Data Article

Life cycle inventory data for banana-fiber-based biocomposite lids

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A B S T R A C T

This data article is related to the research article “Comparative life cycle assessment of coffee jar lids made from biocomposites containing poly (lactic acid) and banana fiber”. The article reports the model parameters used to construct each stage and unit process inventory of the life cycle of coffee jar lids, and the subsequent inventories of the investigated system. It also contains details of calculations and descriptions of inventory uncertainties. Primary data were obtained from lab-scale and pilot-scale tests during product preparation. Secondary data collection was based on detailed review of related international and regional literature, databases and recognized web sites. The data presented here can be used by future life cycle assessment studies on natural fiber composites in packaging applications.

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Specifications table

| Subject                          | Environmental Engineering |
|---------------------------------|---------------------------|
| **Specific subject area**       | Life Cycle Assessment    |
| **Type of data**                | Table                     |
| **How data were acquired**      | Data related to the agricultural production of the raw materials, as well as transport to the factory, were obtained by means of direct questions to the appropriate technologist or responsible of the concerned stages. Transformation processes data were taken from characterization assays of materials and products, material and energy balances from laboratory and pilot tests. Regional reports, scientific literature, databases (Ecoinvent 3.3), personal communications with stakeholders and own calculations were also used to consolidate data. |
| **Data format**                 | Raw and processed.        |
| **Parameters for data collection** | Representative samples selected to characterize materials, mass and energy balance of unit processes. Data collected on-site or extracted from Ecoinvent 3.3 by using the software program SimaPro 8.3 (PRe-Consultants, the Netherlands). |
| **Description of data collection** | Much of primary data for the coffee jar lids life cycle was collected directly from real processes at laboratory and pilot scale. Supplementary primary data were collected via face-to-face, telephone and email communication and interviews with stakeholders. Secondary data were generated through trustworthy site visits, technical and academic literature and regional database analysis. |
| **Data source location**        | Universidad Nacional de Colombia sede Manizales |
| **Data accessibility**          | With the article          |
| **Related research article**    | L.J. Rodríguez, S. Fabbri, C.E. Orrego, M. Owsianiak, Comparative life cycle assessment of coffee jar lids made from biocomposites containing poly(lactic acid) and banana fiber, J. Environ. Manage., 2020, In Press [1]. |

Value of the Data

- The data increase transparency of the LCA reported in the main article.
- The data can be used by other researchers or by stakeholders that are interested in modelling of natural fiber composites in packaging applications.
- The modelling parameters and the unit process inventories can be adapted to generate similar process inventory.
- The data has Latin-American relevance, and originates mainly from Colombia.

1. Data description

This article reports the modelling parameters and the life cycle inventory data of stages for manufacturing and landfilling of coffee jar lids made from biocomposites with banana fiber. Table 1 contains all the parameters used to calculate the inventory data for each stage of the life cycle: cultivation, transport, production and preparation of the banana pseudostem, the fabrication of the lids and end of life. These parameters were based on direct measurements from laboratory and pilot tests, by asking direct questions to producers, companies, and analysis of local literature and web data. Table 1 also shows the description of the data and how the calculations were made. Tables 2–10 complement table 1 with data from the region of interest, namely the volumes of production taken from local government databases, soil characteristics and percentage of fertilizer emissions from studies of the region, transport distance from google maps and own calculations, fuel emissions from a Colombian database and electrical demand of the machines based on information from a local company and laboratory data. The tables 11–20 refer to all input and outputs flows a functional unit of 1 coffee jar lid for each process throughout the biochar life cycles constructed using model parameters given in tables 1–10. These tables include data-related uncertainties following the ecoinvent pedigree approach and the squared geometric standard deviation.
Table 1
Model parameters and data sources for foreground processes in the life cycle. Sensitivity scenario was treated BF with economic allocation between banana fruit and fiber. Biocomposite composition: 40% BF, 30% HDPE and 30% PLA. LCI data source “Banana [CO]banana production| Alloc Def, U” was improved when required according local information and conditions.

