ENVIRONMENTAL PRODUCT DECLARATION

In accordance with ISO 14025:2006 for Lion's City 12 G EfficientHybrid from MAN Truck & Bus SE

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EPD

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MAN

PROGRAMME INFORMATION

Programme Information

Programme	The International EPD® System EPD International AB Box 210 60 SE-100 31 Stockholm Sweden www.environdec.com info@environdec.com	
Product Category Rules (PCR)	PCR 2016:04 Public and private passenger buses and coaches (2.0.1) (valid until 2024-12-04)	
PCR review was conducted by:	The Technical Committee of the International EPD® System Chair: Maurizio Feschi Contact via: info@environdec.com	
LCA study conducted by	MAN Truck & Bus SE Dachauer Strasse 667 80995 Munich Contact via: lina-josefin.kindermann@man.eu	EDAG Engineering GmbH Frankfurter Ring 77 80807 Munich Contact via: alexander.erler@edag.com
Independent third-party verification of the declaration and data, according to ISO 14025:2006	☒ EPD verification by individual verifier Third-party verifier: Håkan Stripple at IVL Swedish Environmental Research Institute E-mail: hakan.stripple@ivl.se Approved by: The International EPD® System	
Procedure for follow-up of data during EPD validity involves third-party verifier	☒ Yes ☐ No	

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COMPANY INFORMATION

Owner of the EPD
MAN Truck & Bus SE
Dachauer Strasse 667
80995 Munich
Germany

Description of the organization
MAN Truck & Bus is a member of the TRATON GROUP and one of Europe's leading commercial vehicle manufacturers. MAN is in the midst of transforming into a provider of environmentally friendly and more sustainable transportation and mobility solutions. The company manufactures in three European countries.

Name and location of production site:
This study provides an environmental assessment of a gas driven 12 m city bus in Europe. The MAN in-house manufacturing steps of city buses take place at the following sites:

