Towards a Circular Economy: Scotland's Bioresource Flows

Annex E — Sources, Sankey Material Flow Diagram and Quality Assessment of Bioresources Data

Sankey diagram of bioresource flows in Scotland.

Bioarising quantities and flows are graphically illustrated in figure E1, in a so-called "Sankey diagram", which visualises the total and relative proportion of the four main sources of bioarisings in Scotland (i.e., agriculture, the food and drink industry, households, and sewage). These four are further disaggregated into types of bioarisings (e.g., manure, straw, …) and their current fate (e.g., spread onto land). The diagram is based on the Biorefining Potential for Scotland report (BPS, 2017). As noted in the main report, these data are outdated and of variable quality.

Sankey diagrams visualise material flows between 'nodes' (i.e., the things being connected, for example, parts of a country's economy or different sectors). The width of the flows is proportional to the flow rate (tonnes of material per year, for example). They are the main method of visualisation used by both Zero Waste Scotland's Material Flow Accounts (see Figure 1 of the main report), and by the Circle Economy in their Circularity Gap reports. In our Sankey diagram there are five nodes, and thus four flow rates between them.

It is possible for Sankey diagrams to show circular movement of flows, but since movement of material in economies is currently linear (with very limited reuse, remanufacturing, or recycling), most Sankey diagrams in this context are also linear, with flows from source (left) to fate (right). Where there is some circular flow of materials in an economy, the Material Flow Accounts and Circularity Gap reports represent this as a return flow moving from right to left (e.g., 'Recycling' in Figure 1).

The Sankey diagram created for this report (Figure E1, below) is also linear, with the sectors which are the sources of bioarisings on the left (e.g., agriculture, households), and the final fates of bioarisings on the right (e.g., animal bedding or feed, application of manure to land). The second, third and fourth columns (or nodes) are not flows per se, but they provide a breakdown of the total material coming from sectors into their different bioarisings. This is useful because different bioarisings have different fates and will also have different uses and economic values in a circular biosector. The width of flows are proportional to the mass of material (in tonnes), but since the data are outdated, and the diagram is for illustrative purposes only, we do not state the mass in numbers.

The data for the first four of the five nodes (from left to right) are extracted from BPS 2017. All data were traced back to their original sources, as far as possible, and a traffic light assessment was made of their quality (Figure 2a and Annex E).

The data for the fifth and right-most column represents the final fate of bioarisings (also in tonnes) and was provided on request by IBiolC. It is understood from conversation with ZWS that the source for this data is interviews with operators conducted by SAC Consulting for ZWS and IBiolC in 2014. These interview transcripts are no longer accessible due to GDPR.

To prepare the Sankey diagram, the data from BPS (2017) and IBiolC were collated into an excel file, then were formatted for, and input into the online freeware SankeyMATIC (sankeymatic.com/build/).

There is a total of approximately 23 Million Tonnes (Mt) of specific bioarisings from a range of sectors and their fates (to the best of available knowledge) (Figure 2). The BPS (2017) report found 27 Mt of bioarisings available in Scotland; the difference in totals may be due to the inclusion of approximately 4 Mt of 'Other wastes' from Household and Commerce & Industry waste in the BPS (2017), which we have excluded because this category refers specifically to non-biogenic wastes such as aggregates, metals, and plastics.

From our investigations of the data on bioarisings and conversations with ZWS, we have found that, while there is some good data on the total amount of waste coming from sectors in Scotland, what happens after potential bioarisings leave their source is often uncertain. Consequently, the data presented becomes increasingly uncertain from left to right (Figure 2). There is anecdotal evidence that since the publication of BPS (2017), anaerobic digestion has grown in Scotland as a route for distillers' dark grains, diverting this stream from animal feed to anaerobic digestion as the latter is willing to pay more for the feedstock (SRUC, 2019). It is also generally known that the availability of food crops for the biosector varies from year to year according to both quality of growing season and what supermarkets are willing to purchase. For example, after a relatively dry year the specification for potatoes is widened for retail thus reducing what would be available for biorefining.

Whilst much of these potential bioarisings currently have limited or no uses or values, some parts have established uses and could be considered circular. However, there may be higher value alternative uses, both now and in the future. Some work has been done to estimate what amount of this waste has the potential to be valorised and by what means.

A good example of this is a report from 2022 by the Scottish Environment, Food and Agriculture Research Institutes (SEFARI), "Circular Bioeconomy Opportunities: Valorising Agricultural Wastes and Co-Products", which focuses on the valorisation potential of bioarisings from primary production: manure and slurry, and crops (i.e., cereal straws, the residues from carrots, potatoes, brassicas etc., and soft fruit crops). It identified that

approximately 16.7Mt of material from agriculture had potential uses that provide greater value than current uses.

Much of the residues from agriculture currently goes to land, is used as animal bedding, or the fate is simply not known (Figure 2). The 2022 SEFARI report proposes that these bioarisings can be, "...used as feedstocks for a broad range of products across multiple sectors including, energy, food, cosmetics, pest and disease control, etc."

The SEFARI report also finds that these routes to valorisation have several technologies in common and, "This suggests that establishing a biorefining hub and spokes, with the technologies distributed across the producer regions, could allow new entrants into the area without significant capital investment."

