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Development and Submission of Life Cycle Inventory Data for Bamboo-Based Construction Materials

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The International Bamboo and Rattan Organisation

The International Bamboo and Rattan Organisation, INBAR, is an intergovernmental organisation dedicated to the promotion of bamboo and rattan for sustainable development.

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1. Introduction

This project was carried out in collaboration between INBAR Construction Task Force, Ecoinvent Association and CCRS at the University of Zürich. The present technical report, presents the process of data submission to the life cycle inventories database ecoinvent. These data represent the production of five bamboo-based construction materials. The values used represent a wide variety of production practices encountered around the world. The values need to be understood as baselines, that should be updated if the user/ practitioners possess more accurate data. The inclusion of these datasets on ecoinvent is a significant step not only to increase the availability of data of bio-based materials but also towards the harmonization of LCIA data of these products.

Life cycle assessment (LCA) is the main method used to evaluate the environmental impacts of products and services. LCA proposes an input-output relationship between human activities and the environment. The results of the assessment can be used to optimise production lines by identifying environmental hotspots. The information highlights the steps in production where innovation is required, helping to increase both the effectiveness of the optimisation process and the returns on investment in these processes. The use of LCA presents several methodological challenges, notably the lack of representative datasets. For example, datasets for bamboo-based construction materials (BBCM) are not included in the LCA databases. Practitioners and scientists have to create their own datasets, and as a consequence, the results have low reliability due to the lack of consistent methodological approaches and peer review. One of the main reasons for the lack of BBCM datasets is the complexity and inherent high cost (Hellweg and Canals, 2014) of the data generation process. To overcome this barrier, Zea et al developed a methodological approach to generate the datasets for five BBCM (Zea Escamilla and Habert, 2014). These datasets had been used in several research projects and their associated publications (Archila et al, 2018, Zea Escamilla et al, 2018, Zea Escamilla et al, 2016), but they had never been submitted to an international LCA database.

ecoinvent (Association 2020) is the most-used LCA database and has the largest dataset. This database is managed by a non-profit organisation of the same name. The database is provided under license for practitioners and researchers in Organisation for Economic Co-operation and Development (OECD) countries, with discounted prices for education and research and as freeware to non-OECD countries. These datasets are important for supporting research activities related to bamboo construction, and they are fundamental for the development of Environmental Product Declarations (EDP) and Product Environmental Footprints (PEF), which are required for the products to enter European markets.

2. Methodology

2.1. Goal

The main goal of this project is to prepare and submit to the LCA database ecoinvent a series of datasets representing the production of BBCM. The project will be divided into five steps: (i) data validation, (ii) preparation of datasets, (iii) submission to LCA database, (iv) revision and publication, and (v) communication and dissemination.

2.2. Data Validation

The work of Zea & Habert (2014) will provide the main structure and inputs for this process. To increase the accuracy of the submitted data, we will validate the data using the DELPHI method with the support of selected members of the Bamboo Construction Task Force and other experts from INBAR.

2.3. Preparation of Datasets

We will work closely with those responsible for data submission in ecoinvent to prepare the datasets following all their requirements. We will use the software ecoeditor to prepare the datasets of five BBCM following the structure proposed by Zea & Habert (2014): (i) bamboo pole, (ii) flattened bamboo, (iii) woven bamboo mat, (iv) glue laminated bamboo, and (v) glue laminated bamboo mat. The names will be adjusted based on the nomenclature proposed by Liu et al (2015) and the naming rules from ecoinvent.

2.4. Submission to LCA Database

We will support the submission process and prepare the metadata required to complete the information on all submitted datasets. The submission process is peer-reviewed, which will require that we answer to reviewers and adjust the datasets according to reviewer and database recommendations. Once the datasets are accepted and incorporated into the database, we will promote and communicate the process through lectures, conferences, and social media.

3. Results

In this section we summarise the development of the datasets and present the methodological decisions taken during the modelling process. The datasets can be accessed through the ecoinvent database from 2021 in version 3.8 and later. In this report the input data (exchanges) will be reported; the full set of data is registered in the datasets and the accompanying .XLSX file.