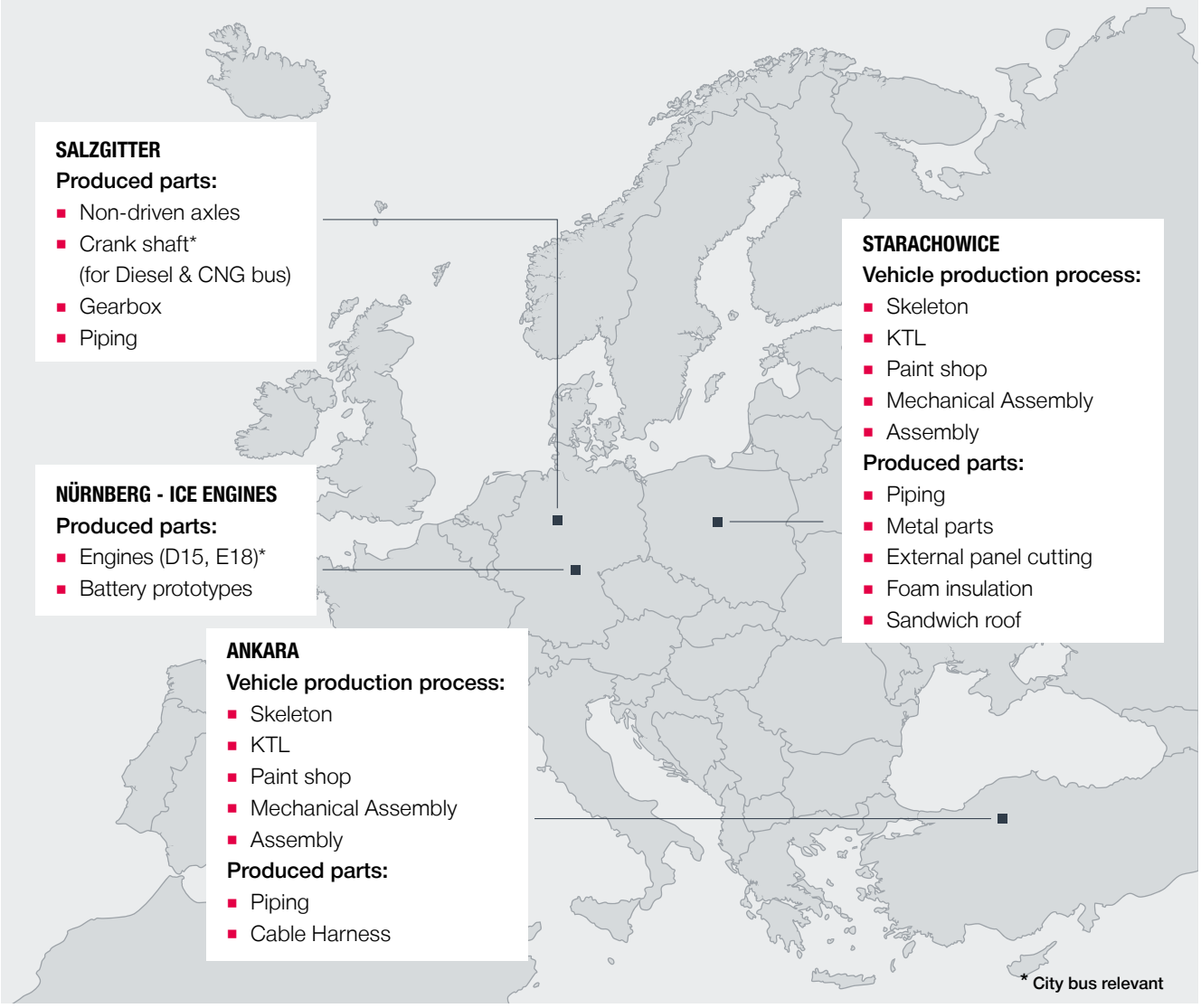


Figure 1: MAN city bus production site overview

PRODUCT INFORMATION

Product identification and description

MAN LION'S CITY CNG EfficientHybrid is the MAN CNG city bus with MAN efficient hybrid technology and available in a 12 m and 18 m version. This EPD assesses the 12 m version. The MAN EfficientHybrid technology consists of a wear-free electric motor used between the engine and the gearbox together with an UltraCap energy accumulator system (48 V, 40 Wh high-performance capacitors) placed on the roof and a smart control system. When the vehicle slows down before coming to a halt, the crankshaft starter generator converts the generated brake energy into electrical energy. In the UltraCaps, the electrical energy is stored electrostatically, this means without chemical processes as with conventional batteries. While the vehicle is at standstill, the combustion engine is turned off and the UltraCap accumulator takes over the supply of the vehicle electrical system for all functions (e.g. opening and closing of the doors, operation of the interior lighting and ventilation). Once driving off again, the crankshaft starter generator uses the available energy from the UltraCap capacitors to start the combustion engine. In addition, the crankshaft starter generator can use excess stored energy to act as an additional hybrid drive and thereby take some of the load off the combustion engine. To evaluate the environmental impacts of the MAN LION'S CITY 12 G, a specific vehicle configuration is determined to represent a typical selection of equipment options. The technical features of this typical vehicle are detailed in the following.

Geographical scope

The geographical scope of this LCA is Europe.

Table 1: Technical description of the vehicles

Group	Concept	Value
General	Abbreviation used within this report	CNG
	Description	Lion's City 12 G EfficientHybrid
	Model year	2021
	Door configuration	3 doors
	Permissible gross vehicle weight	19.5 t
	Calculated empty weight in running order without driver (EU type approval regulation)	11.587 t
Chassis	Denomination/Chassis number	B12CGE03
	Length	12.2 m
	Capacity (total/seating/standing) at 100 % load	96/29/67 passengers
	Driver cabin position	Front left
Engine	Denomination/Engine type	E1856 six-cylinder | 9514 cm^3
	Fuel	CNG
	Nominal power	235 kW/ 320 hp
	Emissions compliance	Euro VI
Gearbox	Type	Automatic gearbox
Axles	Axles	2
	Axle configuration	4 x 2 (Front axle with independent wheel steering)
	Wheels	6 x 275/70 R22.5 on steel wheel 22.5 x 7.5
Air Conditioning	Type passenger area heating	Valeo (Spheros) REVO air-conditioning system (max. cooling output 32 kW) (R134a based technology)
	Type driver area heating	Without driver's workplace air conditioning system
Ece Regulation Nº51	Moving sound level [dB(A)]	73
	Stationary sound level [dB(A)]	85

LCA INFORMATION

This assessment follows the PCR 2016:04 – UN CPC 49112 and 49113 – Public and private buses and coaches. Version 2.0.1 requirements.