BPS (2017) identifies several opportunities to valorise waste streams, though it discusses these only in general terms. It also points out that further work is needed to understand the opportunities to valorise the following poorly understood and under-recorded potential bioarising streams: bakery waste, coffee grounds, forestry waste, fats oils and grease (FOGs) from wastewater processing, and macroalgae. The latter may prove to be a significant bioarising from decommissioning of oil platforms in the North Sea.

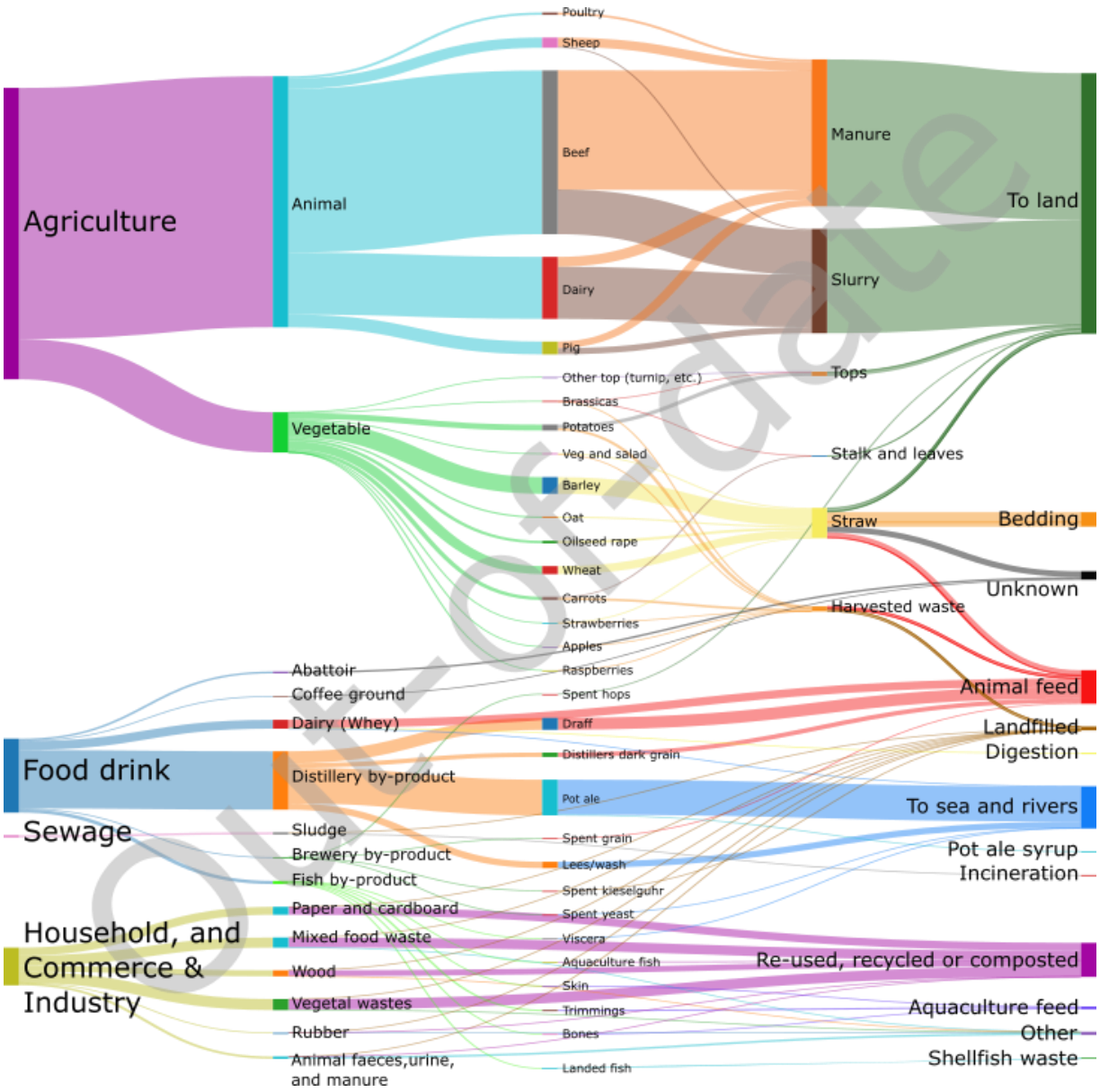

Figure E1: Sankey diagram produced using data from BPS (2017) and IBiolC's Bioresource Mapping Tool. Flows of bioarisings are from left (source sector) to right (fate). The width of flows are in proportion to the mass of flows (in tonnes). The second, third and fourth columns (or nodes) do not represent flows, but they provide a breakdown of the total material coming from sectors into their different bioarisings. The right-most column gives the final fates of bioarisings. For illustrative purposes only — this data is likely to be out-of-date.

scottish science advisory council

ANNEX E

Below is a 'traffic light' assessment of data sources and quality that was conducted in the process of creating a Sankey diagram of material flows. The most detailed data on bioresources in Scotland currently available is found in Zero Waste Scotland's Biorefinery Potential for Scotland (2017); therefore, it is that report and data sources contained within it that are the focus of this assessment. The report is referred to as BPS (2017) in the table.

