Data Article

Data for life cycle assessment of legume biorefining for alcohol

Theophile Lienhardt a, b, Kirsty Black c, d, e, f, Sophie Saget g, Marcela Porto Costa a, David Chadwick a, Robert Rees h, Michael Williams g, Charles Spillane b, Pietro Iannetta d, Graeme Walker d, David Styles a, b, *

a School of Environment, Natural Resources and Geography, Bangor University, Bangor LL57 2UW, UK, Wales
b Plant and AgriBiosciences Centre, Ryan Institute, National University Ireland Galway, Galway, Ireland
c Arbikie Distilling Ltd, Inverkeilor, Arbroath DD11 4UZ, Scotland, UK
d Division of Food & Drink, Abertay University, Dundee DD1 1HG, UK
e Ecological Sciences, The James Hutton Institute, Dundee DD2 5DA, Scotland, UK
f Yeast Research Group, Abertay University, Dundee, DD1 1HG, Scotland, UK
g Department of Botany, School of Natural Sciences, Trinity College Dublin, Dublin 2, Ireland
h Scotland’s Rural College, West Mains Road, Edinburgh EH9 3JG, Scotland, UK

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Abstract

Benchmarking the environmental sustainability of alcohol produced from legume starch against alcohol produced from cereal grains requires considering of crop production, nutrient cycling and use of protein-rich co-products via life cycle assessment. This article describes the mass balance flows behind the life cycle inventories for gin produced from wheat and peas (Pisum sativum L.) in an associated article summarising the environmental footprints of wheat- and pea-gin [1], and also presents detailed supplementary results. Activity data were collected from interviews with actors along the entire gin value chain including a distillery manager and ingredient and packaging suppliers. Important fertiliser and animal-feed substitution effects of co-product use were derived using detailed information and models on nutrient flows and animal feed composition, along with linear optimisation modelling. Secondary data on environmental burdens of specific materials and processes were obtained from the Ecoinvent v3.4 life cycle assessment database. This article provides a basis for further
quantitative evaluation of the environmental sustainability of legume-alcohol value chains. © 2019 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Data

Primary and secondary data used to build the life cycle inventories for wheat- and pea-gin are described in the next section, with key information summarised in Tables 1–8.

Key data outputs are summarised in Tables within the associated MS Excel file, including: (i) life cycle inventory data (Table SI 9 for wheat gin and Tables SI 10 and SI 11 for wheat gin produced at

Specifications Table

| Subject                  | Environmental Science (General) |
|--------------------------|---------------------------------|
| Specific subject area    | Life cycle assessment of agri-food chains |
| Type of data             | Text & Tables                   |
| How data were acquired   | Mass flow and life cycle inventory data were collated from primary and secondary sources, including: (i) interviews with value chain stakeholders to identify quantities, origins and transport of inputs used in gin production; (ii) statistics on agronomic inputs and yields of wheat and pea crops; (iii) commercial LCA databases, primarily Ecoinvent v3.5. |
| Data format              | Data presented are collated raw and processed data that have been converted into mass balance flows for wheat and pea-gin value chains, and analysed results. |
| Parameters for data collection | Mass flows of materials and constituent nutrients in value chains of wheat- and pea-gin production. |
| Description of data collection | Primary data were collated via face-to-face, telephone and email communication with stakeholders. Secondary data were collated via searches of the academic literature (Google Scholar) and through access to the commercial Ecoinvent v.3.5 database using Open LCA v1.7. |
| Data source location     | Data collection related to gin production in the Arbikie Distillery, Inverkeilor, Arbroath, Scotland Latitude: 56.64662 Longitude: −2.55632 |
| Data accessibility       | With the article                |
| Related research article | Theophile Lienhardt, Kirsty Black, Sophie Saget, Marcela Porto Costa, David Chadwick, Robert Rees, Mike Williams, Charles Spillane, Pietro Iannetta, Graeme Walker, David Styles |