| Parameter                          | Unit     | Note                                                                                                                                  | Source                  |
|------------------------------------|----------|----------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| Agricultural production Inputs     |          |                                                                                                                                       |                         |
| Land use                           | 0.38 m²/kg/year | Estimated from measured production of banana fiber from technified banana farm. See technified cultivation [2], Average yield = 342 kg/ha. | Calculated[2]           |
| Photosynthesis                     | 26 μmol CO₂ m⁻¹ s⁻¹ | The carbon dioxide from the air and solar energy for the photosynthesis process presents maximum photosynthesis rates. | [2]                     |
| Carbon dioxide                     |          |                                                                                                                                       |                         |
| Fertilizers                        |          |                                                                                                                                       |                         |
| Urea                               | 462 kg/ha/year | The amount of fertilizers used are according to the soil studies include pH, and the content of organic matter, phosphorus, sulfur, iron, magnesium, zinc, copper and boron. These considerations depend not only on the crop under consideration but also on the climatic conditions of the soil. Table 3 show the soil characteristics of the region. | Interview/ata[3]        |
| DAP Phosphate                      | 152 kg/ha/year |                                                                                                                                       |                         |
| Potassium chloride                 | 692 kg/ha/year |                                                                                                                                       |                         |
| Organic matter                     | 4000 kg/ha/year |                                                                                                                                       |                         |
| CAL                                | 875 kg/ha/year |                                                                                                                                       |                         |
| Maintenance                        | 4.80 m²/kg/year | The maintenance is carried out by pruning 5-7 times/year. The extraction process is done by a scythe 1.07 kw fuel machine, weight of 7.5 kg, rate 1.5l/h fuel and 0.05l oil/fuel. It is estimated 1ha/day and lifetime of 10 years. | Calculated[2]           |
| Prune weeds                        | 1.56 kg/ha/year |                                                                                                                                       |                         |
| Glifosato                          | 6.87 kg/ha/year | Although, pests and diseases can be prevented with manual maintenance practices and other insects. Pesticides/ herbicides are used in necessary cases and the ultimate goal is to reduce their dependency completely. In this case they are considered some of the most used. | [3]                     |
| Mancozeb                           | 0.41 kg/ha/year |                                                                                                                                       |                         |
| Chlothalonil                       |          |                                                                                                                                       |                         |
| Output                             |          |                                                                                                                                       |                         |
| Emissions                          |          |                                                                                                                                       |                         |
| Amonia (air)                       | 22.06 % | The amount of nitrogen was calculated based on the fertilizers applied. A proportion of nitrogen is evaporated as ammoniac NH₃ to the air. Average losses of different regions were taken to perform the calculation, see Table 4 | Calculated[2]           |
| Phosphorous (water)                | 13.00 % | The amount of phosphorus was calculated based on the fertilizers applied. Losses of phosphorus are emitted to water. Average losses of different regions were taken to perform the calculation, see Table 4 | Calculated[2]           |
| Potassium (water)                  | 34.33 % | The amount of potassium was calculated based on the fertilizers applied. Losses of potassium are emitted to water. Average losses of different regions were taken to perform the calculation, see Table 4 | Calculated[2]           |
| Calcium (water)                    | 32.64 % | The amount of calcium was calculated based on the fertilizers applied. Losses of calcium are emitted to 60% to soil and 40% to water. Average losses of different regions were taken to perform the calculation, see Table 4 | Calculated[2]           |
| Magnesium (water)                  | 1.00 % | The amount of magnesium was calculated based on the fertilizers applied. Losses of magnesium are emitted to 60% to soil and 40% to water. Average losses of different regions were taken to perform the calculation, see Table 4 | Calculated[2]           |

(continued on next page)
| Parameter                                      | Unit       | Note                                                                                                                                                                                                 | Source |
|------------------------------------------------|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
| Postharvest residues Organic waste Transport 1 Distance | 0.12 tkm   | Distance corresponds to transport the pseudostem from the farms to the collecting centers of the subregions \( T_1 \). The distance \( T_1 \) was estimated by the center of gravity method. Data was calculated according to total production of pseudostem 157940 ton/year, car capacity of 1.5 tons and average distance from Table 6. | Calculated² |
| Natural gas                                    | 0.06 m³/km | The transportation of the farms corresponds to a small car of 1.4 L which has sufficient capacity for tertiary roads. Selected car of 1.5 tons capacity, is estimated to consume 10 m³/160 km. | [4]    |
| Emissions                                      |            |                                                                                                                                                                                                      |        |
| Carbon dioxide, fossil                         | Table 7 kg/m³ | The emissions are similar to a large passenger car. The CO₂ and CH₄ emissions from transportation was calculated based in the Mining Energy Planning Unit, Colombia’s energy emissions calculator. These values have been considered and used to modify some of the values of the Ecoinvent databases. | [5]    |
| Methane                                        | Table 7 kg/m³ |                                                                                                                                                                                                      | [5]    |
| Fiber production Rate production               | 20 kg/h    | The desfibrating process is done by a 10 HP fiber decorticator diesel machine, weight of 125 kg, rate production was 20kg/h and lifetime of 10 years (see Fig.1). A machine operation by diesel was selected from Ecoinvent and data were recalculated. | Measured¹ |
| Diesel                                         | 1.03E-02 l/kg² | This data was calculated based on 70 kg of wet* banana fiber extracted.                                                                                                                                 | Measured¹ |
| Emission                                       |            |                                                                                                                                                                                                      |        |
| CO₂                                            | Table 7 kg/m³ | The CO₂ emissions of diesel consume was calculated based in the Mining Energy Planning Unit, Colombia’s energy emissions calculator. These values have been considered and used to modify some of the values of the Ecoinvent databases. | [5]    |
| Washing and Drying Transport 2 Dry BF          | 5.00E-3 m³/kg² | After extraction, the fibers are submerged in water for 24 hours. wet* banana fiber                                                                                                                                 | Measured¹ |
| Diesel Emissions                                |            |                                                                                                                                                                                                      |        |
| CO₂                                            | Table 7 kg/m³ | The CO₂ emissions from transportation was calculated based in the Mining Energy Planning Unit, Colombia’s energy emissions calculator. These values have been considered and used to modify some of the values of the Ecoinvent databases. | [5]    |
| Fiber preparation Rate milling production       | Table 8 kg/h | Based on selected machine, the data of a selected ecoinvent machine was recalculated. Lifetime 20 years.                                                                                                                                 | Calculated² |
| Milling electricity demand                      | Table 8 kWh | The banana fiber were conditioned by the grinding process. The demand of electricity was calculated based on the performance of the machine at the laboratory level to two industrial machines. | Calculated² |