During the development process of the datasets, it became clear that it was possible to adjust sets to represent the use of different bamboo species and the production practices in different countries. Therefore, five sets of data were developed: (i) China – ***Phyllostachys edulis***; (ii) Colombia – ***Guadua angustifolia kunt***; (iii) Philippines – ***Bambusa blumeana***; (iv) Brazil – ***Dendrocalamus asper***; and (v) global. The last set was developed by the database using information from all the other sets. The global set is useful in cases where either the bamboo species or the country of production is unknown. The datasets are divided into three groups: the production of bamboo culms; the production of low industrialised bamboo-based materials, like bamboo poles; and the production of industrialised materials like glue laminated bamboo. The product flow for the different BBCM is presented in Figure1. From this figure we can see how some materials are inputs for more industrialised materials or can be used directly in the built environment. Figure 2 presents an example of each BBCM.

It is important to note that the datasets for each country have a high degree of similarity, as we tried to represent an average production process. Nevertheless, relevant factors, such as the land use for each bamboo species, are represented. Moreover, the electricity used in the production process is represented by the electricity mix for each country. Finally, calculations for potential transport distances were also developed and are included in the database for calculations. These differences are not obvious in this document, but they have a significant impact once the datasets are evaluated and the environmental impacts calculated.

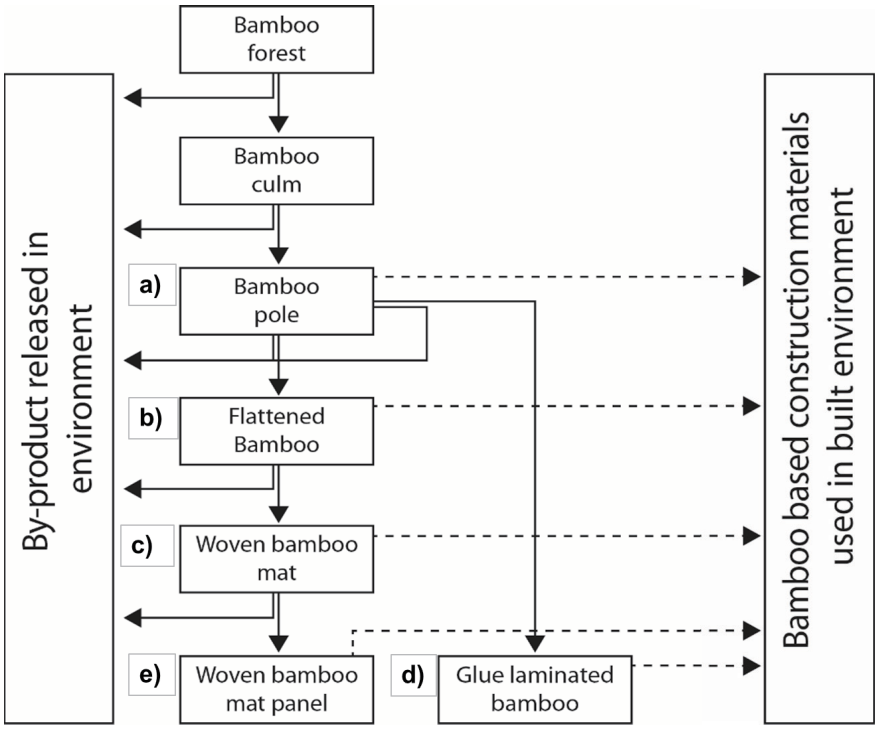

Figure 1. Bamboo-based construction materials product flow (Zea Escamilla and Habert, 2014)

