Environmental Product Declaration

In accordance with ISO 14025 for:

Citaro G hybrid bus

from

EvoBus GmbH

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Programme information

Programme:	The International EPD® System EPD International AB Box 210 60 SE-100 31 Stockholm Sweden www.environdec.com info@environdec.com

Accountabilities for PCR, LCA and independent, third-party verification
Product Category Rules (PCR)
PCR2016:04 – UN CPC 49112 & 49113, Public and private buses and coaches. Version 2.0
PCR review was conducted by: *The Technical Committee of the International EPD© System. See www.environdec.com/about-us/the-international-epd-systemabout- the-system for a list of members.* *Review chair:* Maurizio Feschi*. The review panel may be contacted via info@environdec.com.*
Life Cycle Assessment (LCA)
LCA accountability: *Sphera Solutions GmbH https://sphera.com/*
Third-party verification
Independent third-party verification of the declaration and data, according to ISO 14025:2006, via: ☒ EPD verification by individual verifier Third-party verifier: *Angela Schindler, Umweltberatung und Ingenieurdienstleistungen* Approved by: The International EPD® System

Company information

Owner of the EPD:

EvoBus GmbH
70771 Leinfelden-Echterdingen
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Description of the organisation:

EvoBus GmbH is Daimler Truck AG's largest European subsidiary. With the brands Mercedes-Benz, Setra, OMNIplus and BusStore, EvoBus is the leading full-line provider in the European bus market and has a global presence, as well. EvoBus has continued to develop and has positioned itself viably for the future. As part of the Daimler Truck Buses business unit, EvoBus is not only Europe's largest bus manufacturer but also one of the leading bus manufacturers worldwide.

Product-related or management system-related certifications:

EvoBus's business management system is certified according to the following standard:

ISO 9001 – Quality management systems

Name and location of production site:

EvoBus is geographically diversified with production sites located in central Europe. The headquarter is in Leinfelden-Echterdingen, Germany.

Product information

Product name: EvoBus Citaro G hybrid
(18 m articulated city bus)

Product identification:

The Citaro G hybrid was specially developed for the demands of regular-service bus routes in urban conurbations and stands for contemporary mobility with reduced consumption. The economical diesel engine is assisted by the additional drive power of a highly efficient, compact hybrid module. The 14 kW electric motor generates energy when coasting and braking. It therefore assists the diesel engine when pulling away. Depending on use, this can reduce the fuel consumption by up to 8.5 percent.

The base function of the Citaro G hybrid is very simple: the disc-shaped and very robustly constructed electric motor is integrated between the combustion engine and automatic transmission. Amongst other things, it works as an alternator during the deceleration of the bus and converts coasting energy into electricity – when braking and when the driver removes their foot from the accelerator. The generated power is stored as electrical energy. Without hybrid technology this energy gained in the recuperation phase would be lost – the Citaro G hybrid uses it and therefore saves as soon as the bus pulls off, the electric motor supports the diesel engine with additional torque – the so-called boost phase. In this way the combustion engine momentarily has to provide less output when pulling away and therefore saves fuel. In addition, the electric motor provides support during idling. This improves the efficiency of the combustion engine and contributes towards a significantly reduced fuel consumption and therefore reduced emissions.
The electric motor does not serve to increase the maximum power. That's why the output and

torque of the Citaro G hybrid remain unchanged compared to a combustion-engine vehicle of the same type and rating. The engine speed of the combustion engine is not reduced in the boost phase. Only the peak performance is imperceptibly reduced and enhanced by the electric motor.
The interplay of combustion engine for the base load and electric motor for peak loads ensures a high level of energy efficiency of the drive system when driving. The components designed for greatly varying loads are constructed in a very robust manner. Their high durability is comparable with those of conventional combustion-engine powertrains. The electric motor is water-cooled and can provide a torque of up to 220 Nm.
The efficiency-optimised lightweight running axle also contributes to increased efficiency in the Citaro G hybrid: on the one hand, through fuel savings due to the lower running resistance, and on the other, through less maintenance and a prolonged maintenance interval from 180 000 to 240 000 km.
In addition, the intelligent eco steering electrohydraulic steering system also contributes to high energy efficiency. It works in a way that is requirements-optimised, while contributing to reduced fuel consumption in public service applications.
To carry out the life cycle analysis of the vehicle, it is necessary to fix a specific vehicle configuration for every bus considered. The technical features are detailed in the next section.