1. Data quality assessment criteria and definitions

	Green is assigned to datasets/sources of data considered of good quality. Good quality data are characterised by collection and publication on a regular basis (usually annually); collection by organisations that have no conflict of interest, or where declaration of any conflict of interest is required by law; and data from peer reviewed academic articles where focus of the study is Scotland.
	Amber is assigned to datasets/sources of data where there is scope for improvement. Examples of these are use of outdated/old datasets, waste estimates that are not currently monitored, computed indirectly, identified as potentially categorizable but not currently monitored, estimates based on a one off report/study that are not regularly monitored, information that is unreferenced, information that is informally provided without associated data, datasets that are not publicly available, data provided by organisations where there might be a conflict of interest, where the primary source of data is of good quality but there is uncertainty around manipulation of data from primary source.
	Red is assigned to non-existing datasets or where there is no information on how estimates have been computed.

2. Red, amber, green mapping

				Assessment	
Waste sector	**Category**	**Subcategory**	**Data sources in BPS (2017)**	**RAG**	**Comments**
Household	Paper and Cardboard		SEPA data on generation and management of household waste		Data are annual and available for waste arisings at a local authority level.

			(BPS (2017) used SEPA's data from 2015)		
Household	Paper and Cardboard	Paper and cardboard packaging	Not available		There is currently no primary data for paper and cardboard packaging subcategories. It may be possible to estimate tonnage of these subcategories using base data reported by SEPA, but a methodology is yet to be explored. BPS (2017) suggests that a database containing information on the composition of biomass and waste (Phyllis2) could be used to characterise the chemical composition of different paper and cardboard subcategories if data were available.
Household	Paper and Cardboard	Paper as received	Not available		
Household	Paper and Cardboard	Paper dried	Not available		
Household	Paper and Cardboard	Other paper and cardboard wastes	Not available		
Household	Paper and Cardboard	Rejects from paper recycling (as received)	Not available		
Household	Paper and Cardboard	Rejects from wastepaper preparation (dried)	Not available		
Household	Rubber		SEPA data on generation and management of household waste (BPS (2017) used SEPA's data from 2015)		Data are annual and available for waste arisings at a local authority level.
Household	Wood waste		SEPA data on generation and management of household waste (BPS (2017) used SEPA's data from 2015)		Data are annual and available for waste arisings at a local authority level.
Household	Animal and mixed food waste		SEPA data on generation and management of household waste (BPS (2017) used SEPA's data from 2015)		Data are annual and available for waste arisings at a local authority level.

					BPS (2017) notes that SEPA data refers to material which is collected from households as 'food waste'; this is more selective than other estimates of total food and organic material waste that also take into account material in residual collection, mixed collections, and disposal to sewer (see "How much food and drink waste is there in Scotland?" (2016)). However, since the biorefinery sector needs food waste to be separated from other streams of waste, SEPA's data is an accurate reflection of what is available.
Household	Vegetal/garden		SEPA data on generation and management of household waste (BPS (2017) used SEPA's data from 2015)		BPS (2017) used SEPA's data from 2015. Data are annual and available for waste arisings at a local authority level.
Commerce and Industry (C&I) waste	Categories are the same as for household waste, with an additional category of "Animal faeces, urine and manure".		SEPA (2012) 'Waste Data Quality Report': uses SEPA regulatory data produced from operator reporting on licensed/permitted site returns and complex exempt activities, as base data for estimates of waste generated by businesses. The 2012 report then categorised waste according to sector using several approaches which are detailed in the report, e.g., the food sector would produce food waste. Once categorised, waste arising from specific sectors (construction, waste management and households) were excluded to produce the final dataset.		No primary data on individual bioarisings from C&I, instead this has to be estimated based on the methods of a single report from 2012. It should be noted that waste with an origin outside Scotland was excluded from the final dataset. Also, waste produced by a business in Scotland that is exported directly and does not pass through a Scottish waste management site was not captured in the dataset. The scale of this missing data is not currently known.

			The BPS (2017) report took a further step by using gross value-added (GVA) data to apportion C&I waste tonnages by local authority with the link being drawn between economic value generation, production, and waste generation.		
By-products of the food and drink industry	Brewing	Spent grain	Zero Waste Scotland (2015) 'Sector study on beer whisky and fish': estimates the amount of each bioarising available from brewing by first making an estimate of the amount of beer produced (in litres). This estimate is based on reporting from the Institute of Brewing and Distilling, Scottish Brewing, and 'industry sources' (unspecified). The Society of Independent Brewers (SIBA) is the source of information for smaller breweries. The 'brewer's equation' is then used to provide factors of by-products per litre of beer produced to estimate the amount of each by-product from beer production in tonnes. The BPS (2017) further manipulates the data from the 2015 study to apportion amounts of by-product to local authorities by making a proportional split that takes into account the number and scale of breweries in each LA region.		Estimates of by-products available from brewing are taken from a single report from 2015, which uses a combination of industry-reported data and bioresource factors to make its estimates. Primary data are available for beer production by some — including the largest — but not all breweries in Scotland. SIBA produces reports which provide estimates of beer production of small independent breweries which are members, but non-SIBA members are not included in reporting.
By-products of the food and drink industry	Brewing	Spent hops			
By-products of the food and drink industry	Brewing	Spent yeast			
By-products of the food and drink industry	Brewing	Spent kieselguhr			