Value of the Data

- These data provide detailed life cycle inventories and full life cycle assessment results for gin made from wheat and peas, including potential substitution of fertilisers and animal feed.
- Data are useful for any academics studying gin value chains, e.g. to calculate environmental footprints or economic profiles, and for any stakeholders interested in the environmental sustainability of gin and other alcohol value chains.
- Data may be used to parameterise basic grain- and legume-life cycle inventories as a basis for new (legume)-alcohol LCAs.
- These high resolution data provide insight into important processes underpinning the life cycle inventories summarised in Lienhardt et al. [1], and indicate the full range of life cycle assessment results derived from sensitivity analyses.
### Table 1
Main inputs to the distillation process for one batch of gin.

| Input/output   | Unit | Wheat gin | Pea gin |
|----------------|------|-----------|---------|
| Wheat grain    | kg   | 2703      | 2782    |
| Pea grist      | kg   |           |         |
| Water          | L    | 25 454    |         |
| Yeast          | kg   | 13.5      |         |
| A-amylase      | kg   | 1.2       |         |
| Glucoamylase   | kg   | 3.3       |         |
| Kerosene       | L    | 870       |         |
| Electricity    | kWh  | 946       |         |
| Botanicals     | kg   | 22.5      |         |

### Table 2
Mass balance of main inputs and outputs for the production of one batch of gin from wheat, based on Arbikie commercial production.

| Input/output   | Dry matter | Starch | Protein | Volume |
|----------------|------------|--------|---------|--------|
| Whole grain    | 2703 kg    | 1865 kg | 341 kg  |         |
| Pot-ale (DDGS) | 1092 kg    | 341 kg  |         | 10547 L |
| Alcohol        | 1159 kg    | 1159   |         |
| Gin            | 1886 kg    | 1886   |         |

### Table 3
Mass balance of main inputs and outputs for the production of one batch of gin from peas, based on Arbikie pilot trials.

| Input/output   | Dry matter | Starch | Protein | Volume |
|----------------|------------|--------|---------|--------|
| Whole grain    | 4558 kg    | 2338 kg | 1089 kg | 10547 L |
| Hulls          | 1777 kg    | 347 kg  |         | 1159   |
| Grist          | 2782 kg    | 1419 kg | 743 kg  | 1886   |
| Pot-ale (DDGS) | 1363 kg    | 743 kg  |         | 1159   |
| Alcohol        | 1159 kg    | 1159   |         |
| Gin            | 1886 kg    | 1886   |         |

### Table 4
Mass balance of main inputs and outputs for the production of one batch of gin from peas, based on equivalent starch input to fermentation.

| Input/output   | Dry matter | Carbohydrates | Starch | Protein | Volume |
|----------------|------------|---------------|--------|---------|--------|
| Whole grain    | 5905 kg    | 3319 kg       | 3030 kg| 1412 kg |        |
| Hulls          | 2301 kg    | 1373 kg       |        | 655 kg  |        |
| Grist          | 3604 kg    | 1946 kg       | 1838 kg| 757 kg  |        |
| Pot-ale        | 1766 kg    | 108 kg        | 757 kg |         | 10547 L |
| Alcohol        | 1159 kg    |               |        | 1159 kg |
| Gin            | 1886 kg    |               |        | 1886 kg |
different alcohol yields); (ii) life cycle assessment results broken down into 11 contributory processes and the four life cycle assessment permutations evaluated in Lienhardt et al. [1], in Tables SI 12–SI 15.

2. Experimental design, materials, and methods

2.1. Input and output mass balance

Data from Arbikie on input quantities to the distillation process (Table 1), and from Feedipedia [2] on pea and wheat grain composition, were used to derive mass balances of macro nutrients for the production of one batch of gin (1886 L) from wheat (Table 2) and peas (Table 3). The alcohol production from fermentation (1159 L) is within 2% of the specific alcohol yield per kg of wheat grain.
reported by Ref. [3], and within 7% of the stoichiometric yield of alcohol from the carbohydrate content of pea grist [4].