Product description:
The analysed vehicle is the Citaro G hybrid Model – a 18 m articulated city bus with four doors and a capacity for 140 passengers.

Table 1: Technical description of the vehicle

Group	Concept	Value
Chassis	Denomination	Citaro G hybrid (4 doors)
	Length	18 125 mm
	Width (mirrors incl.)	2 950 mm
	Height	3 350 mm
	Capacity	140 Passengers
	Driver cabin position	Front
Diesel Engine	Denomination	OM 936 h
	Fuel	Diesel
	Nominal power	260kW
	Maximum torque	1 400 Nm
	Cylinders	6
	Emission compliance	Euro 6
	Engine position	Rear
Electric Engine	Denomination	eMachine
	Nominal power	14 kW
	Maximum torque	220 Nm
	Engine position	between the diesel engine and the transmission in a mounting flange (spacer)
Axles	Axles	3
	Wheels	6
	Front axle load (max)	7 500 kg
	Middle axle load (max)	10 000 kg
	Rear axle load (max)	13 000 kg
	Distance between axles	5 900 mm / 5 990 mm
	Front overhang	2 805 mm
	Rear overhang	3 430 mm
Steering control	Denomination	ZF Power steering
	Maximum front axle turning angle, inside/outside wheel	53° / 46°
	Minimum turning cycle	22 970 mm

Energy Storage System	Denomination	Mild Hybrid Storage (MHS)
	Technology	Supercaps in capacitor technology, 48 V low-voltage technology
Brake system	Denomination	Electropneumatic-Braking-System (EBS) with disk brakes
Suspension	Denomination	Air suspension via electronic level control system (ENR)
Security	Systems	ABS, ESP, ATC (G hybrid), ASR, EBS, Preventive Brake Assist, Sideguard Assist
Air conditioner	Denomination	Roof-mounted system made by Konvekta
ECE Regulation N°51	Moving sound level	76 dB(A)
	Stationary sound level	90 dB(A)

LCA Information

Functional Unit

The functional unit is the “transport of 1 passenger for 1 kilometre”.

The bus capacity is calculated according to available seats and space for standing at 100% load factor (140 passengers: 37 seats and 103 standing). The lifetime of the bus is assumed with a travelled distance of 600 000 km as stated by EvoBus (see Table 2).

Table 2: Functional Unit

Passenger Capacity	Lifetime distance (km)	Passenger * km (pkm)
140	600 000	84 000 000

Time Representativeness

All primary specific data were collected for the year 2021. All secondary data come either from Sphera’s GaBi 2022.1 databases [1] and are representative of the years 2012-2021.

Databases and LCA Software

To carry out the life cycle impact assessment of the Citaro G hybrid, an LCA model using Sphera’s GaBi software and the therein available databases was created. The life cycle impact indicators are calculated based on the version 2.0 of the default list of indicators defined by EPD International which is valid from 29/03/2022 [2].