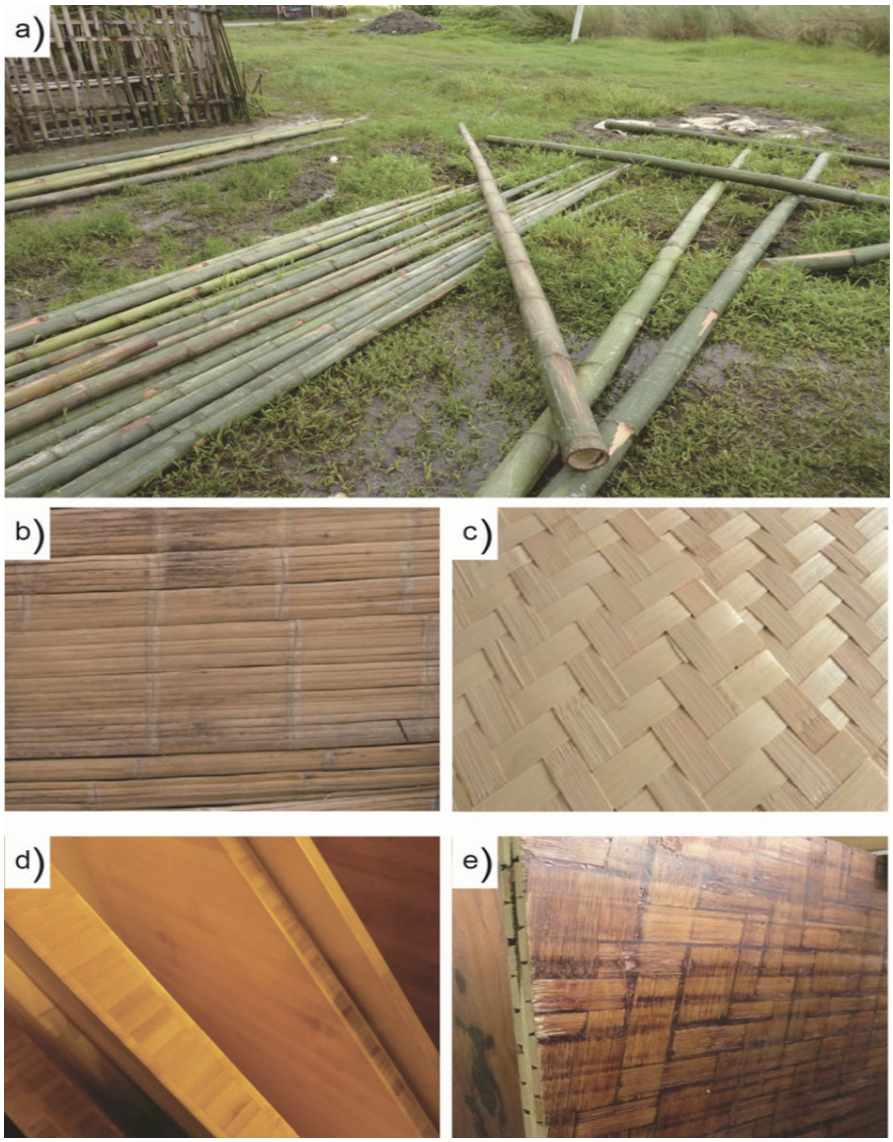

Figure 2. Bamboo-based construction materials (Zea Escamilla, 2016).
a) Bamboo pole, b) flattened bamboo, c) woven bamboo mat,
d) glue laminated bamboo, e) glue laminated woven bamboo mat panel

3.1. China – *Phyllostachys edulis*

These were the first datasets developed, as the most updated information can be found from China. The datasets represent an industrialised production of materials and extraction of materials from a sustainably managed bamboo forest. This model uses technical drying facilities and generates energy from bamboo trims to fuel the drying process. The model uses the electricity mix for China, and the potential transport distances were calculated using the method developed by Zea & Habert (2016). Tables 1 through 6 present the input values used to model each BBCM.