(continued on next page)
| Parameter                  | Unit   | Note                                                                 | Source                  |
|---------------------------|--------|----------------------------------------------------------------------|-------------------------|
| Pretreatment              |        |                                                                      |                         |
| Anhydride Acetic         | 10.80  | ml/kg                                                               | Calculated²             |
| Epiclorohydrine           | 18.30  | ml/kg                                                               | Calculated²             |
| Acetone                   | 71.19  | ml/kg                                                               | Calculated²             |
| Water                     | 10     | l/kg                                                                | Calculated²             |
| Rate drying machine       |        |                                                                      | Calculated²             |
| Drying electricity demand | Table 8| Kg/h                                                                | Calculated²             |
| Lid production            |        |                                                                      |                         |
| HDPE                      | Table 9| g/lid                                                               | Calculated²             |
| PLA                       | Table 9| g/lid                                                               | Calculated²             |
| PE-g-MA                   | 1.12   | g/lid                                                               | Calculated²             |
| Extrusion electricity     | Table 8| kWh                                                                 | Calculated²             |
| demand                    |        |                                                                      |                         |
| Injection molding         | Table 8| kWh                                                                 | Calculated²             |
| electricity demand        |        |                                                                      |                         |
| Transport to landfill     |        |                                                                      |                         |
| Lid                       | 6.7E-5 | Tkm                                                                 | Calculated²             |
| Emissions                 |        |                                                                      |                         |
| CO₂                       | Table 7| kg/m³                                                               | Ecoinvent               |
| Landfill                  | 1      | Lid                                                                 | Ecoinvent               |
| HDPE                      | 5.37   | Gr                                                                  | Ecoinvent               |
| PLA and BF                | 8.07   | Gr                                                                  | Ecoinvent               |

1 Average output of a set of standard experimental assays at lab-scale or pilot-scale.
2 Data were mathematically determined from experimental work or secondary data from reputable sources.
3 Agrosavia, Corporación Colombiana de investigación agropecuaria, 2018 Comité de cafeteros de Caldas-Manizales, 2018, and Gobernación-Caldas, 2018, Alcaldía-Manizales, 2018.
Table 2

Banana fruit and banana fiber production volume for two types of cultivation (non-technified and technified) within the selected region used for the allocation at farming stage.

| Agricultural production | Area (Ha) | Banana fruit (ton) | Fiber (ton) | Rate (%) | Banana (kg/ha) | Fiber (kg/ha) | Banana US$ millions$^1$ | Fiber US$ millions$^2$ | Source |
|-------------------------|-----------|-------------------|------------|----------|----------------|--------------|--------------------------|-------------------------|--------|
| Non-Technified          | 21359     | 235216            | 3058       | 90.26    | 11012.35       | 143.17       | 70.56                    | 6.47                    | Interview/data$^3$ and Calculated$^4$ |
| Technified              | 967       | 25390             | 330        | 9.74     | 26270.05       | 341.51       | 7.62                     | 0.70                    | |
| TOTAL                   | 22326     | 260606            | 3388       |          | 12499.48       | 162.50       | 78.18                    | 7.17                    | |

$^1$ US$ 0.3/kg banana.
$^2$ US$ 2.1/kg fiber (UVR 3000 December 2018).
$^3$ Data from various regional institutions (2018): Agrosavia, Corporación Colombiana de investigación agropecuaria; Comité de cafeteros de Caldas, Manizales; Gobernación-Caldas; Alcaldía-Manizales.
$^4$ The data was mathematically determined based on experimental measurements, or from secondary data such as literature.
Table 3
Soil characteristics of the studied region.

|        | pH  | Organic matter | Phosphorus | Sulfur | Iron  | Magnesium | Zinc  | Copper | Boron | Source                  |
|--------|-----|----------------|------------|--------|-------|-----------|-------|--------|-------|-------------------------|
| Min    | 4.85| 1.73           | 4.03       | 0.07   | 32.59 | 0.39      | 0.45  | 0.36   | 0.07  | Interview/ data¹        |
| Max    | 6.38| 5.57           | 51.71      | 16.88  | 328.96| 18.81     | 8.48  | 10.95  | 1.88  | data¹                   |

¹ Agrosavia, Corporación Colombiana de investigación agropecuaria, and Comité de cafeteros de Caldas-Manizales, 2018.