By-products of the food and drink industry	Brewing	Trub	Not available		Trub (the sediment left after fermentation) remains a data gap in the model. A potentially valuable bioresource, the BPS (2017) says that further work can be undertaken to provide a robust quantification should there be industry interest.
By-products of the food and drink industry	Whisky distillation	Draff	Zero Waste Scotland (2015) 'Sector study on beer whisky and fish': takes data on whisky production (in litres) from the Scottish Whisky Association (SWA Statistical Report 2013 [not readily available online]) and applies bioresource factors* to make estimates of potential bioarisings; these are the amounts used in the BPS (2017). The actual potential bioarisings are greater than what is reported because what is reported by SWA is only what was made available for animal feed in 2013. An unrecorded quantity of by-products will have had alternative fates (including discharge to sea and spreading on land). Apportionment of bioresource data by distillery and local authority region was calculated by the BPS (2017) using data from the Scottish Whisky Association and SAC Consulting (unspecified) that estimated the by-product by distillery and local authority region. *Bell, J; Morgan, C; Dick, G; and Reid, G. (2012) 'Distillery feed by-products briefing:		Estimates of each whisky distillation by-product are based on a single report which depends on bioresource factors and incomplete data from the whisky industry to estimate bioresource arisings. The 2015 sector study acknowledges that, "...variability [in how by-products are dealt with] across different distilleries combined with a lack of formal data presents difficulties in identifying the weights and destinations of distillery by-products." SWA regularly publishes export analysis reports and informal reporting of the whisky sector's production figures, but no formal data on production is publicly available on their website. Further calculations have had to be made using unspecified data to estimate amounts of bioarisings in each LA.
By-products of the food and drink industry	Whisky distillation	Pot ale			
By-products of the food and drink industry	Whisky distillation	Spent lees/wash			
By-products of the food and drink industry	Whisky distillation	Pot ale syrup			
By-products of the food and drink industry	Whisky distillation	Distillers dark grain			

			An AA211 Special Economic study for the Scottish Government' SAC Consulting: a briefing by SRUC/ SAC Consulting prepared for the Scottish Government (datasets can be accessed through tabs in feedipedia.org). A copy of the briefing can be found here.		
By-products of the food and drink industry	Fish processing	Skin	Zero Waste Scotland (2016) 'Sector study on beer whisky and fish 2015' gives an estimate — based on a range of data sources* and insight gathered from the stakeholders engaged — of the total annual process waste** from the fishing industry. Bioresource factors taken from multiple studies*** are then used to estimate the amounts of each bioarising from fish process waste. The amount of by-products available in each local authority region were then estimated using the Aquaculture Scotland site database to provide a count of aquaculture sites in each LA and by-products were apportioned accordingly. *Including, total fish landings reported annually by Marine Scotland. Scottish Sea		Primary data on fish processing bioarisings are not currently available. Fish by-product subcategories (e.g., skin, bones) are not yet monitored or reported and, as such, only very high-level aggregated data is available on the tonnage of fish waste or carcasses produced as a waste product. Subcategories were averaged estimates based on factors taken from multiple reports. Hence subcategories indicate potential by-products that could be separated and used as bioresources but do not represent current bioresources available. It remains unclear from the report and further communication with Zero Waste Scotland and IBioIC what current waste management practices are in place for this waste. It is noted in the sector study that publication of mortality data in fish farms is commercially
By-products of the food and drink industry	Fish processing	Trimmings			
By-products of the food and drink industry	Fish processing	Bones			

By-products of the food and drink industry	Fish processing	Viscera	Fisheries data is reported annually to the Scottish Government, with data available since 2010. **This includes all varieties of farmed and sea-caught fish. ***Ghaly et al (2013) – Fish Processing Wastes as a Potential Source of Proteins, Amino Acids and Oils: A Critical Review; Pascal et al (2013) – By-products from Fish Processing: Focus on French Industry; Secretariat of the Pacific community (2014) Adding value to fish by-products.		sensitive and is not legally required by SEPA. However, mortality by weight data is published monthly via 'Scotland's Aquaculture' and the data is supplied by SEPA.
By-products of the food and drink industry	Fish processing	Shellfish waste			
By-products of the food and drink industry	Abattoir	Carcass	Tonnage of bioarisings was calculated in BPS (2017) by first taking an estimate of the number of each type of livestock in Scotland from a single report: from 2014 by Resource Efficient Scotland '5th Quarter Blood management project'*. These values were then multiplied by the average weight of each type of animal carcass in tonnes as reported by Quality Meat Scotland (QMS) in 2014. An estimate of abattoir bioarisings was then made by applying bioresource factors obtained from a single study** to the total tonnage of carcasses by type. *This report is no longer available, and the		Primary data on bioarisings from abattoirs is not currently available. As the BPS (2017) observes, "Abattoir data required a similar approach to fisheries data to combine several data sources to transform key data on material arisings and disaggregating it into the wastes streams." Publicly available data on slaughtered animals is reported at UK level through DEFRA National Statistics, which includes data for Scotland from 2000 to 2017 on a monthly basis. At the time of writing, there was no data after 2018.
By-products of the food and drink industry	Abattoir	Blood			
By-products of the food and drink industry	Abattoir	Bone			
By-products of the food and drink industry	Abattoir	Fat			
By-products of the food and drink industry	Abattoir	Hide/skin			