Functional unit and reference flow

The function in this LCA is the transportation of passengers in urban areas. The functional unit chosen to quantify the main function is transport of one passenger over one km distance (= one passenger kilometre) in a defined drive cycle with a set payload in a defined region. This functional unit corresponds to the goal of the study and the EPD requirements.

Table 2: Basic conditions of functional unit

Characteristic	Value
Lifetime mileage	1.3 million km
Drive cycle	SORT 2 (reference)
Capacity (total / seating / standing) at 100 % load [1]	96/29/67 passengers
Region	Europe
Passengers x km	124 800 000

1 Maximum number of passengers according to regulatory weight restrictions, divided into available seating and standing area

Reference service life

The vehicle lifetime mileage can vary depending on specific use cases. According to performed analysis, a life time mileage of 1.3 million km for city buses sold in the EU can represent the total usage by the first and by further owners.

Time representativeness

Primary data is collected for the years 2020 and 2021. The utilized GaBi databases edition CUP 2022.2 have reference year 2018 or 2020 (depending on the dataset) and data is valid until 2024.

Database(s) and LCA software used

The life cycle assessment of the vehicle is carried out by modelling in GaBi software. Secondary data is selected from VW LEAD[2] Database 2022.2 which is based on Sphera's GaBi databases edition CUP 2022.2 (www.gabi-software.com).

2 LEAD database is the Volkswagen Group internal database composed of GaBi datasets and Volkswagen Group internally developed models (e.g. battery cell production, tire production)

System boundaries

The following figure depicts the system boundary of this assessment and provides an overview over the included single life cycle stages. The life cycle stages are summarized into the three required models by the applied PCR.

The life cycle assessment considers the impacts over the whole life cycle of the assessed product system from raw material acquisition to end-of-life and therefore represents a cradle-to-grave perspective.