Table 1. Bamboo culm LCI, CN

	Flow	Unit	Amount
Output	Bamboo culm	kg	1.00E+00
	Carbon dioxide, fossil	kg	3.38E-03
	Flow	**Unit**	**Amount**
Input	Carbon dioxide, in air	kg	1.01E+00
	Occupation, forest, intensive	m^2*a	5.44E-01
	Phosphate fertiliser, as P_2O_5	kg	1.02E-02
	Potassium chloride, as K_2O	kg	1.12E-03
	Power sawing, with catalytic converter	h	3.33E-04
	Transformation, from pasture, man-made	m^2	2.72E-02
	Transformation, to forest, intensive	m^2	2.72E-02
	Urea, as N	kg	4.61E-03
	Wood, unspecified, standing	m^3	3.17E-03

Table 2. Bamboo pole LCI, CN

	Flow	Unit	Amount
Output	Bamboo pole	kg	1.00E+00
	Sawdust, wet, measured as dry mass	kg	3.03E-02
	Water	m^3	5.00E-04
	Flow	**Unit**	**Amount**
Input	Agricultural machinery, unspecified	kg	6.09E-07
	Air compressor, screw-type compressor, 300kW	Item(s)	4.64E-06
	Bamboo culm	kg	1.53E+00
	Boric acid, anhydrous, powder	kg	1.90E-04
	Electricity, high voltage, CN	kWh	3.00E-01
	Heat, central or small-scale, natural gas	MJ	2.42E-01
	Power sawing, with catalytic converter	h	5.10E-04
	Technical wood drying facility	Item(s)	6.09E-07

Table 3. Flattened bamboo LCI, CN

	Flow	Unit	Amount
Output	Bamboo flattened	kg	1.00E+00
	Bamboo trims	kg	2.50E-01
	Flow	**Unit**	**Amount**
Input	Bamboo pole	kg	1.25E+00

Table 4. Woven bamboo mat, CN

	Flow	Unit	Amount
Output	Bamboo mat woven	kg	1.00E+00
	Bamboo trims	kg	6.97E-02
Input	**Flow**	**Unit**	**Amount**
	Bamboo flattened	kg	1.07E+00

Table 5. Glue laminated bamboo, CN

	Flow	Unit	Amount
Output	Bamboo Glue Laminated	m^3	1.00E+00
	Bamboo trims	kg	2.19E-02
	Glued laminated bamboo panel trims	kg	1.40E-01
	Water	m^3	1.66E-01
Input	**Flow**	**Unit**	**Amount**
	Bamboo Pole	kg	2.33E+03
	Electricity, high voltage, CN	kWh	4.87E+02
	Furnace, wood chips, with silo, 300kw	unit	5.53E+01
	Melamine formaldehyde resin	kg	6.25E-02
	Sawmill	Item(s)	4.86E-04
	Wooden board factory, organic bonded boards	Item(s)	3.33E-08

Table 6. Glue laminated woven bamboo mat panel, CN

	Flow	Unit	Amount
Output	Bamboo Mat Woven Panel	m^3	1.00E+00
	Glued laminated bamboo panel trims	kg	4.61E+01
	Water	m^3	6.19E-02
Input	**Flow**	**Unit**	**Amount**
	Bamboo Mat Woven	kg	7.85E+02
	Electricity, medium voltage CN	kWh	2.61E+02
	Furnace, wood chips, with silo, 300kw	unit	8.38E-07
	Melamine formaldehyde resin	kg	4.94E+01
	Wooden board factory, organic bonded boards	Item(s)	3.33E-08

3.2. Colombia – *Guadua angustifolia kunt*

These datasets represent an industrialised production of materials and extraction of materials from a sustainably managed natural bamboo forest. This model uses technical drying facilities and generates energy from bamboo trims to fuel the drying process. The model uses the electricity mix for Colombia, and the potential transport distances were calculated using the method developed by Zea & Habert (2016). Tables 7 through 12 present the input values used to model each BBCM.

Table 7. Bamboo culm LCI, CO

	Flow	Unit	Amount
Output	Bamboo culm	kg	1.00E+00
	Carbon dioxide, fossil	kg	3.38E-03
	Flow	**Unit**	**Amount**
Input	Carbon dioxide, in air	kg	1.01E+00
	Occupation, forest, intensive	m^2*a	3.27E-01
	Phosphate fertiliser, as P_2O_5	kg	0.00E+00
	Potassium chloride, as K_2O	kg	0.00E+00
	Power sawing, with catalytic converter	h	3.33E-04
	Transformation, from pasture, man-made	m^2	1.63E-02
	Transformation, to forest, intensive	m^2	1.63E-02
	Urea, as N	kg	0.00E+00
	Wood, unspecified, standing	m^3	8.41E-03