To reflect some uncertainty in alcohol yields for pea flour at the commercial scale, we also undertook an LCA of pea gin based on an equivalent carbohydrate input from pea flour (1946 kg) as from

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**Table 8**
Life cycle impact assessment methods employed in this study.

| Impact category                  | Indicator                                      | Unit                  | Recommended default LCIA method                                                                 | Source of CFs | Robustness | Selected method in OpenLCA |
|----------------------------------|------------------------------------------------|-----------------------|-------------------------------------------------------------------------------------------------|---------------|------------|----------------------------|
| Climate change                   | Radiative forcing as Global Warming Potential (GWP100) | kg CO2 eq             | Baseline model of 100 years of the IPCC (based on IPCC 2013)                                    | EC-JRC, 201721 | I          | IPCC 2013                  |
| Ozone depletion                  | Ozone Depletion Potential (ODP)                | kg CFC-11 eq          | Steady-state ODPs as in (WMO 1999)                                                              | EC-JRC, 201721 | I          | ILCD+                      |
| Human toxicity, cancer*          | Comparative Toxic Unit for humans (CTUh)       | CTUh                  | USEtox model (Rosenbaum et al., 2008)                                                           | EC-JRC, 201721 | III/interim | ILCD+                      |
| Human toxicity, non-cancer*      | Comparative Toxic Unit for humans (CTUh)       | CTUh                  | USEtox model (Rosenbaum)                                                                       | EC-JRC, 201721 | III/interim | ILCD+                      |
| Ionising radiation, human health | Human exposure efficiency relative to U235     | kBq U235 eq           | Human health effect model as developed by Dreicer et al., 1995 (Frischknecht et al., 2000)    | EC-JRC, 201721 | II         | ILCD+                      |
| Photochemical ozone formation, human health | Tropospheric ozone concentration increase | kg NMVOC eq           | LOTOS-EUROS model (Van Zelm et al., 2008) as implemented in ReCiPe 2008                       | EC-JRC, 201721 | II         | ILCD+                      |
| Acidification                    | Accumulated Exceedance (AE)                    | mol H+ eq             | Accumulated Exceedance (Seppälä et al., 2006, Posch et al., 2008)                              | EC-JRC, 201721 | II         | ILCD+                      |
| Eutrophication, terrestrial      | Accumulated Exceedance (AE)                    | mol N eq              | Accumulated Exceedance (Seppälä et al., 2006, Posch et al., 2008)                              | EC-JRC, 201721 | II         | ILCD+                      |
| Eutrophication, freshwater       | Fraction of nutrients reaching freshwater end compartment (P) | kg P eq               | EUTREND model (Struijs et al., 2009) as implemented in ReCiPe                                 | EC-JRC, 201721 | II         | ILCD+                      |
| Eutrophication, marine           | Fraction of nutrients reaching marine end compartment (N) | kg N eq               | EUTREND model (Struijs et al., 2009) as implemented in ReCiPe                                | EC-JRC, 201721 | II         | ILCD+                      |
| Ecotoxicity, freshwater*         | Comparative Toxic Unit for ecosystems (CTUe)    | CTUe                  | USEtox model, (Rosenbaum et al., 2008)                                                          | EC-JRC, 201721 | III/interim | ILCD+                      |
| Resource use, minerals and metals | Abiotic resource depletion (ADP ultimate reserves) | kg Sb eq              | CML 2002 (Guinée et al., 2002) and van Oers et al., 2002.                                      | EC-JRC, 201721 | III        | CML IA Baseline            |
| Resource use, fossils            | Abiotic resource depletion – fossil fuels (ADP-fossil) | MJ                    | CML 2002 (Guinée et al., 2002) and van Oers et al., 2002.                                      | EC-JRC, 201721 | III        | CML IA Baseline            |
| Land occupation                  | Cropping land occupation (LO)                  | m².yr                 |                                                                                                 |               | II         | NA                         |
wheat grist (Table 4). This represents a 30% higher input of peas compared with data provided by Arbikie, and may be regarded as a worst case estimate of alcohol production efficiency from peas.