By-products of the food and drink industry	Abattoir	Viscera	reference could not be checked. ** K. Jayathilakan et al (2012) Utilization of by-products and waste materials from meat, poultry, and fish processing industries: a review		
By-products of the food and drink industry	Dairy	Whey	No information on source data for whey is provided in the BPS (2017).		Neither the source data nor the means of estimating 'whey (diary)' is given in the BPS (2017), though figures are provided. The BPS (2017) notes that many by-products of dairy are disposed of via sewer or sea. For whey that is disposed of by sewer, it is captured as a homogenised wastewater material. If disposed of to sea, whey is not captured at all. It is not clear whether whey disposed of by sewage has been estimated and included in the figures presented in the report. Although not referenced by BPS (2017); Zero Waste Scotland has produced a recent report 'The ultimate guide: Managing waste in cheese manufacturing' which details waste reduction and reuse options. The report does not provide data for whey production but provides an estimate of litres of whey generated per kilogram of cheddar cheese.
Agriculture	Vegetable waste	Apples — harvested waste	The Scottish Government's June Agricultural Census 2015: provides the data for the number of hectares being used to grow each crop type, and these are used as base data		A single dataset used from agricultural survey data: the Scottish Government's June Agricultural Census 2015. The Agricultural Census has been reported annually since 2012
Agriculture	Vegetable waste	Barley straw			

Agriculture	Vegetable waste	Brassica stalks and leaves	to estimate bioarisings. However, it is not made clear how vegetable waste subcategories for non-cereal products (e.g., carrot harvested waste, leaves) were computed from hectares of land and crop yield. BPS (2017) says estimations are informed by expert opinion from SAC consulting/ SRUC, and best practice or benchmark data from a range of industry reports, none of which are specified.		but there is data since 1999. The June Agricultural Census is conducted annually by the Scottish Government's Rural and Environmental Science Analytical Services division (RESAS). Since 2009, data on land use presented in the Agricultural Census has been obtained from the Single Application Form (SAF) for holdings claiming Basic Payment Scheme entitlements (previously Single Farm Payments). This has been combined with land use data from all other holdings, collected through June Census forms, to generate overall results. The SAF database is estimated to cover 90 per cent of the total agricultural area. Data reported in the agricultural census includes the area of land used for production of cereals, oilseeds, potatoes, horticultural crops, crops for stock feeding, fruits, vegetables, bulbs, and flowers. The current list of items contemplated in the ZWS report could be expanded using these datasets. Statistics on crop yield and production for cereals and oilseed rape were obtained from Scottish Harvest Publications.
Agriculture	Vegetable waste	Brassica tops			
Agriculture	Vegetable waste	Carrot stalks and leaves			
Agriculture	Vegetable waste	Carrots — harvested waste			
Agriculture	Vegetable waste	Fresh vegetables and salad			
Agriculture	Vegetable waste	Oat straw			
Agriculture	Vegetable waste	Oilseed rape straw			
Agriculture	Vegetable waste	Other tops (turnip etc.)			
Agriculture	Vegetable waste	Potatoes — harvested waste			
Agriculture	Vegetable waste	Potato haulms			
Agriculture	Vegetable waste	Raspberries — harvested waste			
Agriculture	Vegetable waste	Strawberries — harvested waste			
Agriculture	Vegetable waste	Strawberries straw			

Agriculture	Vegetable waste	Vegetable straw			
Agriculture	Vegetable waste	Wheat straw			
Agriculture	Animal waste	Slurry	The Scottish Government's June Agricultural Census 2015 provides a count of livestock which are used as base data for estimating bioarisings. It remains unclear how animal waste subcategories (e.g., slurry, manure) were computed from livestock numbers. Waste factors may have been informed by SRUC/SAC consulting, but this is not stated in the BPS (2017).		A single dataset was used from agricultural survey data: the Scottish Government's June Agricultural Census 2015. The Agricultural Census has been taken annually by the Scottish Government's Rural and Environmental Science Analytical Services division (RESAS) since 2012, and data are available since 1999. In the Agricultural Census, livestock numbers were collected from the Cattle Tracing Scheme (CTS) administrative source, effectively with 100 per cent coverage as it is mandatory to report animal numbers. From 2021, all cattle births, deaths and movements must be reported to ScotMoves+, operated by ScotEID.
Agriculture	Animal waste	Manure			
Wastewater	Sludge		Scottish Water, as the principal service provider in Scotland for wastewater and water treatment, is the source of data relating to sludge. However, the data are not publicly available and no further information on how the data was measured or estimated is given in BPS (2017).		BPS (2017) states that a report from Scottish Water from 2005 (broken link) was used to indicate what percentage of sludge (from wastewater and water treatment) ended up in different outlets that year, i.e., recycling to agricultural land; land reclamation; energy from waste/power generation; and other.