Table 4
Gaseous emissions from fertilizer components.

| Regions         | 1  | 2  | 3  | 4  | 5  | 6  | 7  | Unit | Source |
|-----------------|----|----|----|----|----|----|----|------|--------|
| Ammonia         | 7.5| 1.0| 24.7| 33.0| 70.0| 0.7| 32.0| %    | [6,7]  |
| Phosphorous     | 0  | 27.0| 43.0| 2.0 | 9.0 | 10.0| 0   | %    | [6]    |
| Potassium       | 25.0| 65.0| 22.5| 36.0|    |    |    | %    | [6]    |
| Calcium         | 70.0| 7.7 |    |    |    |    |    | %    | [6]    |
| Magnesium       |    | 1.0 |    |    |    |    |    | %    | [6]    |

Table 5
Composition of product and by-product.

| Unit          | Pseudostem | Organic waste | Measured through proximate analysis |
|---------------|------------|---------------|-------------------------------------|
| Ash (DB)¹     | %          | 9.34          | 27.43                               |
| Moisture      | %          | 12.45         | 11.09                               |
| K             | %          | 2.95          | 10.31                               |
| Ca            | %          | 1.47          | 0.46                                |
| Mg            | mg/Kg      | 1060.58       | 233.42                              |
| P             | mg P/L     | 473.53        | 447.00                              |
| Fat (DB)¹     | %          | 0.64          | 0.92                                |
| Protein (DB)¹ | %          | 0.50          | 1.06                                |
| Fiber (DB)¹   | %          | 14.95         | 5.26                                |
| Carbohydrates (DB)¹ | % | 74.60 | 65.33 | Nitrogen-free extract |

¹ DB (dry base).

Table 6
Distance to transport pseudostem from farms to collecting center of the subregions (T₁). Distance to transport banana fiber from collecting center to manufacturing plant (T₂).

| Sub region     | T₁ ¹(km) | T₂ ²(km) |
|----------------|----------|----------|
| Magdalena      | 124      | 136.0    |
| High east      | 96       | 108.0    |
| North          | 71       | 51.0     |
| South central  | 80       | 0        |
| High West      | 95       | 81.2     |
| Low West       | 50       | 55.1     |

¹ All distances are average values between farm and gathering center, mathematically determined from measured data, by using the center of gravity method.
² All distances were calculated by distance between biomass collecting point and the plant, calculated using Google maps, the data was mathematically determined based on measured data, or secondary data such as literature.

Table 7
Emission factors for fuels.

| Emission Species | CO₂     | CH₄     | Unit      |
|------------------|---------|---------|-----------|
| Natural Gas      | 1.9800  | 0.0033  | kg/m³     |
| Diesel           | 0.2837  |         | kg/m³     |

Data Source, Mine and Energy Planning Unit, Colombia’s [5].
| Process     | Consumption | Unit   | Rate  | Unit  | Source      |
|-------------|-------------|--------|-------|-------|-------------|
| Milling     | 265.50      | kWh    | 8800  | kg/h  | [8, 9]      |
| Dry         | 0.06        | kWh/kg | 160   | kg/h  | [10]        |
| Extrusion   | 0.25        | kWh/kg | 250   | kg/h  | [11]        |
| Injection   | 7.00        | kWh    | 300000| kg/h  | Interview – Local company |

Table 8

Equipment specifications for banana fiber preparation

| Blend (%) BF HDPE PLA | 1 Ld (12.9 g) BF HDPE PLA |
|-----------------------|---------------------------|
| 1                     | 10                        | 45         | 45 | 1.3 | 5.8 | 5.8 |
| 2                     | 20                        | 40         | 40 | 2.7 | 5.1 | 5.1 |
| 3                     | 30                        | 35         | 35 | 3.9 | 4.5 | 4.5 |
| 4                     | 40                        | 30         | 30 | 5.1 | 3.9 | 3.9 |
| 5                     | 40                        | 60         | 60 | 5.1 | 7.8 | 0   |
| 6                     | 40                        | 0          | 60 | 5.1 | 0   | 7.8 |

Table 9

Amount of banana fiber, HDPE and PLA per 1 lid.

Table 10

Experimental electricity demand for extrusion and injection.

| Blend (%) BF HDPE PLA | Torque Rheometer | Extrusion | Injection | Unit |
|-----------------------|-------------------|-----------|-----------|------|
| 1                     | 0.072             | 7.30E-04  | 6.01E-04  | kWh/kg |
| 2                     | 0.091             | 9.19E-04  | 7.57E-04  | kWh/kg |
| 3                     | 0.102             | 10.27E-04 | 8.46E-04  | kWh/kg |
| 4                     | 0.098             | 9.98E-04  | 8.21E-04  | kWh/kg |
| 5                     | 0.078             | 7.89E-04  | 6.49E-04  | kWh/kg |
| 6                     | 0.084             | 8.53E-04  | 7.03E-04  | kWh/kg |

Data measured during the real process and using an instrument.