Table 8. Bamboo pole LCI, CO

	Flow	Unit	Amount
Output	Bamboo pole	kg	1.00E+00
	Sawdust, wet, measured as dry mass	kg	3.03E-02
	Water	m^3	5.00E-04
	Flow	**Unit**	**Amount**
Input	Agricultural machinery, unspecified	kg	6.09E-07
	Air compressor, screw-type compressor, 300kW	Item(s)	4.64E-06
	Bamboo culm	kg	1.53E+00
	Boric acid, anhydrous, powder	kg	1.90E-04
	Electricity, high voltage, CO	kWh	3.00E-01
	Heat, central or small-scale, natural gas	MJ	2.42E-01
	Power sawing, with catalytic converter	h	5.10E-04
	Technical wood drying facility	Item(s)	6.09E-07

Table 9. Flattened bamboo LCI, CO

	Flow	Unit	Amount
Output	Bamboo flattened	kg	1.00E+00
	Bamboo trims	kg	2.50E-01
Input	**Flow**	**Unit**	**Amount**
	Bamboo pole	kg	1.25E+00

Table 10. Woven bamboo mat, CO

	Flow	Unit	Amount
Output	Bamboo mat woven	kg	1.00E+00
	Bamboo trims	kg	6.97E-02
Input	**Flow**	**Unit**	**Amount**
	Bamboo flattened	kg	1.07E+00

Table 11. Glue laminated bamboo, CO

	Flow	Unit	Amount
Output	Bamboo Glue Laminated	m^3	1.00E+00
	Bamboo trims	kg	2.19E-02
	Glued laminated bamboo panel trims	kg	1.40E-01
	Water	m^3	1.66E-01
Input	**Flow**	**Unit**	**Amount**
	Bamboo Pole	kg	2.33E+03
	Electricity, high voltage, CO	kWh	4.87E+02
	Furnace, wood chips, with silo, 300kw	unit	5.53E+01
	Melamine formaldehyde resin	kg	6.25E-02
	Sawmill	Item(s)	4.86E-04
	Wooden board factory, organic bonded boards	Item(s)	3.33E-08

Table 12. Glue laminated woven bamboo mat panel, CO

	Flow	Unit	Amount
Output	Bamboo Mat Woven Panel	m^3	1.00E+00
	Glued laminated bamboo panel trims	kg	4.61E+01
	Water	m^3	6.19E-02
Input	**Flow**	**Unit**	**Amount**
	Bamboo Mat Woven	kg	7.85E+02
	Electricity, medium voltage CO	kWh	2.61E+02
	Furnace, wood chips, with silo, 300kw	unit	8.38E-07
	Melamine formaldehyde resin	kg	4.94E+01
	Wooden board factory, organic bonded boards	Item(s)	3.33E-08

3.3. Brazil – *Dendrocalamus asper*

These datasets represent an industrialised production of materials and extraction of materials from a natural wild bamboo forest. This model does not use technical drying facilities; drying is usually done through natural processes. The model uses the electricity mix for Brazil, and the potential transport distances were calculated using the method developed by Zea & Habert (2016). Tables 13 through 18 present the input values used to model each BBCM.

Table 13. Bamboo culm LCI, BR

	Flow	Unit	Amount
Output	Bamboo culm	kg	1.00E+00
	Carbon dioxide, fossil	kg	3.38E-03
	Flow	**Unit**	**Amount**
Input	Carbon dioxide, in air	kg	1.01E+00
	Occupation, forest, intensive	m^2*a	2.04E-01
	Phosphate fertiliser, as P_2O_5	kg	0.00E+00
	Potassium chloride, as K_2O	kg	0.00E+00
	Power sawing, with catalytic converter	h	3.33E-04
	Transformation, from pasture, man-made	m^2	1.02E-02
	Transformation, to forest, intensive	m^2	1.02E-02
	Urea, as N	kg	0.00E+00
	Wood, unspecified, standing	m^3	8.77E-03

