Unveiling Biodiesel's Environmental Trade-Offs: A Comparative Life Cycle Assessment for Urban Buses

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ABSTRACT

This study presents a comparative Life Cycle Assessment (LCA) of urban buses powered by Diesel S10 with three fuel blends: B7 (7% biodiesel), B15 (14% biodiesel), and B100 (100% biodiesel). Employing a well-to-wheel approach, the analysis covers the extraction, production, distribution, and use of the fuels, as well as vehicle manufacturing and maintenance. The environmental impacts were quantified using the CML-IA and ReCiPe 2016 (Midpoint and Endpoint) methods. Results indicate that B100 significantly reduces Global Warming Potential, yet exhibits higher impacts in eutrophication, abiotic depletion, and ecotoxicity. Sensitivity analysis regarding vehicle occupancy revealed greater variability for B100. In conclusion, the optimal fuel choice depends on the prioritization of specific impact categories, providing insights for sustainable transportation policies.

INTRODUCTION

This study forms part of a Life-Cycle Assessment (LCA) of urban buses powered by Diesel S10 blended with B7, B15, and B100 biodiesel for public transport in Campinas, São Paulo. The municipality is preparing a new public-transport tender, and establishing parameters that evaluate available technologies and their respective impacts helps define the tender's boundary conditions, supports public decision-making, and guides the formulation of public policies.

METHODOLOGICAL APPROACH

An attributional approach was adopted, following the methodological steps recommended by ISO 14040 (see Figure 1):

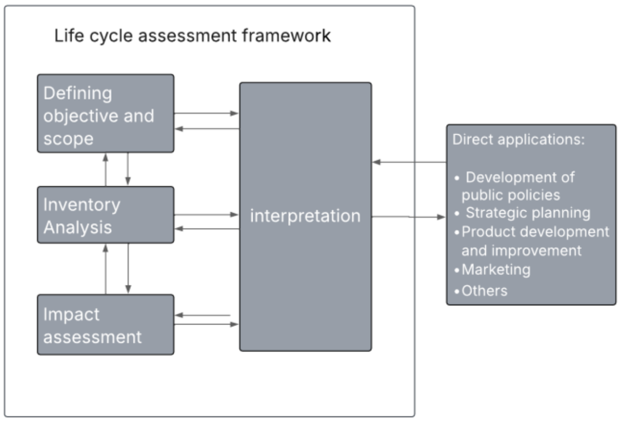


Figure 1: Steps for conducting an LCA in accordance with ISO 14040.

GOAL AND SCOPE DEFINITION PHASE

Objetive

As previously outlined, this study aimed to compare the environmental impacts of urban buses powered by Diesel S10 blended with B7, B15, and B100, used in Campinas (São Paulo State) public transport. The analysis is warranted because municipal transport authorities are currently discussing strategies to introduce new vehicle technologies during fleet renewals, coinciding with the upcoming renegotiation of public-transport concession contracts. Technological choice strongly affects the concession's economic–financial balance, which in turn largely determines any public subsidy required to operate the system, the timetable for fare adjustments, service quality, the fleet's technological modernization, and compliance with the greenhouse-gas (GHG) targets set in municipal plans. Campinas exemplifies this context: the city is preparing to renew its concession and is therefore assessing how best to improve transport quality by adopting vehicle technologies that curtail local pollutants and CO_2 emissions while maintaining affordable fares for residents. Accordingly, this analysis is valuable both to public authorities, because it qualifies the environmental performance of each configuration, and to transport operators, who gain information that underpins their choices and offers a broader view of the impacts of current and future fleet technologies.