System Boundary

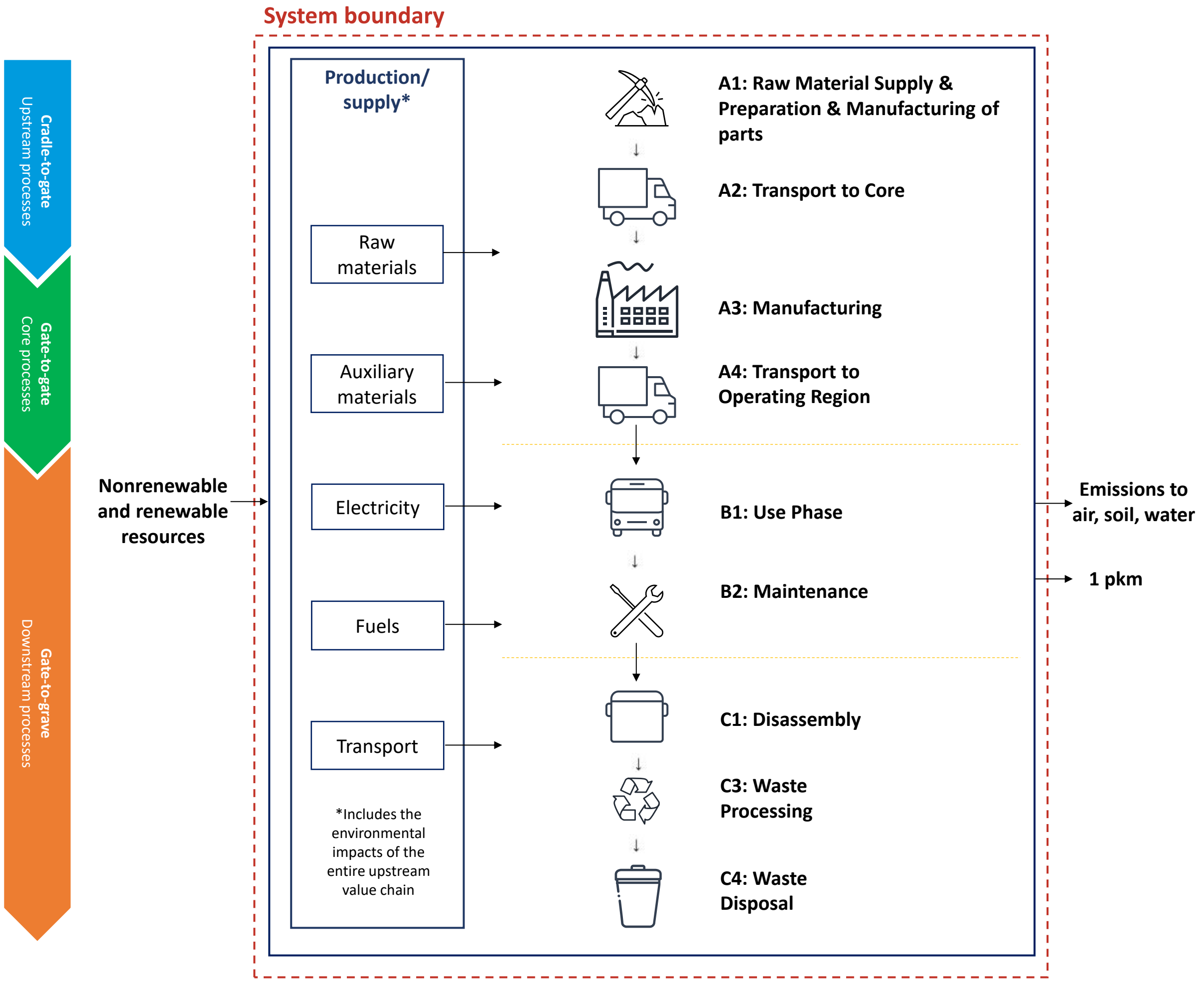
This EPD considers the impacts of 1 pkm using a cradle-to-grave perspective. This means, that it considers impacts associated with the extraction of resources from nature (through mining) through to the point at which the bus reaches his end of life.

The LCA is separated in three different life cycle stages following the PCR [3]:

- Upstream processes represent the input to the core processes as raw material acquisition and refinement and production of intermediate components.
- Core processes include processes managed by the organisation owning the EPD, in this case EvoBus.
- Downstream processes cover the use stage of the vehicle and end of life scenarios and treatments.

For the processes within the system boundary, all available energy and material flow data have been included in the model. Only 5 kg of material flows have been omitted.

Following the PCR, no credits are given for produced energy and recyclable materials within the system boundaries.



Details about the life cycle assessment

EvoBus collected the required data for the material composition of the Citaro G hybrid in 2022. To account for raw material acquisitions and external manufacturing of parts, the GaBi Software and databases developed by Sphera were used [1].

EvoBus has determined the transport distances from the suppliers to core to a large extend. The transports of 96% of the bus weight were considered for the transport to core.