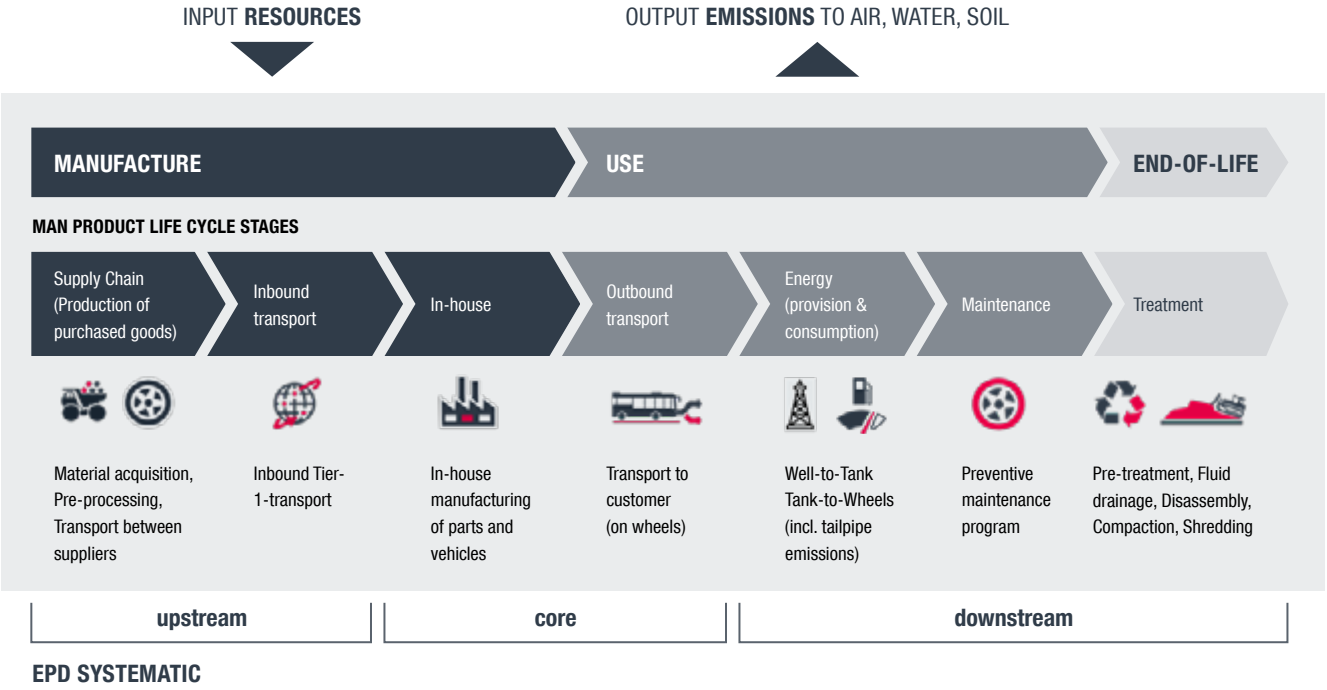


Figure 2: System boundary

Upstream module

For the **supply chain model**, material data is aggregated in 2022. VW group internal datasets, as well as external GaBi datasets are assigned to the incorporated materials. The percentage of material designations defined in the LCA is 98 % of the theoretical total weight of the product. The rest of the vehicle weight is upscaled via the material distribution to represent 100 % of the vehicle weight.

All serial production **inbound logistics** processes relevant for city bus production are included based on existing corporate logistics information and assigned to this specific vehicle via a top-down approach based on a mass criterion. Inbound transport from direct suppliers of MAN is included in this assessment.

Core module

The **In-house production** model is based on externally reviewed site-specific environmental management data from 2021 (energy, water, process gas, waste, wastewater, emissions to air), as well es additional paint shop specific data for 2020. The information is allocated to the relevant components and city bus production via a top-down approach based on a mass criterion.

The transport of the produced vehicles to customers takes place on wheels in the majority of cases. Therefore, the **outbound logistic** is modelled according to the use stage model for an average distance of approx. 1975 km.

Downstream module

The **use stage model** includes energy consumption, tailpipe emissions and preventive maintenance parts. A simulation approach is chosen to determine the energy consumption values by an MAN in-house simulation tool. Consumption due to heating and air conditioning, auxiliaries, etc. is included. The CNG fuel provision is modelled based on EU natural gas mix from fossil sources. Production of and waste from maintenance materials and spare parts (based on the road vehicle preventive maintenance program) are included in LCA calculations. This includes replacements of tyres, brake pads, brake discs, starter batteries, fire extinguisher, engine oil, axle oil, hydraulic oil, coolant, air compressor oil, coolant compressor oil and refrigerants.

The **End-of-Life model** follows the ISO 22628:2002 requirements. A cut-off approach is defined and credits as well as burdens from energy or material recovery are excluded.

Limitations

Comparability - It is important to bear in mind that product LCAs for vehicles are complex calculations that require many specific methodological as well as data related decisions by the practitioner which have an impact on the impact results of an LCA. This is the case even under strict application of the before mentioned PCR, with more specific requirements. Differences in use case profiles, data aggregation methods (top-down / bottom-up), data quality, databases etc. may lead to differences in the outcome. When comparing the order of magnitude of results from this study and city bus LCAs from other OEMs, this needs to be taken into account. A comparison of the direct results from different studies without taking the differences in consideration is not recommended. The underlying scope and assumptions would first need to be understood and aligned in order to allow a fair comparison of the environmental product performance although all standards and PCRs are followed. This limited comparability also applies to other presented values, such as recycling and recoverability rates and emission data.

Representativeness - This LCA is conducted for one typical vehicle configuration with a set of assumptions that compose a typical reference scenario. In reality, different vehicle configurations, use cases and end-of-life scenarios may occur and would lead to deviating results. This shall be considered when using the results of this study.

Content declaration

Material distribution [kg]

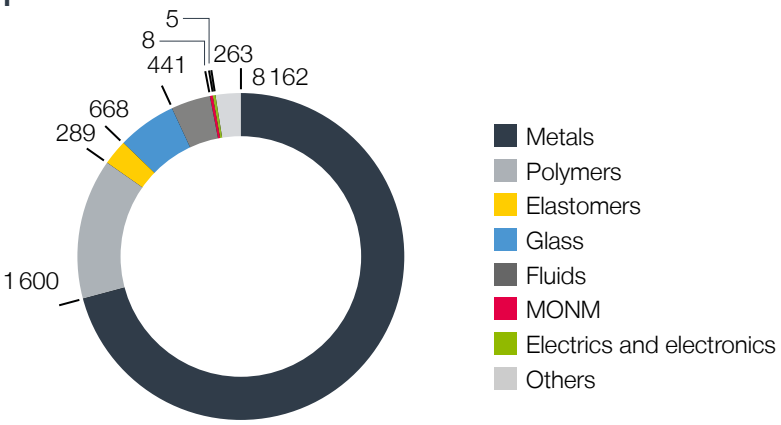
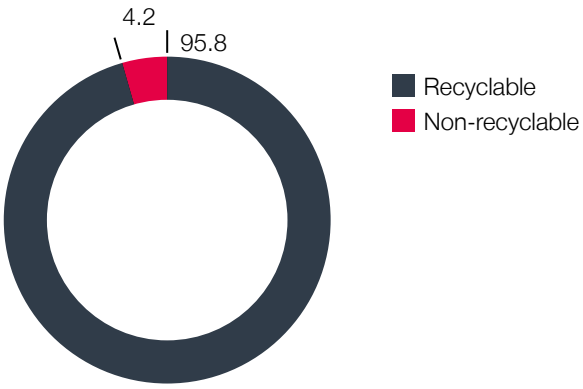