Other	Bakery sector	Bread waste	No data currently		It is implied, but not clearly stated, that there is currently no data on bread waste in Scotland; “It would be helpful therefore to have a better understanding of the wasted resources across the bakery sector in Scotland – especially the populous city regions. Zero Waste Scotland is conducting work to better understand the raw material inputs and waste resource outputs.”
Other	Coffee industry	Coffee grounds	Out of scope of the BPS (2017).		There is some data available: an estimate of 40,000 tonnes of grounds generated annually in Scotland was given, but the source given in the BPS (2017) was a single blog article which is no longer available.
Other	Forestry	Wood fibre	Out of scope of the BPS (2017).		No report was found that clearly estimates available biomass from the forestry sector. Some reports have been identified from 2011-2012, prepared for the Forestry Commission Scotland and the Scottish Government, to assess the potential for energy production from wood and assess environmental cost compared to other forms of energy generation. However, these consider available wood (produced) rather than wood waste. Scottish Forestry is the Scottish Government agency responsible for forestry policy, support and regulations and could produce necessary data on forestry waste in the future. Currently, no report was identified that estimated waste from the sector.

Other	Sewage	Fats, oils, and grease (FOGs)	Out of scope of the BPS (2017) and little or no data available		The BPS (2017) says that there is a need for better understanding of the volumes of FOGs to open up the opportunities to valorise this potentially valuable waste stream. Capturing FOGs from food waste before they are disposed of which could reduce the cost of managing FOGs in the sewage system.
Other	Aquaculture	Seaweed	Out of scope of the BPS (2017).		BPS (2017) says that "Macro-algae was out of scope for this study but there is growing interest from a biorefining perspective. The 8-10 million tonnes of harvestable biomass could not be included as it does not 'arise', and it would need to be harvested. Future work should focus on the waste arising from processes using macro algae (e.g., the cellulose waste arising from production of alginates)." There is uncertainty over the maximum capacity for wild harvesting (close to maximum capacity where wild harvesting currently occurs, but it may be possible to expand to other areas of coastline). There is potential for cultivation, but methods are still in the trial stages.

3. Table of documents reviewed.

Organisation	Year	Document	Link
Scottish Science Advisory Council	2020	The Environmental Impacts of the Scottish Manufacturing Industry Report	https://scottishscience.org.uk/article/ssac-report-environmental-impacts-scottish-manufacturing-industry
	2021	SSAC Sustainable Chemicals Technical Briefing Note	https://scottishscience.org.uk/article/ssac-technical-briefing-note-sustainable-chemicals

Industry	2017	Biorefinery Roadmap for Scotland	https://www.lifesciencesscotland.com/wp-content/uploads/2017/08/BiorefineryRoadmapforScotland.pdf
	2019	National Plan for Industrial Biotechnology: Driving Progress to 2025	https://www.lifesciencesscotland.com/wp-content/uploads/2019/01/National-Plan-for-IB-2019-PDF.pdf
	2020	Biorefinery Roadmap for Scotland: Building a sustainable future	https://www.sdi.co.uk/media/2092/biorefinery-roadmap-for-scotland-building-a-sustainable-future.pdf
Industrial Biotechnology Innovation Centre (IBioIC)	2021	Sugar Beet: A Just Transition for the Chemicals Sector and a Net Zero Solution for Manufacturing	https://www.ibioic.com/publications-database/sugar-beet-a-just-transition-for-the-chemicals-sector-and-a-net-zero-solution-for-manufacturing
Climate X Change	2021	Review of the Scottish TIMES energy system model	https://www.climatexchange.org.uk/media/4738/cxc-review-of-the-scottish-times-energy-system-model-february-2021.pdf
Scottish Environment, Food and Agriculture Research Institutes (SEFARI)	2022	Circular Bioeconomy Opportunities Valorising Agricultural Wastes and Co-products - Report	https://sefari.scot/sites/default/files/documents/SEFARI%20Gateway_Fellowship_%20Agrbyproduct_FINAL.pdf
Zero Waste Scotland	2015	Circular Economy Beer Whisky Fish Report	https://consult.gov.scot/zero-waste-delivery/making-things-last/supporting_documents/ZWS645%20Beer%20Whisky%20Fish%20Report_0.pdf
	2017	Biorefining Potential for Scotland Final report: Mapping bioresource arisings across Scotland	https://www.zerowastescotland.org.uk/sites/default/files/Biorefining%20Potential%20for%20Scotland%20Final%20report.pdf
	2017	Waste Composition Analysis Programme 2021-2024: The composition of household waste at the kerbside in 2014-15	https://www.zerowastescotland.org.uk/content/waste-composition-analysis-programme-2021-2024
	2017	Biogas and Composting sectors: Scottish anaerobic digestion and biogas sector survey	https://www.zerowastescotland.org.uk/biogas-compost-composting-sector-survey-2017
	2017	Biogas and Composting sectors: Scottish composting sector survey	https://www.zerowastescotland.org.uk/biogas-compost-composting-sector-survey-2017
	2020	the Decoupling Advisory Group Building Back Better: Principles for sustainable resource use in a wellbeing economy - report	https://www.zerowastescotland.org.uk/sites/default/files/Decoupling%20Advisory%20Group%20Report.pdf
	2020	Measuring Scotland's progress towards a circular economy to help combat the climate emergency. Results from a preliminary scoping study reviewing key indicators.	https://zerowastescotland.org.uk/sites/default/files/Branded%20Report%20MetricsV1.pdf
	2020	Measuring Scotland's progress towards a circular economy to help combat the climate emergency. Results from a preliminary scoping study reviewing key indicators – Reflections report	https://circulareconomy.europa.eu/platform/sites/default/files/reflections_metrics_report_v2_0.pdf
	?	Scotland and the Circular Economy: A preliminary examination of the opportunities for a circular economy in Scotland	https://consult.gov.scot/zero-waste-delivery/making-things-last/supporting_documents/Scotland%20and%20the%20Circular%20Economy%20a%20report%20for%20the%20Scottish%20Government.pdf
	2021	Material Flow Account: technical report	https://www.zerowastescotland.org.uk/sites/default/files/ZWS1658%20MFA%20technical%20report%20v4_0.pdf
Scottish Government Strategies/Plans	2016	Making Things Last: a circular economy strategy for Scotland	https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2016/02/making-things-last-circular-economy-strategy-scotland/documents/00494471-pdf/00494471-pdf/govscot%3Adocument/00494471.pdf
	2022	Route Map to 2025: Delivering Scotland's circular economy	https://www.gov.scot/publications/consultation-delivering-scotlands-circular-economy-route-map-2025-beyond/