Table 14. Bamboo pole LCI, BR

	Flow	Unit	Amount
Output	Bamboo pole	kg	1.00E+00
	Sawdust, wet, measured as dry mass	kg	3.03E-02
	Water	m^3	5.00E-04
	Flow	**Unit**	**Amount**
Input	Agricultural machinery, unspecified	kg	6.09E-07
	Air compressor, screw-type compressor, 300kW	Item(s)	4.64E-06
	Bamboo culm	kg	1.53E+00
	Boric acid, anhydrous, powder	kg	1.90E-04
	Electricity, high voltage, BR	kWh	3.00E-01
	Heat, central or small-scale, natural gas	MJ	2.42E-01
	Power sawing, with catalytic converter	h	5.10E-04
	Technical wood drying facility	Item(s)	6.09E-07

Table 15. Flattened bamboo LCI, BR

	Flow	Unit	Amount
Output	Bamboo flattened	kg	1.00E+00
	Bamboo trims	kg	2.50E-01
Input	**Flow**	**Unit**	**Amount**
	Bamboo pole	kg	1.25E+00

Table 16. Woven bamboo mat, BR

	Flow	Unit	Amount
Output	Bamboo mat woven	kg	1.00E+00
	Bamboo trims	kg	6.97E-02
Input	**Flow**	**Unit**	**Amount**
	Bamboo flattened	kg	1.07E+00

Table 17. Glue laminated bamboo, BR

	Flow	Unit	Amount
Output	Bamboo Glue Laminated	m^3	1.00E+00
	Bamboo trims	kg	2.19E-02
	Glued laminated bamboo panel trims	kg	1.40E-01
	Water	m^3	1.66E-01
Input	**Flow**	**Unit**	**Amount**
	Bamboo Pole	kg	2.33E+03
	Electricity, high voltage, BR	kWh	4.87E+02
	Furnace, wood chips, with silo, 300kw	unit	5.53E+01
	Melamine formaldehyde resin	kg	6.25E-02
	Sawmill	Item(s)	4.86E-04
	Wooden board factory, organic bonded boards	Item(s)	3.33E-08

Table 18. Glue laminated woven bamboo mat panel, BR

	Flow	Unit	Amount
Output	Bamboo Mat Woven Panel	m^3	1.00E+00
	Glued laminated bamboo panel trims	kg	4.61E+01
	Water	m^3	6.19E-02
Input	**Flow**	**Unit**	**Amount**
	Bamboo Mat Woven	kg	7.85E+02
	Electricity, medium voltage BR	kWh	2.61E+02
	Furnace, wood chips, with silo, 300kw	unit	8.38E-07
	Melamine formaldehyde resin	kg	4.94E+01
	Wooden board factory, organic bonded boards	Item(s)	3.33E-08

3.4. Philippines – *Bambusa blumeana*

These datasets represent an industrialised production of materials and extraction of materials from a sustainably managed bamboo forest. This model does not use technical drying facilities; drying is usually done through natural processes. The model uses the electricity mix for the Philippines, and the potential transport distances were calculated using the method developed by Zea & Habert (2016). Tables 19 through 24 present the input values used to model each BBCM.

Table 19. Bamboo culm LCI, PH

	Flow	Unit	Amount
Output	Bamboo culm	kg	1.00E+00
	Carbon dioxide, fossil	kg	3.38E-03
	Flow	**Unit**	**Amount**
Input	Carbon dioxide, in air	kg	1.01E+00
	Occupation, forest, intensive	m^2*a	4.08E-01
	Phosphate fertiliser, as P_2O_5	kg	1.02E-02
	Potassium chloride, as K_2O	kg	1.12E-03
	Power sawing, with catalytic converter	h	3.33E-04
	Transformation, from pasture, man-made	m^2	2.04E-02
	Transformation, to forest, intensive	m^2	2.04E-02
	Urea, as N	kg	4.61E-03
	Wood, unspecified, standing	m^3	2.69E-03