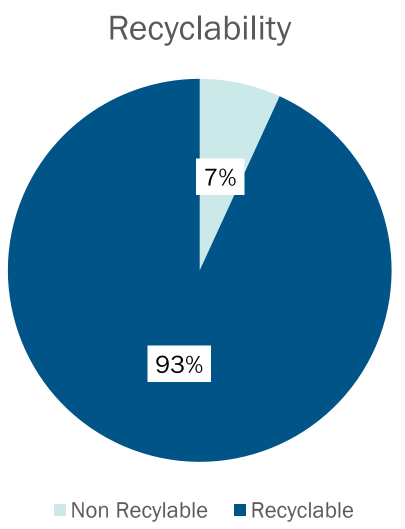
The manufacturing includes all EvoBus's manufacturing and assembly sites, at which the bus was produced. These sites are located in Neu-Ulm (Germany), Mannheim (Germany), Holysov (Czech Republic) and Ligny (France). Material, emission, and energy consumption data from these sites were gathered from EvoBus for the year 2021.

For the transport to operating region, the distance to one specific customer was taken as basis. The bus drives itself to the customer.

The modelling of the use phase is based on the diesel consumption data from the SORT 2 test report. The air emissions are derived from measurements as well as literature data [4] [5] [6].

For maintenance all spare parts required over the life cycle, are included into the analysis.

The vehicle recycling of the bus follows the requirements of the End of Life Vehicle Ordinance [7]. Also, rules of the ISO 22628:2002 were followed, in order to calculate the buses' recyclability and recoverability (see Figure 1).



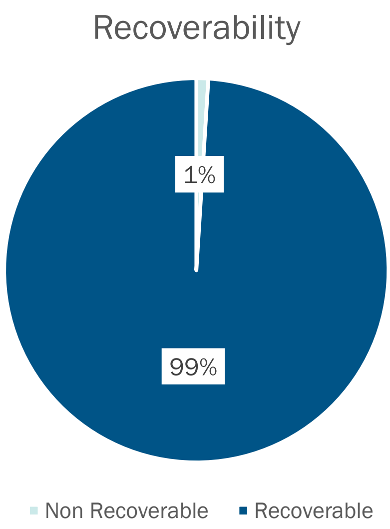


Figure 1: Recyclability and Recoverability

Content declaration

Product

For the EPD, a theoretical weight of 17 145 kg was applied since the final vehicle was not yet produced during the study period (see Table 3). The final approved bus has a weight of 16 700 kg, which is lower than the theoretical weight. Environmental performance of the bus may therefore be slightly overestimated in this EPD since the approved weight is higher than the weight of the theoretical bus.

Figure 2 and Figure 3 show the material breakdown and material declaration for each vehicle group.

The Citaro G hybrid fulfils the requirements of REACH [8]. EvoBus continuously identifies the substances that may be present above a concentration of 0.1% (w/w) in the individual articles used in Mercedes-Benz City buses and publishes the list of substances on a website [9].

Table 3: Analysed weight vs. forecast

Vehicle Group	Analysed weight (kg)	Forecast axle load (kg)
Powertrain	6 104	Not defined for axle load forecast
Exterior	877	
Interieur	2 002	
Frame	6 024	
Electric harness and systems	461	
Heating ventilation and air conditioning (HVAC)	598	
Doors	559	
Windows	689	
Total weight	17 314	17 145 (Approved bus: 16 700)