Figure 3: Content declaration according to DIN ISO 22628

Based on this content declaration, the vehicle's recyclability and recoverability rates are calculate as defined in the ISO 22628:2002 standard – "Road vehicles – Recyclability and recoverability – Calculation method". The results are shown in the following figure.

End-of-Life treatment:
Recyclability rate [%]



End-of-Life treatment:
Recoverability rate [%]

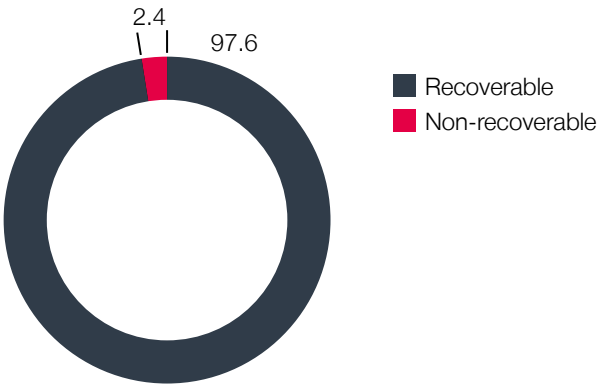


Figure 4: Recycling and recoverability rates according to DIN ISO 22628

ENVIRONMENTAL PERFORMANCE

In the following, the mandatory impact assessment results, as well as further mandatory indicators according to the applicable PCR and EPD standard are presented as relative values per passenger km for the reference scenario. Many output flows result in the value “0” due to cut-off approach in End-of-Life and data gaps. A modular balancing of biogenic carbon for tyres is applied in order to maintain conformity with the EPD requirements regarding biogenic carbon accounting. The impact assessment methods are chosen as defined in Version 1.0 of the default list of indicators (valid until 2022-12-31) [EPD 2022].

It shall be taken into account that the results of the environmental impact indicators for Abiotic depletion potential (ADP) and Water deprivation potential (WDP) shall be used with care as the uncertainties of the results are high and as there is limited experience with the indicator.

Impact assessment results

Table 4: Impact assessment results per passenger kilometre

Parameter		Unit	Upstream	Core	Downstream	Total
Global warming potential (GWP)	Fossil	kg CO_2 eq.	3.84E-04	1.47E-04	1.48E-02	1.53E-02
	Biogenic	kg CO_2 eq.	6.92E-07	1.14E-06	1.62E-06	2.56E-05
	Land use and land use change	kg CO_2 eq.	2.27E-07	4.22E-07	4.57E-07	1.11E-06
	Total	kg CO_2 eq.	3.85E-04	1.49E-04	1.48E-02	1.54E-02
Acidification potential (AP)		kg SO_2 eq.	1.29E-06	1.98E-07	5.46E-06	6.94E-06
Eutrophication potential (EP)		kg PO_4^{3-} eq.	1.04E-07	3.42E-08	1.01E-06	1.15E-06
Photochemical oxidant creation potential (POCP)		kg NMVOC eq.	7.67E-07	1.01E-06	7.78E-06	9.56E-06
Abiotic depletion potential (ADP)	Metals and minerals/ elements	kg Sb eq.	8.54E-09	6.86E-11	8.40E-09	1.70E-08
	Fossil resources	MJ, net calorific value	5.61E-03	5.01E-03	2.45E-01	2.55E-01
Water deprivation potential (WDP)		m^3 world eq.	7.07E-05	1.46E-05	2.59E-04	3.44E-04