	2019	Circular Economy Bill: Proposals for Legislation	https://www.gov.scot/publications/delivering-scotlands-circular-economy-consultation-proposals-circular-economy-bill/

Table 2 List of potentially useful documents

Organisation	Year	Document	Link
Scottish Council for Development and Industry (SCDI)	2020	Clean Growth Manifesto: Clean Growth opportunities for Scotland's transition to Net Zero	https://www.scdi.org.uk/policy/clean-growth-download-our-manifesto/
	2021	2030 Blueprint for Scotland's Economy	https://www.scdi.org.uk/policy/blueprint2030/
	2021	Innovation Critical: Scotland's Net Zero mission & Climate Tech Opportunity	https://www.scdi.org.uk/policy/climatetech/
Scottish Aquaculture Innovation Centre (SAIC)	2016	Exploring the concept of a centre of innovation excellence	
		Scottish aquaculture: a view towards 2030. Innovation roadmap and sector needs study	https://www.sustainableaquaculture.com/media/1174/scottish-aquaculture-a-view-towards-2030.pdf
	2021	Fish Farming in Scotland: Optimising its Contribution to Climate and Environmental Policies – Policy Report	https://www.sustainableaquaculture.com/media/2264/scottish-aquaculture-innovations_ou-scotland-report_180821.pdf
Industrial Biotechnology Innovation Centre (IBioIC)	2020	A year of innovation exploration for net-zero in Scotland – Review Conference	https://www.ibioic.com/publications-database/cop26-innovation
UK Climate Change Committee	2016	Reducing emissions in Scotland: 2016 progress report	https://www.theccc.org.uk/wp-content/uploads/2016/09/Reducing-emissions-in-Scotland-2016-Progress-Report-Committee-on-Climate-Change.pdf
Scottish Environment, Food and Agriculture Research Institutes (SEFARI)	2019	Food Waste in Primary Production Milk Loss with Mitigation Potentials – Research article	
Zero Waste Scotland	2017	Waste Composition Analysis Programme 2021-2024: A standard methodology for household sampling	https://www.zerowastescotland.org.uk/content/waste-composition-analysis-programme-2021-2024
	2020	Waste Composition Analysis Programme 2021-2024: Developing the business case for a programme of waste composition analysis in Scotland	https://www.zerowastescotland.org.uk/content/waste-composition-analysis-programme-2021-2024
	2021	Waste Composition Analysis Programme 2021-2024: Methodology	https://www.zerowastescotland.org.uk/content/waste-composition-analysis-programme-2021-2024
	2021	The climate change impact of burning municipal waste in Scotland Technical Report	https://www.zerowastescotland.org.uk/sites/default/files/The%20climate%20change%20impact%20of%20burning%20municipal%20waste%20in%20Scotland%20Technical%20Report%20July%202021.pdf
	?	ZWS1557 Managing waste in cheese manufacturing	https://www.zerowastescotland.org.uk/sites/default/files/ZWS1557%20EEBS%20Dairy%20Guidance.pdf
	2007	SB 07-59 Waste Management in Scotland. Towards Zero Waste	https://archive2021.parliament.scot/Research%20briefings%20and%20fact%20sheets/SB07-59.pdf