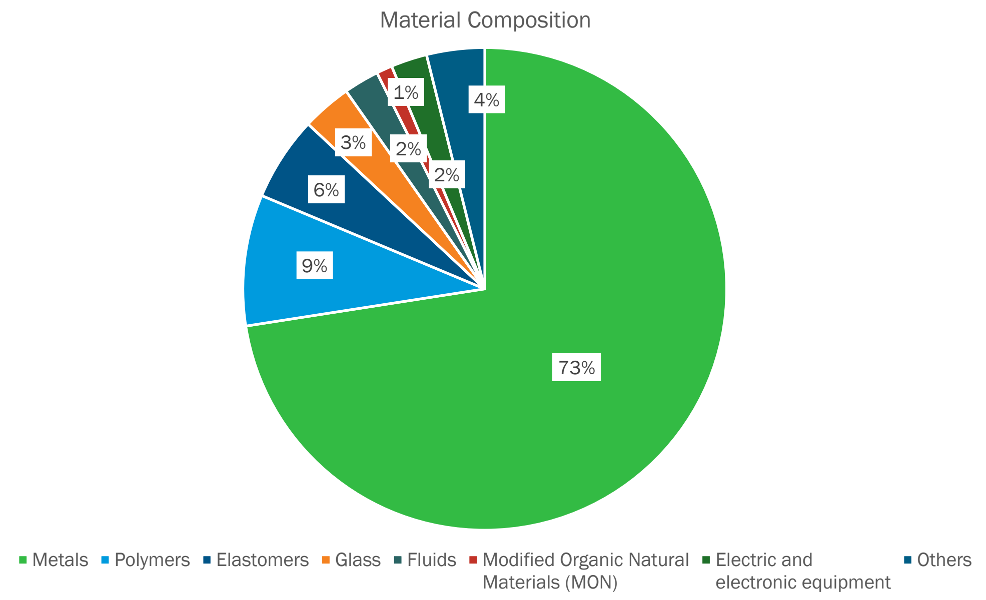


Figure 2: Material Content

The metal material groups ”steel and iron materials” and ”light alloys, cast and wrought alloys” are partially based on recycled materials. For steel and iron materials, the share of pre-consumer materials is calculated to be 40.0% of the total amount of steel and iron materials used for the bus. For light alloys, cast and wrought alloys, 10.8% of the total amount of those alloys is calculated to be based on pre-consumer materials.[1] Post-consumer material shares are unknown.

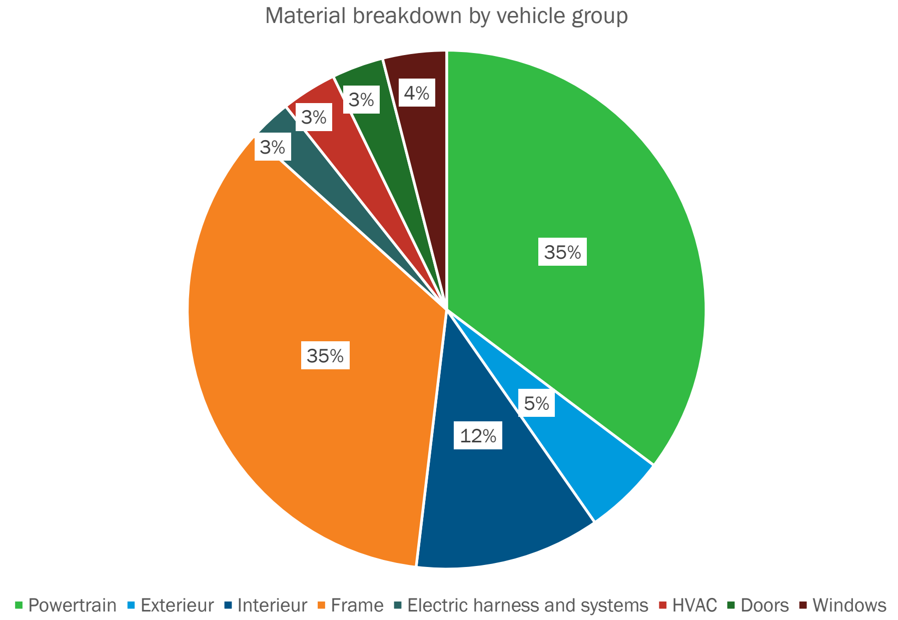


Figure 3: Material Breakdown by Vehicle Group

[1] Shares of pre-consumer materials are based on generic LCA data from GaBi databases [1].

Environmental performance

For the assessment of the environmental performance, the indicator version 2.0 valid since 29/03/2022 from the EPD website is used [2]. Compared to the earlier Version 1.0, the calculation methodology for the GWP changed, e.g., the GWP potential for Methane increase from 27 to 36.9 kg CO2 eq. [2].

Environmental impacts

Table 4 displays the environmental impacts of 1 pkm. Nearly all environmental impacts are predominantly influenced by the downstream processes. Impacts from downstream processes are driven by the bus operation. Only the impacts for photochemical ozone creation and abiotic depletion potential occur largely in the upstream processes.