2.2. Cultivation and field emissions

Table 5 displays major inputs and outputs expressed per hectare for wheat and pea cultivation, based on a combination of specific activity data from the Arbikie Estate (where wheat is grown for the distillery) and national statistics. 

Soil emissions and nutrient leaching factors following the application of synthetic and organic fertilizers were primarily taken from relevant inventory reports [9–11]. Nitrogen losses from pot ale spreading were calculated based on the MANNER-NPK tool [12] which integrates equations derived from decades of empirical observations across the UK on emissions, leaching and fertiliser replacement value for different organic nutrient additions [12]. Ammonia emissions and N leaching are related to factors including total N, NH4 and dry matter contents of organic amendments, application method, soil type and moisture status during application, cropping sequence, and prevailing meteorological conditions during and after application (as specified by users and inferred from background meteorological data related to the post code). The soil hydrological balance is also important for calculating N leaching. We ran the MANNER-NPK tool for pot ale application by trailing hose in spring and autumn, under good spreading conditions (calm weather, moist soils, no rain immediately after application), on a medium textured soil prior to a spring cereal crop.

Credits for avoided fertiliser application comprised avoided manufacture taken from the Ecoinvent database [13] and avoided field emissions post-application based on emission factors of 0.017 NH₃--N [11], 0.1 NO₃--N [14] and 0.01 for P following N- and P-fertiliser application [15]. Unless otherwise stated, nitrogen, phosphorus and potassium fertilisers were assumed to be in the forms of ammonium nitrate, triple superphosphate and potassium chloride fertilisers.

2.3. Avoided animal feed

Pea hulls and pot ale (following conversion to dried distillers grains with solubles, DDGS) may be used as cattle feed, substituting a mix of protein- and energy-feeds. Based on the same approach as Leinonen et al. [16], we assumed that soybean meal and barley were the main feeds substituted. We applied linear optimisation run in MS Excel solver to calculate the amount of soybean meal and barley grain substituted by pea hulls, wheat-based DDGS and pea-based DDGS in order to deliver exactly the same amount of crude protein and metabolizable energy. Crude protein and metabolizable energy content values for the different feed stuffs (Table 6) were taken from Feedipedia [2]. The protein content of pea-derived DDGS was calculated based on the protein mass balance in Table 7. The mass balance of animal feed substitution following optimisation is displayed in Table 7. In the case of pea-based DDGS, substitution of soybean meal leaves a deficit of metabolizable energy, which is satisfied by feeding additional barley grain (a burden that offsets some of the feed substitution credit calculated in the expanded boundary LCA).

2.4. Impact assessment

Life cycle impact assessment was undertaken across 14 environmental impact categories (Table 8). Thirteen of these are from the suite of impact assessment methods recommended for the European Product Environmental Footprint (PEF) harmonisation initiative [17]. We took all these methods that were available in OpenLCA v.1.7.4. This resulted in the exclusion of the following PEF-recommended impact categories: Particulate Matter, Water Resource Depletion and Land Use & Soil Quality. Owing to the important land use implications of wheat substitution with peas in gin production, we represented Land Occupation with a simple metric of m²·yr of cropland required [18], using inventory data reported in Ecoinvent v3.5 [13] (Table SI8).
3. Results

Tables SI 9—SI 11 summarise life cycle inventory inputs and outputs underpinning the LCA results across 14 impact categories (Table 8) and 11 key contributory process categories. Tables SI 12–SI 15 provide results for four LCA permutations: (i) attributional LCA of gin, with pot-ale treated as a waste product; (ii) attributional LCA of gin, with allocation across gin and pot-ale as an animal feed co-product; (iii) expanded boundary LCA with pot-ale used as a bio-fertiliser substituting synthetic fertiliser; (iv) expanded-boundary LCA, with pot-ale used as an animal feed substituting soybean and barley.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dib.2019.104242.

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