2. Experimental design, materials, and methods

The parameters and inventory data of coffee jar lids were generated in three stages, cultivation of banana, fiber and lid production. Data on the cultivation stage were collected from local government and regional literature. Data on fiber production were obtained from a pilot process using approximately 1.8 tons of pseudostem collected from three farms. The banana fiber was extracted by a fiber decorticator, washed and dried. Data regarding material flows were measured with an industrial balance. Chemical components of fiber and residue were measured through proximate analysis. Transport distances between locations of the different life cycle stages were taken from Google maps and the fuel emissions from regionalized inventories [2]. The lid production was conducted at laboratory scale, the fibers were milled and chemically treated. Mass balance and time were taken and calculated. Six blends of Poly (lactic acid), PLA (0 – 60%), High Density Polyethylene, HDPE (0 – 60%), and Banana Fiber, BF (10-40%) were made in a torque rheometer as experimental process and then injected. Data on mass, energy and machine characteristics were recorded and used to calculate data for industrial machines.

3. Unit processes and LCI data

The information given here includes all input and outputs flows from each process throughout the biochar life cycles constructed using model parameters given in Section 3. Pedigree criteria and subsequent geometric standard deviations squared (σ²) underlying uncertainty analysis were described in detail in Rodríguez et al. (2020) [1].
Table 11
Inventory for the unit process of cultivation stage, output 46.62 kg pseudostem to produce 1 kg (dry banana fiber). The unit processes are representative of the farming systems in Colombian selected region. “Banana [CO] [banana production] Alloc Def, U” was the LCI data source that was modified according to model parameters of the regional conditions in Table 1. Some data were changed such as occupation land, fertilization, maintenance and emissions. Technified process including irrigation and tractor use was removed and remained data were recalculated from Ecoinvent.

| Activity | Amount | Unit | Pedigree | $\sigma^2$ | Source |
|----------|--------|------|----------|-----------|--------|
| Product  |        |      |          |           |        |
| Output pseudostem | 46.62 | kg | (1,1,1,1,1,1) | 1.1 | See Table 1 |
| Resources |        |      |          |           |        |
| Occupation, permanent crop, irrigated | 3.16E-02 | $m^2$ | (1,1,1,1,1,1) | 1.1 | See Table 1 |
| Transformation, from permanent crop, irrigated | 1.49E-03 | $m^2$ | (1,1,1,1,1,1,1) | 1.238 | Calculated based on Ecoinvent |
| Transformation, to permanent crop, irrigated | 1.49E-03 | $m^2$ | (1,1,1,1,1,1,1) | 1.238 | Calculated based on Ecoinvent |
| Carbon dioxide, in air | 4.15E-03 | kg | (1,1,1,1,1,1) | 1.113 | See Table 1 |
| Energy, gross calorific value, in biomass | 4.49E-02 | MJ | (1,1,1,1,1,1,1) | 1.117 | Ecoinvent |
| Materials/fuels |        |      |          |           |        |
| Establishing orchard [GLO] market for establishing | 2.07E-05 | | (1,1,1,1,1,1) | 1.117 | Calculated based on Ecoinvent |
| Agricultural machinery, unspecified [RoW] production | 3.32E-05 | | (1,1,1,1,1,1) | 1.117 | Calculated based on Ecoinvent |
| Agricultural machinery, tillage [RoW] production | 3.32E-05 | | (1,1,1,1,1,1) | 1.117 | Calculated based on Ecoinvent |
| Urea, as N [GLO] market for | Alloc Def, U | 1.49E-03 | kg | (1,1,1,1,1,1) | 1 | See Table 1 |
| Phosphate fertiliser, as P2O5 [GLO] market for | Alloc Def, U | 4.98E-04 | kg | (1,1,1,1,1,1) | 1 | See Table 1 |
| Potassium chloride, as K2O [RoW] potassium chloride production | Alloc Def, U | 2.16E-03 | kg | (1,1,1,1,1,1) | 1 | See Table 1 |
| Compost [RoW] treatment of biowaste, composting | Alloc Rec, U | 1.26E-02 | kg | (1,1,1,1,1,1) | 1 | See Table 1 |
| Soil pH raising agent, as CaCO3 [GLO] market for | Alloc Def, U | 2.74E-03 | kg | (1,1,1,1,1,1) | 1 | See Table 1 |
| Mowing, by motor mower [RoW] processing | Alloc Def, U | 1.06E-05 | m$^3$ | (1,1,1,1,1,1) | 1 | See Table 1 |
| Packaging, for fertilizers or pesticides [GLO] market for packaging, for fertilizers or pesticides | Alloc Def, U | 3.23E-04 | kg | (1,1,1,1,1,1) | 1.148 | Calculated based on Ecoinvent |
| Land use change, perennial crop [Co] market for land use change, perennial crop | Alloc Def, U | 1.67E-06 | ha | (1,1,1,1,1,1) | 1.238 | Calculated based on Ecoinvent |
| Packaging film, low density polyethylene [GLO] market for | Alloc Def, U | 1.04E-05 | kg | (1,1,1,1,1,1) | 1.148 | Calculated based on Ecoinvent |
| Glyphosate [GLO] market for | Alloc Def, U | 8.30E-06 | kg | (1,1,1,1,1,1) | 1 | See Table 1 |
| Mancozeb [GLO] market for | Alloc Def, U | 2.16E-05 | kg | (1,1,1,1,1,1) | 1 | See Table 1 |
| Chlorothalonil [GLO] market for | Alloc Def, U | 1.66E-06 | kg | (1,1,1,1,1,1) | 1 | See Table 1 |
| Fruit tree seeding, for planting [GLO] market for fruit tree seedling, for planting | Alloc Def, U | 9.88E-07 | p | (1,1,1,1,1,1) | 1.148 | Calculated based on Ecoinvent |
| Planting tree [GLO] market for planting tree | Alloc Def, U | 6.30E-09 | p | (1,1,1,1,1,1) | 1.148 | Calculated based on Ecoinvent |