Use of resources

Table 5: Resource use per passenger kilometre

Parameter		Unit	Upstream	Core	Downstream	Total
Primary energy resources	Use as energy carrier	MJ, net calorific value	1.39E-03	5.99E-04	6.19E-03	8.18E-03
	Used as raw materials	MJ, net calorific value	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Total	MJ, net calorific value	1.39E-03	5.99E-04	6.19E-03	8.18E-03
Primary energy resources - Non-renewable	Use as energy carrier	MJ, net calorific value	5.62E-03	5.01E-03	2.45E-01	2.55E-01
	Used as raw materials	MJ, net calorific value	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Total	MJ, net calorific value	5.62E-03	5.01E-03	2.45E-01	2.55E-01
Secondary material		kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Renewable secondary fuels		MJ, net calorific value	6.45E-28	0.00E+00	0.00E+00	6.45E-28
Non-renewable secondary fuels		MJ, net calorific value	7.58E-27	0.00E+00	0.00E+00	7.58E-27
Net use of fresh water		m^3	3.98E-06	4.99E-07	1.50E-05	1.94E-05

Waste production and output flows

Table 6: Waste production of BEV vehicle per passenger kilometre

Parameter	Unit	Upstream	Core	Downstream	Total
Hazardous waste disposed	kg	1.13E-09	1.69E-12	4.67E-11	1.18E-09
Non-hazardous waste disposed	kg	4.90E-05	1.04E-05	4.27E-05	1.02E-04
Radioactive waste disposed	kg	2.29E-07	5.41E-08	1.58E-06	1.86E-06

Table 7: Output flows per passenger kilometre

Parameter	Unit	Upstream	Core	Downstream	Total
Components for reuse	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material for recycling	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for energy recovery	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported energy, electricity	MJ	0.00E+00	1.47E-05	0.00E+00	1.47E-05
Exported energy, thermal	MJ	0.00E+00	2.74E-05	0.00E+00	2.74E-05

Other environmental information

Table 8: Engine exhaust gas emissions according to Regulation (EC) 595/2009, ECE R49 and corresponding applicable regulations

Source	Parameter	Unit	Total
WHSC Fuel G_R	PM emissions	mg/kWh	0.13
	NO_x emissions	mg/kWh	90.65
	NH_3	ppm	1.81
	NMHC emissions	mg/kWh	20.08
	CO emissions	mg/kWh	414.92
	PN	number/kWh	1.58E+11
WHTC Fuel G_{25}	CH_4 emissions	mg/kWh	155.40
	PM emissions	mg/kWh	2.36
	NO_x emissions	mg/kWh	87.69
	NH_3 emissions	ppm	2.11
	HC emissions	mg/kWh	3.72
	CO emissions	mg/kWh	473.68
	PN	number/kWh	2.06E+11

SENSITIVITY ANALYSIS

Extensive further analysis of use case-, modelling- and technological scenarios are conducted to assess potential changes in environmental performance. Within this report, only one scenario in alignment with the above mentioned reference vehicle is further detailed, namely the variation of the vehicle lifetime mileage. In the following, only the total global warming potential impacts are depicted. For results of further scenarios from sensitivity analysis, as well as other impact assessment results for the presented scenarios, the EPD owners may be approached.

Lifetime mileage

The vehicle lifetime mileage can vary depending on specific use cases. According to an internal analysis of various sources (companies, online export sites, own fleet data, German authorities (KBA/BASt)), city buses, regardless of their location, have an average constant annual mileage of about 60 000 km/year and can reach a lifetime mileage of approximately 1.3 million km for city buses sold in the EU. The data suggest that this can represent the total usage by the first and by further owners and is set as the reference lifetime mileage for this LCA. Nevertheless, an uncertainty exists due to rather scarce data availability for city bus End-of-usage statistics. Further analysis of additional data sources is therefore conducted in order to scrutinize this parameter as a basis for future LCAs. In order to assess the range of potential outcomes in this study, 800 000 km are chosen for a scenario analysis.