Table 4: Environmental impacts

Parameter		Unit	Upstream	Core	Downstream		Total
					Operation	Maintenance & EoL	
Global warming potential	GWP-fossil	Kg CO2 eq.	8.20E-04	5.86E-05	9.88E-03	1.81E-04	1.09E-02
	GWP-land use and land use change	Kg CO2 eq.	6.49E-06	1.29E-07	6.75E-05	3.43E-05	1.08E-04
	GWP-biogenic[2]	Kg CO2 eq.	-4.75E-06	7.80E-06	4.27E-05	-3.68E-05	8.97E-06
	TOTAL	Kg CO2 eq.	8.21E-04	6.65E-05	9.99E-03	1.78E-04	1.11E-02
Acidification potential		Mol H+ eq.	3.09E-06	8.56E-08	1.36E-05	6.63E-07	1.74E-05
Eutrophication potential	Aquatic freshwater	Kg P eq.	8.71E-09	4.31E-10	3.59E-08	2.34E-08	6.84E-08
	Aquatic marine	Kg N eq.	5.63E-07	3.53E-08	4.82E-06	8.88E-08	5.51E-06
	Terrestrial, accumulated exceedance	Kg N eq.	6.29E-06	3.96E-07	5.65E-05	2.34E-06	6.55E-05
Photochemical ozone creation potential		Kg NMVOC eq.	1.79E-06	8.33E-07	1.39E-05	4.48E-07	1.70E-05
Ozone depletion potential (ODP)		Kg CFC-11 eq.	9.48E-14	5.76E-17	1.25E-15	3.56E-15	9.97E-14
Abiotic depletion potential for minerals and metals (non-fossil resources)		Kg Sb eq.	1.59E-08	1.33E-11	1.02E-09	4.17E-10	1.74E-08
Abiotic depletion potential for fossil resources		MJ, net calorific value	1.25E-02	8.04E-04	1.33E-01	5.42E-03	1.52E-01
Water deprivation potential (WDP)		m3 world eq.	3.71E-04	3.91E-06	1.17E-04	2.05E-04	6.97E-04

[2] For upstream processes, the biogenic GWP is negative, due to the natural rubber share of the tyres and the wooden part of the floor. For downstream processes, the biogenic GWP is negative due to the tyre changes (natural rubber share).

Use of resources

The use of resources describes the amount of primary as well as secondary materials and fuels. Primary resources are resources that are extracted from the environment for the first time. Secondary materials and fuels consist of substances that have already been used before and are made available to the bus life cycle after recycling.

Resources are elementary flows which cross the system boundary (see Table 5).

Resources can either be used as an energy carrier or as a raw material. Primary non-renewable and renewable raw materials enter the upstream phase via raw material acquisition and supplier manufacturing. In the downstream phase the raw materials are then either used as an energy carrier (thermal recovery) or as a material (material recycling).

Table 5: Use of resources

Parameter		Unit	Upstream	Core	Downstream		Total
					Operation	Maintenance & EoL	
Primary energy resources – Renewable	Use as energy carrier	MJ, net calorific value	2.64E-03	8.02E-04	9.24E-03	1.18E-03	1.39E-02
	Used as raw materials	MJ, net calorific value	2.53E-04	0.00E+00	0.00E+00	1.38E-03	1.63E-03
	TOTAL[3]	MJ, net calorific value	2.89E-03	8.02E-04	9.24E-03	2.56E-03	1.55E-02
Primary energy resources – Non-renewable	Use as energy carrier	MJ, net calorific value	1.15E-02	8.04E-04	1.33E-01	3.92E-03	1.50E-01
	Used as raw materials	MJ, net calorific value	1.04E-03	0.00E+00	0.00E+00	1.50E-03	2.54E-03
	TOTAL[3]	MJ, net calorific value	1.25E-02	8.04E-04	1.33E-01	5.42E-03	1.52E-01
Secondary material		Kg	9.93E-05	0.00E+00	0.00E+00	0.00E+00	9.93E-05
Renewable secondary fuels		MJ, net calorific value	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Non-renewable secondary fuels		MJ, net calorific value	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Net use of fresh water		m^3	1.32E-05	8.65E-07	1.08E-05	3.09E-05	5.58E-05

[3] "TOTAL" is the sum of "Use as energy carrier" and "Used as raw materials".