Emissions to air

(continued on next page)
Table 11 (continued)

| Activity                          | Amount  | Unit  | Pedigree                        | $\sigma^2$ | Source                                |
|-----------------------------------|---------|-------|---------------------------------|------------|---------------------------------------|
| Ammonia                           | 2.05E-06| kg    | (1,1,1,1,1,1,2)                 | 1.228      | See Table 1                           |
| Nitrogen oxides                   | 2.51E-06| kg    | (1,1,12,1,03,1,001,1,1,4)       | 1.485      | Calculated based on Ecoinvent         |
| Dinitrogen monoxide               | 3.48E-06| kg    | (1,1,1,2,1,03,1,001,1,1,4)      | 1.485      | Calculated based on Ecoinvent         |
| Water/m3                          | 6.02E-03| m³    | (1,1,1,2,1,03,1,001,1,na)       | 1.148      | Calculated based on Ecoinvent         |
| Emissions to water                |         |       |                                 |            |                                       |
| Phosphorous (river)               | 2.76E-03| kg    | (1,1,103,1,1,1,5)               | 1.502      | See Table 1                           |
| Potassium (river)                 | 3.51E-07| kg    | (1,1,1,03,1,1,1,5)              | 1.502      | See Table 1                           |
| Calcium (river)                   | 1.12E-07| kg    | (1,1,1,03,1,1,1,5)              | 1.502      | See Table 1                           |
| Magnesium (river)                 | 3.44E-09| kg    | (1,1,1,1,1,1,5)                 | 1.50       | See Table 1                           |
| Water, CO (river)                 | 1.31E-03| m³    | (1,1,1,1,na)                    | 1.00       | 25% of water of organic waste, see Table 1. |
| Water, CO (groundwater)           | 3.93E-03| m³    | (1,1,1,1,na)                    | 1.00       | 75% of water of organic waste, see Table 1. |
| Emissions to soil                 |         |       |                                 |            |                                       |
| Calcium (agricultural)            | 1.66E-07| kg    | (1,1,1,03,1,1,na)               | 1.03       | see Table 1                           |
| Magnesium (agricultural)          | 5.15E-09| kg    | (1,1,1,03,1,1,na)               | 1.03       | see Table 1                           |
| Waste to treatment                |         |       |                                 |            |                                       |
| Postharvest residues Banana       | 4.63E-01| kg    | (1,1,1,1,na)                    | 1.00       | see Table 1 and Table 5               |
Table 12
Inventory for the pseudostem transport stage from farm to collecting center, output 1 km. The data source “Transport, passenger car, large size, natural gas, EURO 5 RoW| transport, passenger car, large size, natural gas, EURO 5 | Alloc Def, U” was selected due to emissions similar to those of current transport.

| Activity | Amount | Unit | Pedigree | $\sigma_g^2$ | Source |
|----------|--------|------|----------|-------------|--------|
| Product | Transport 1 | 1 | km | | For 1 Lid is required 1.9E-03 km |
| Materials/fuels | Natural gas, high pressure [RoW] market for | 6.25E-02 | m³ | (1,1,1,1,1,2) | 2 | See Table 1 |
| | Emissions to air | | | | | |
| Carbon dioxide, fossil | | 1.24E-06 | kg | (1,1,1,1,1,05) | 1.05 | See Table 7 |
| Methane | | 2.05E-09 | kg | (1,1,1,1,1,5) | 1.5 | See Table 7 |

Table 13
Inventory for the decortication unit process, output 1 h of wet banana fiber. Process similar to “machine operation, diesel, < 18.64 kW, generators GLO”.

| Activity | Amount | Unit | Pedigree | $\sigma_g^2$ | Source |
|----------|--------|------|----------|-------------|--------|
| Product | Output wet Banana Fiber decorticated | 1 | h | | For 1 lid is required 1.15 sec |
| Materials/fuels | Diesel [RoW] market for | 4.82E-02 | kg | (1,1,1,1,1,2) | 2.003 | See Table 1 diesel density 832kg/m³ |
| | Emissions to air | | | | | |
| Carbon dioxide | | 1.54E-00 | kg | (1,1,1,1,1,1) | 1.05 | See Table 1 and Table 7 |
| Emissions to water | Water, CO | 4.10E-02 | m³ | (1,1,1,1,1,na) | | Calculated 88% of pseudostem is water |