Total Global Warming Potential (GWP) - absolute [t CO_2eq]
incl. GWP from direct land use change and biogenic sources

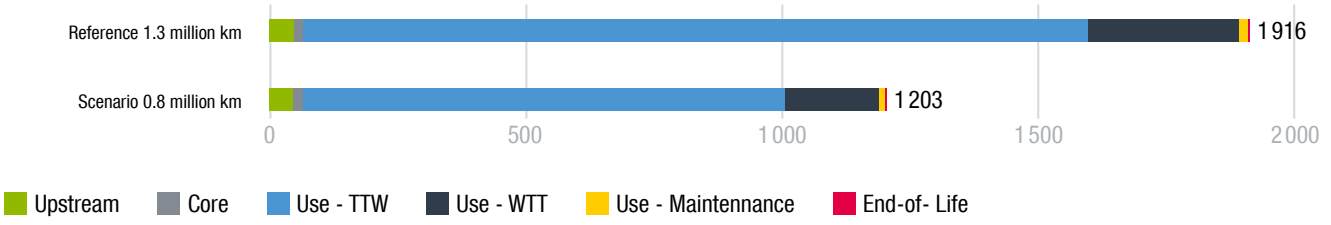


Figure 5: Absolute GWP results per vehicle over the entire life cycle for lifetime mileage scenarios

Total Global Warming Potential (GWP) - relative [g CO_2eq/pkm]
incl. GWP from direct land use change and biogenic sources

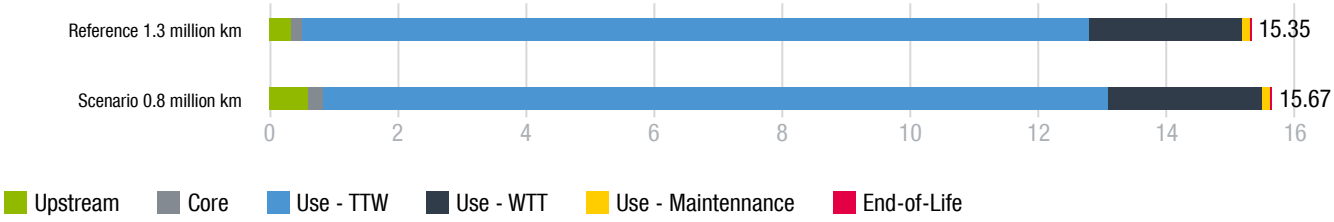


Figure 6: Relative GWP results per passenger kilometre for lifetime mileage scenarios

The shorter lifetime creates a lower absolute result per vehicle. A reduction of the lifetime mileage from 1.3 million km to 800 000 km to 61.5 % causes the absolute GWP results over lifetime to decrease to 63 %. The use phase remains the main contributor with a share of 95 % over life cycle for CNG in the 0.8 million km scenario.

Whereas the absolute values decrease with a shorter lifetime mileage, the relative results slightly increase. For the other impact categories that are dominated by the use phase, this scenario leads to analogous results. For the categories mainly influenced by the material input (ADP elements), the absolute results are affected very little by this analysis, whereas the relative results per passenger kilometer increase due to the decreased number of kilometers that the unit refers to.

List of Abbreviations

AC	Air conditioning
ADP	Abiotic depletion potential
AP	Acidification Potential
BASt	Bundesanstalt für Straßenwesen
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalents
DIN	German Industrial Standard
EN	European Standard
EoL	End-of-Life
EP	Eutrophication Potential
EPD	Environmental Product Declaration
eq.	Equivalents
FU	Functional unit
GaBi	LCA software with Databasis from Spehra Solutions GmbH
GWP	Global warming potential
ICE	Internal Combustion Engine
ISO	International Organization for Standardization
KBA	Kraftfahrtbundesamt
kW	Kilowatt
kWh	Kilowatt hours
LCA	Life Cycle Assessment
LEAD	Volkswagen Group developed LCI database
MONM	Modified Organic Natural Materials
NH_3	Ammonia
NMHC	Non-methane hydrocarbons
NO_x	Nitrous oxides
PCR	Product Category Rules
PM	Particulate matter
PN	Particle number
POCP	Photochemical ozone creation potential
SORT	Standardized on-road test cycles
tonne	Metric tonne (1000 kg)
TTW	Tank-to-wheel
VOC	Volatile organic compounds
WHSC	World Harmonized Stationary Cycle
WHTC	World Harmonized Transient Cycle
WSF	Water Scarcity Footprint
WWT	Well-to-tank

External References

[EPD 2020] PUBLIC AND PRIVATE BUSES AND COACHES PRODUCT CATEGORY CLASSIFICATION:
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[EPD 2022] EPD website - Environmental performance indicators www.environdec.com/indicators (accessed 30.08.2022)

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