuel oil

As was highlighted at the stakeholder meeting, some distilleries are not on the gas network and use heavy fuel oil (HFO) brought in by road instead. This sensitivity uses the energy generated by draff combustion to offset heavy fuel oil use rather than natural gas, to represent a distillery that is off the gas grid. The results of this sensitivity are shown in Table 16 below.

Table 16: comparison of top level results for HFO sensitivity GWP_{100} (in units of t CO_2 eq)

Scenario	Draff only
Renewable Energy	**-264**
Animal Feeds (rape meal)	**-177**
Animal Feeds (soy meal)	**-181**

In the core study, the animal feed scenarios received some benefit from offsetting HFO instead of gas within the pot ale syrup production and bioplant stages. Under the draff only extension these processes are bypassed and the animal feed scenarios receive no benefit from offsetting HFO. The renewable energy scenario continues to receive a significant benefit (over 40%) from offsetting HFO rather than natural gas. Under these conditions, the margin of difference is significant and the renewable energy scenario is clearly preferred.

Co-firing with wood chips

Applying the wood-chip co-fuel sensitivity to the draff only extension delivers a significant benefit to the renewable energy scenario and no additional benefit to the animal feed scenario. As with the core model, sourcing sufficient wood-chip to combust 1,000 t of draff adds an impact of 16.45 t CO_2 eq to the model; however, it offsets significantly more heat and grid electricity. Including wood-chip co-firing to the model takes the renewable energy scenario from -187 t CO_2 eq to -414 t CO_2 eq, a benefit increase of ~221%.

As stated in the core study's co-firing sensitivity, the key focus of this study is how best to use the distillery by-products. Combining the benefit of using wood and draff for renewable energy obscures the benefit received from sending draff for renewable energy.

Conclusion

Focussing the study solely on draff still results in net GHG emission reductions under each scenario. However, the margin between the scenarios is seen to narrow significantly when pot ale is excluded. While the renewable energy scenario still provides a larger GWP benefit, there is a just a ~5% difference under the basic assumptions, which is insignificant given the overall accuracy of the modelling. This margin shrinks further when we apply the soy meal sensitivity.

A critical differentiating factor between the two scenarios is what energy source is being offset by the renewable energy scenario. Applying the HFO sensitivity, to represent a distillery that is off the gas grid, provides a large additional benefit to the renewable energy scenario but none to the animal feed scenario, making the renewable energy scenario clearly preferred once more. The best use for draff only is therefore dependent on an individual distillery's circumstances.

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