Table 20. Bamboo pole LCI, PH

	Flow	Unit	Amount
Output	Bamboo pole	kg	1.00E+00
	Sawdust, wet, measured as dry mass	kg	3.03E-02
	Water	m3	5.00E-04
	Flow	**Unit**	**Amount**
Input	Agricultural machinery, unspecified	kg	6.09E-07
	Air compressor, screw-type compressor, 300kW	Item(s)	4.64E-06
	Bamboo culm	kg	1.53E+00
	Boric acid, anhydrous, powder	kg	1.90E-04
	Electricity, high voltage, PH	kWh	3.00E-01
	Heat, central or small-scale, natural gas	MJ	0.00E+00
	Power sawing, with catalytic converter	h	5.10E-04

Table 21. Flattened bamboo LCI, PH

	Flow	Unit	Amount
Output	Bamboo flattened	kg	1.00E+00
	Bamboo trims	kg	2.50E-01
Input	**Flow**	**Unit**	**Amount**
	Bamboo pole	kg	1.25E+00

Table 22. Woven bamboo mat, PH

	Flow	Unit	Amount
Output	Bamboo mat woven	kg	1.00E+00
	Bamboo trims	kg	6.97E-02
Input	**Flow**	**Unit**	**Amount**
	Bamboo flattened	kg	1.07E+00

Table 23. Glue laminated bamboo, PH

	Flow	Unit	Amount
Output	Bamboo Glue Laminated	m^3	1.00E+00
	Bamboo trims	kg	2.19E-02
	Glued laminated bamboo panel trims	kg	1.40E-01
	Water	m^3	1.66E-01
Input	**Flow**	**Unit**	**Amount**
	Bamboo Pole	kg	2.33E+03
	Electricity, high voltage, PH	kWh	4.87E+02
	Furnace, wood chips, with silo, 300kw	unit	5.53E+01
	Melamine formaldehyde resin	kg	6.25E-02
	Sawmill	Item(s)	4.86E-04
	Wooden board factory, organic bonded boards	Item(s)	3.33E-08

Table 24. Glue laminated woven bamboo mat panel, PH

	Flow	Unit	Amount
Output	Bamboo Mat Woven Panel	m^3	1.00E+00
	Glued laminated bamboo panel trims	kg	4.61E+01
	Water	m^3	6.19E-02
Input	**Flow**	**Unit**	**Amount**
	Bamboo Mat Woven	kg	7.85E+02
	Electricity, medium voltage PH	kWh	2.61E+02
	Furnace, wood chips, with silo, 300kw	unit	8.38E-07
	Melamine formaldehyde resin	kg	4.94E+01
	Wooden board factory, organic bonded boards	Item(s)	3.33E-08

4. How to Use the Datasets

The best approach for using this data is with the use of LCA software, like the freeware openLCA (GD, 2017) and the database ecoinvent. ecoinvent grants free access to users in non-OECD countries. It is important to note that these sets represent a wide range of production practices found in each country. Nevertheless, a user can adapt these sets to better represent either their production process or their object of study. These datasets provide a solid foundation when there are unknowns in the data and serve as a frame for the development of new and more accurate sets. It is important to use these sets in combination with adequate LCA evaluation methods. Many methods are not designed for bio-based materials or bamboo-producing countries which makes them not suitable for this kind of assessment. We recommend using the method from the intergovernmental panel for climate change IPCC20XX (current available version 2013) (Edenhofer et al, 2014). These sets are useful for understanding the environmental ot-spots" in the production process of bamboo-based materials. Moreover, the information generated with these sets can help in the optimisation and innovation processes within the bamboo value chain. Finally, these sets can be used in comparative studies. It is of great importance to have an experienced LCA practitioner to support these kinds of process, as they present significant methodological challenges.

A second option for using this data is with the accompanying XLSX calculation tool. This tool is aimed toward academic use and basic understanding of the LCA methodology, not for certification or environmental declaration processes. The basic tool represents a simplified LCA calculation, where each input is assigned a unit value of environmental impact. These impacts were pre-calculated using the software openLCA, the database ecoinvent 3.7, and the evaluation method IPCC2013. The input values can be updated by the user to the best of their knowledge; if a process is not used it can be set at zero. The results will present the environmental impact or carbon footprint for the whole material as well as for each of its input processes.

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