Table 14
Inventory for the washing and drying unit processes, output 1 kg banana fiber.

| Activity | Amount | Unit | Pedigree | $\sigma_g^2$ | Source |
|----------|--------|------|----------|-------------|--------|
| Product | Output Banana Fiber washed and Dried | 1 | kg | | For 1 lid, BF is 6.38E-03 kg |
| Resources | Water, river, CO | 2.80E-02 | m³ | (1,1,1,1,1,na) | 1 | See Table 1 |
| | Emissions to air | | | | | |
| | Water/m³ | 4.32E-03 | m³ | (1,1,1,1,1,na) | 1 | Calculated 82% of wet fiber is water |
| | Emissions to water | Water, CO | 2.80E-03 | m³ | (1,1,1,1,1,na) | 1 | Calculated 10% of used water is discarded |

Table 15
Inventory for banana fiber transport from collecting center to transformation company, output 1 tkm. “Transport, light commercial truck, diesel powered, Southeast/tkm/RNA”.

| Activity | Amount | Unit | Pedigree | $\sigma_g^2$ | Source |
|----------|--------|------|----------|-------------|--------|
| Product | Transport 2 | 1 | tkm | | For lid is required 5.48E-04 km |
| Materials/fuels | Diesel, at refinery/l/US | 0.26 | l | (1,1,1,1,1,2) | 2.003 | See Table 1 |
| | Emissions to air | | | | | |
| Carbon dioxide, fossil | | 70.03E-05 | kg | (1,1,1,1,1,1) | 1.05 | See Table 7 |
Table 16
Inventory for the milling unit process, 1 kg of banana fiber.

| Activity                                      | Amount | Unit | Pedigree            | $\sigma_2$ | Source                                                   |
|-----------------------------------------------|--------|------|---------------------|------------|----------------------------------------------------------|
| Product                                       |        |      |                     |            |                                                          |
| Output Banana Fiber Milled                    | 1      | kg   |                     |            |                                                          |
| Electricity/heat                              | 3.25E-02 | kWh | (1,1,1,1,1,1,102,1,2,na) | 1.256      | See Table 1 and 8                                        |
| Chipper, stationary, electric [GLO] market for | 1.48E-06 | p   | (1,2,1,1,1,1001,1,2,na) | 1.316      | See Table 1 and 8                                        |

Table 17
Inventory for the unit process scenarios for chemically treated banana fiber, output 1 kg.

| Activity                                      | Amount | Unit | Pedigree            | $\sigma_2$ | Source                                                   |
|-----------------------------------------------|--------|------|---------------------|------------|----------------------------------------------------------|
| Product                                       |        |      |                     |            |                                                          |
| Output Banana Fiber treated                   | 1      | kg   |                     |            |                                                          |
| Resources                                     |        |      |                     |            |                                                          |
| Water, well, in ground, CO                    | 2.16E-03 | m³  | (1,1,1,1,1,2,na)    | 1.2        | Measured                                                 |
| Acetic anhydride [RoW] market for | Alloc Def, U | 1.00E-02 | kg | (1,1,1,1,1,2,na) | 1.2 | Calculated using data in Table 1 and Table 9. Acetic anhydride density 1.08 g/cm³ |
| Epichlorohydrin [GLO] market for | Alloc Def, U | 9.00E-03 | kg | (1,1,1,1,1,2,na) | 1.2 | Calculated using data in Table 1 and Table 9. Epichlorohydrin density 1.18 g/cm³ |
| Acetone, liquid [GLO] market for | Alloc Def, U | 9.00E-02 | kg | (1,1,1,1,1,2,na) | 1.2 | Calculated using data in Table 1 and Table 9. Acetone density 784 kg/m³ |
| Packaging glass, white [GLO] market for | Alloc Def, U | 1.70E-03 | kg | (1,1,1,1,1,2,na) | 1.2 | Calculated                                                 |
| Emissions to air                              |        |      |                     |            |                                                          |
| Water/m3                                      | 2.14E-04 | m³  | (1,1,1,1,1,2,na)    | 1.2        | Measured                                                 |
| Waste/water, average [Europe without Switzerland] treatment of wastewater, average, capacity 1E9/year | 1.93E-03 | m³ | (1,2,1,1,1,1,1,1,2,na) | 2.261 | Measured                                                 |

Table 18
Inventory for the drying unit process, 1 kg of banana fiber.