Waste production and output flows

Waste production

Table 6 describes the waste production over the entire life cycle. The waste can be divided into three categories: Hazardous, non-hazardous and radioactive waste. The amount of non-hazardous waste disposed outweighs the hazardous waste disposed. In addition, also radioactive waste is disposed. However, the radioactive waste of the core is not produced by the Citaro G hybrid bus directly, since no radioactive waste is generated here (radioactive waste is produced for example at electricity production for raw materials).

Table 6: Waste production

Parameter	Unit	Upstream	Core	Downstream		Total
				Operation	Maintenance & EoL	
Hazardous waste disposed	Kg	7.73E-07	7.54E-14	9.85E-13	1.46E-09	7.74E-07
Non-hazardous waste disposed	Kg	4.82E-05	3.63E-06	2.20E-05	1.14E-05	8.52E-05
Radioactive waste disposed	kg	3.39E-07	4.22E-08	2.59E-07	3.63E-08	6.77E-07

Output flows

Table 7 displays the output flows. During the life cycle, no components for reuse accrue. The amount of materials for recycling outweighs the amount of materials for energy recovery. The comparatively high values for materials for recycling reflect that 73 % share of the overall mass, are materially recycled. In the downstream phase, the tyre exchanges increase the value for recycling as well as for energy recovery. Therefore, the mass of material for recycling and energy recovery outweighs the total weight of the Citaro G hybrid bus.

Table 7: Output flows

Parameter	Unit	Upstream	Core	Downstream		Total
				Operation	Maintenance & EoL	
Components for reuse	Kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material for recycling	Kg	1.14E-04	1.44E-05	0.00E+00	2.45E-04	3.74E-04
Material for energy recovery[4]	Kg	3.18E-07	1.02E-05	0.00E+00	3.48E-05	4.53E-05
Exported energy. electricity	MJ	0.00E+00	0.00E+00	0.00E+00	1.67E-04	1.67E-04
Exported energy. thermal	MJ	0.00E+00	0.00E+00	0.00E+00	3.31E-04	3.31E-04

[4] In this EPD, it is assumed that “materials for energy recovery” consider materials that can be incinerated in waste incineration plants. These materials are produced by upstream, core and downstream processes.

Results Interpretation

The following Table 8 shows the environmental impacts per process stage. The bus use is for all environmental impact categories except water deprivation potential and abiotic depletion potential elements the largest contributor.

Water deprivation potential is mainly driven by raw material acquisition and bus maintenance. The impacts of this impact category for bus maintenance come from the board net battery exchange.

The abiotic depletion potential elements, which quantifies the use of mineral and metallic resources, is the highest during the raw material acquisition since mainly for raw material acquisition those types of resources are applied. The bus use is mainly based on fossil energy resources (diesel) and shows high shares in the abiotic depletion potential (ADP) for fossil resources.

Table 8: Environmental Impacts per Process Stage

Life cycle stage	GWP	POCP	AP	EP	ADP-EL	ADP-FF	WDP
Raw material acquisition	7.3%	10.5%	17.6%	9.5%	91.7%	8.1%	53.2%
Raw material transport	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%
Bus manufacturing	0.5%	4.8%	0.4%	0.5%	0.1%	0.4%	0.5%
Transport to operating region	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%
Bus use	90.4%	81.9%	78.0%	86.2%	5.9%	87.7%	16.8%
Bus maintenance	1.4%	2.5%	3.7%	3.4%	2.4%	2.0%	25.5%
End of life	0.2%	0.1%	0.1%	0.1%	0.0%	1.6%	3.9%
Total	100%	100%	100%	100%	100%	100%	100%

GWP: Global Warming Potential | POCP: Photochemical creation potential | AP: Acidification potential | EP: Eutrophication terrestrial | ADP EL: Abiotic depletion potential elements | Abiotic depletion potential fossil fuels | WDP: Water deprivation potential

References

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