Scottish Parliament Information Centre (SPICe) briefings	2009	SB 09 04 Climate Change (Scotland) Bill Waste provisions	https://archive2021.parliament.scot/Research%20briefings%20and%20fact%20sheets/SB09-04.pdf
	2012	SB 12-18 The Waste (Scotland) Regulations 2012	https://archive2021.parliament.scot/ResearchBriefingsAndFactsheets/S4/SB_12-18.pdf
	2013	SB 13-41 Treatment options for residual waste	https://archive2021.parliament.scot/ResearchBriefingsAndFactsheets/S4/SB_13-41.pdf
	2013	SB 13-72 Circular Economy	https://archive2021.parliament.scot/ResearchBriefingsAndFactsheets/S4/SB_13-72.pdf
	2022	SB 22-06 Incineration and Energy from Waste	https://sp-bpr-en-prod-cdnep.azureedge.net/published/2022/2/3/5f556355-32d7-4e78-8a08-d44c743eaf13/SB%2022-06%20.pdf
Scottish Government Strategies/Plans	2018	Climate Change Plan 2018 – 2032: Securing a Green Recovery on a Path to Net Zero	Securing a green recovery on a path to net zero: climate change plan 2018–2032 - update - gov.scot (www.gov.scot)
Scottish Government Strategies/Plans	2022	Scotland's National Strategy for Economic Transformation: Delivering Economic Prosperity	Scotland's National Strategy for Economic Transformation - gov.scot (www.gov.scot)
Scottish Government Programme 2015-2023	2015	Programme for Government 2015-2016: A stronger Scotland	https://www.gov.scot/collections/programme-for-government/
	2016	Programme for Government 2016-2017: A plan for Scotland	https://www.gov.scot/publications/plan-scotland-scottish-governments-programme-scotland-2016-17/
	2017	Programme for Government 2017-2018: A nation with ambition	A nation with ambition: the Government's Programme for Scotland 2017-2018 - gov.scot (www.gov.scot)
	2018	Programme for Government 2018-2019: Delivering for today, investing for tomorrow	Delivering for today, investing for tomorrow: the Government's programme for Scotland 2018-2019 - gov.scot (www.gov.scot)
	2019	Programme for Government 2019-2020: Protecting Scotland's Future	Protecting Scotland's Future: the Government's Programme for Scotland 2019-2020 - gov.scot (www.gov.scot)
	2020	Programme for Government 2020-2021: Protecting Scotland, Renewing Scotland	Protecting Scotland, Renewing Scotland: The Government's Programme for Scotland 2020-2021 - gov.scot (www.gov.scot)
	2021	Programme for Government 2021-22: A fairer, greener Scotland	A Fairer, Greener Scotland: Programme for Government 2021-22 - gov.scot (www.gov.scot)
	2022	Programme for Government 2022 to 2023: A stronger and more resilient Scotland.	A stronger and more resilient Scotland: the Programme for Government 2022 to 2023 - gov.scot (www.gov.scot)
Legislation: Scottish Statutory Instruments & Acts of the Scottish Parliament	2012	2012 No. 148 ENVIRONMENTAL PROTECTION: The Waste (Scotland) Regulations 2012	https://www.legislation.gov.uk/ssi
	2015	2015 No. 438 Environmental Protection: The Waste (Meaning of Recovery) (Miscellaneous Amendments) (Scotland) Order	
	2015	2015 No. 101 ENVIRONMENTAL PROTECTION: The Waste (Recyclate Quality) (Scotland) Regulations 2015	
	2019	2019 No. 273 EXITING THE EUROPEAN UNION ENVIRONMENTAL PROTECTION: The Management of Extractive Waste (EU Exit) (Scotland) (Miscellaneous Amendments) Regulations 2019	

	2019	2019 No. 356 WASTE: The Waste (Miscellaneous Amendments) (Scotland) Regulations 2019	
	2020	2020 No. 281 CLIMATE CHANGE: The Climate Change (Duties of Public Bodies: Reporting Requirements) (Scotland) Amendment Order 2020	
	2020	2020 No. 66 (C. 4) CLIMATE CHANGE: The Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 (Commencement) Regulations 2020	
	2020	2020 No. 387 ENVIRONMENTAL PROTECTION: The Producer Responsibility Obligations (Packaging Waste) Amendment (Scotland) Regulations 2020	
	2020	2020 No. 314 ENVIRONMENTAL PROTECTION: The Waste (Miscellaneous Amendments) (Scotland) Regulations 2020	
	2022	2022 No. 87 CLIMATE CHANGE: The Climate Change (Nitrogen Balance Sheet) (Scotland) Regulations 2022	
	2019	Climate Change (Emissions Reduction Targets) (Scotland) Act 2019	
Official statistics website	1998-2017	Breakdown Of Scotland's Carbon Footprint	https://statistics.gov.scot/resource?uri=http%3A%2F%2Fstatistics.gov.scot%2Fdata%2Fcarbon-footprint-breakdown
	2005-2019	Energy consumption by sector	https://statistics.gov.scot/resource?uri=http%3A%2F%2Fstatistics.gov.scot%2Fdata%2Fenergy-consumption
	2002-2019	Exports by industry	https://statistics.gov.scot/resource?uri=http%3A%2F%2Fstatistics.gov.scot%2Fdata%2Fexports
	1990-2019	Greenhouse Gas Emissions by National Communications Category	https://statistics.gov.scot/resource?uri=http%3A%2F%2Fstatistics.gov.scot%2Fdata%2Fgreenhouse-gas-emissions-by-national-communications-category
	2004-2012	SEPA: Municipal waste	https://statistics.gov.scot/resource?uri=http%3A%2F%2Fstatistics.gov.scot%2Fdata%2Fmunicipal-waste
	2011-2019	SEPA: Generation and Management of Household Waste	https://statistics.gov.scot/resource?uri=http%3A%2F%2Fstatistics.gov.scot%2Fdata%2Fhousehold-waste