| Activity                                      | Amount | Unit | Pedigree            | $\sigma_2$ | Source                                                   |
|-----------------------------------------------|--------|------|---------------------|------------|----------------------------------------------------------|
| Product                                       |        |      |                     |            |                                                          |
| Output Banana Fiber Dried                     | 1      | kg   |                     |            |                                                          |
| Electricity/heat                              | 6.00E-02 | kWh | (1,1,1,1,1,1,02,1,2,na) | 1.256      | See Table 1 and 8                                        |
| Technical wood drying facility [RoW] market for | 1.87E-07 | p   | (1,2,1,1,1,1,001,1,2,na) | 1.316      | See Table 1 and 8                                        |
| Water/m3                                      | 9.33E-05 | m³  | (1,1,1,1,1,na)      | 1          | Measured                                                 |
Table 19
Inventory for the extrusion unit process, 1 kg of biocomposite. Scenario: 40% banana fiber, 30% HDPE and 30% PLA. Production by extrusion and thermoforming of plastic sheets. [CA-QC] production | Alloc Def, U and Injection molding [CA-QC], injection molding | Alloc Def, U.

| Activity                                      | Amount | Unit | Pedigree       | $\sigma^2$ | Source                           |
|-----------------------------------------------|--------|------|----------------|-----------|----------------------------------|
| Production of lids                            | 1      | lid  |                |           |                                  |
| Extrusion                                     | 3.90E-03 | kg  | (1,1,1,1,1,na) | 1         | Ecoinvent see Table 1            |
| Polyethylene, high density, granulate [GLO]   | 3.90E-03 | kg  | (1,1,1,1,1,na) | 1         | Ecoinvent see Table 1            |
| Polyactide, granulate [GLO]                   | 1.12E-03 | kg  | (1,1,1,1,1,na) | 1         | Ecoinvent see Table 1            |
| Maleic anhydride [GLO]                        | 5.10E-03 | kg  | (1,1,1,1,1,na) | 1         | Ecoinvent see Table 1            |
| Banana Fiber                                  | 9.98E-04 | kWh | (1,1,1,1.02,1.2,na) | 1.21     | See Table 8 and 10              |
| Electricity/heat                              | 8.21E-04 | kWh | (1,1,1,1.02,1.2,na) | 1.21     | See Table 8 and 10              |

Table 20
Inventory for the transport stage of disposable lids to landfill, output 1 km. “Transport, truck 10-20t, EURO5, 100%LF, empty return/GLO Mass”.

| Activity                                      | Amount | Unit | Pedigree       | $\sigma^2$ | Source                           |
|-----------------------------------------------|--------|------|----------------|-----------|----------------------------------|
| Transport to landfill                         | 1      | tkm  |                |           | For 1 Lid is required 6.7E-05    |
| Materials/fuels                               | 5.98E-02 | kg  | (1,1,1,1,1,2)  | 2.003     | Ecoinvent                       |
| Diesel, from crude oil, consumption mix, at refinery | 1.93E-06 | kg  | (1,1,1,1,1,1)  | 1.05      | See Table 7                     |

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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.
References

[1] L.J. Rodríguez, S. Fabbri, C.E. Orrego, M. Owsianiak. Comparative life cycle assessment of coffee jar lids made from biocomposites containing poly(lactic acid) and banana fiber, J. Environ. manage. (2020).

[2] J.L. Barrera Violeth, C.E. Cardona Ayala, D. Cayón Salinas, El cultivo de plátano (musa aab simmonds): Ecofisiología y manejo cultural sostenible, 2011.

[3] N.A. Colmenares, Caribbean Environment Programme. Mejorando el manejo de plaguicidas agrícolas en Colombia, Costa Rica y Nicaragua (2012).

[4] I.E. Torrico Silva, Natural gas vs. Gasoline: the user decides, https://www.elmundo.com/portal/noticias/economia/gas_versus_gasolina_decide_el_usuario.php#.XjycQhNKgWo, 2016 (accessed August 2018).

[5] Unidad de Planeación Minero Energética UPME. http://www.upme.gov.co (accessed January 20 2019).

[6] S. Sadeghian Khalajabadi, H. González Osorio, E. Arias Suárez, Lixiviación de nutrientes en los suelos de la zona cafetera-Prácticas que ayudan a reducirla, Cenicafé, Boletín Técnico No. 40 (2015).

[7] L.A. Leal-Varón, A. Salamanca-Jiménez, S. Sadeghian-Khalajabadi, Pérdidas de Nitrógeno por volatización en cafetales en etapa productiva, Cenicafé 58 (2007) 216–226.

[8] Simec Force Feeding Hammer Mill, http://www.simecpellet.com/product/size_reduction_equipment/force_feeding_hammer_mill.html, 2018 (accessed December 10 2018).

[9] Simec Ultra Micro Pulverizer, http://www.simecpellet.com/product/size_reduction_equipment/ultra_micro_pulverizer.html, 2018 (accessed December 10 2018).

[10] Summit Systems Plastics Automation, Rotor Wheel Dryer, https://www.summitsystems.co.uk/wp-content/uploads/2018/01/Rotor-Wheel-Dryer-Vismec-Drywell-Dryplus-Range.pdf, 2018 (accessed December 10, 2018).

[11] Useon Counter-rotating Twin Screw Extruder, https://www.summitsystems.co.uk/wp-content/uploads/2018/01/Rotor-Wheel-Dryer-Vismec-Drywell-Dryplus-Range.pdf, 2018 (accessed December 10, 2018).