System Boundaries (Function and System Considered)

The function of the system under study is urban public passenger transport, with boundaries defined on a Well-to-Wheel basis. These boundaries encompass all processes associated with fuel extraction (well), production, and distribution up to its use in the vehicle (wheel). The analysis also incorporated inventories for vehicle production and maintenance. These data were not intended to extend the boundary to Cradle-to-Wheel; rather, they enabled a sensitivity assessment of those processes within the impact results. Equipment, machinery, installations, and infrastructure employed in the manufacture, transport, and distribution of the fuels and the vehicle were excluded from the scope (capital goods), under the premise that their impacts are less significant than those arising from operational processes. Accordingly, the product systems considered meet the functional requirement of urban passenger transport by means of an internal-combustion diesel-cycle bus fitted with selective catalytic reduction (SCR) after-treatment (including ARLA 32 fluid) and operated with Diesel S-10 B7 (7 % biodiesel), B15 (14 % biodiesel), and B100 (100 % biodiesel). Figure 2 presents the BX product system (applicable to B7 and B15), whereas Figure 3 depicts the system for B100.

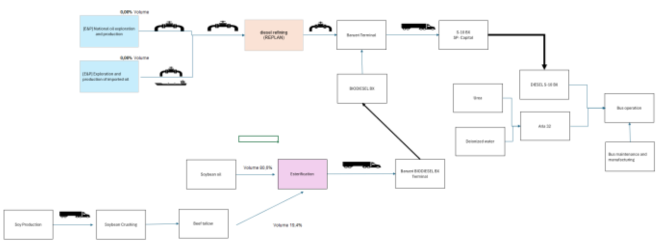


Figure 2: BX product system (B7 and B15).

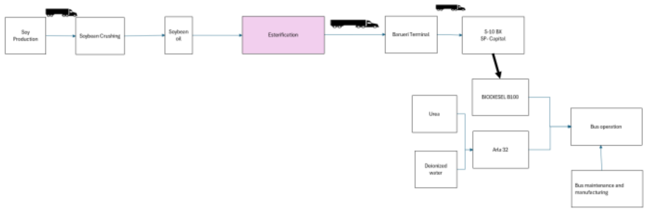


Figure 3: Product system for B100.

Functional Unit and Key Process Considerations

The functional unit adopted is 1 km travelled. In the BX product system (B7 and B15), the fuel consists of Diesel S10 blended with biodiesel produced from soybean oil and beef tallow. For the B100 product system, the biodiesel is derived exclusively from soybean oil.

Scopes

Geographical scope

Diesel, soybean, and beef-tallow exploitation and production were modelled using Brazilian national profiles, with refining at the REPLAN facility. Vehicle production, maintenance, and operation were assumed to occur in the state of São Paulo. The diesel blend was taken to be 74 % domestically produced and 26 % imported. For the BX fuels (B7 and B15), the biodiesel fraction was modelled as 91 % soybean-derived and 9 % beef-tallow-derived (by volume).

Temporal scope

Inventory data were drawn from secondary sources dated 1990–2019; thus, the analysis does not capture the societal effects of the COVID-19 pandemic or the war in Ukraine.

Technological scope

- Diesel-cycle urban bus with SCR after-treatment and ARLA 32 consumption (5 % of fuel volume)
- Emission standard: EURO V
- Chassis: Mercedes-Benz OH 1621 L
- Bodywork: CAIO
- Length: 12 m; curb mass: 11 800 kg (no passengers)
- Reference operating condition: 50 % passenger load, with the following fuel economies:
    - S10 B7: 2.17 km L^{-1}
    - S10 B15: 2.16 km L^{-1}
    - B100: 2.04 km L^{-1}
- Estimated service life: 1 180 000 km

Allocation Procedures

For the analysis, the following allocations were applied:

- National crude-oil and natural-gas exploration and production (Campos Basin profile), on an energy basis:
  - 99.97 % assigned to crude oil
  - 0.03 % assigned to natural gas
- Petroleum refining and product generation (REPLAN profile), on a volumetric basis:
  - Diesel: 51 %
  - Gasoline A: 24 %
  - Petroleum coke: 7 %
  - LPG: 6 %
  - Fuel oil, aviation kerosene, asphalt, naphtha, and illuminating kerosene together account for the remaining 12 %
- Soybean lipid extraction and processing, on a mass basis:
  - Soybean oil: 18 %
  - Soybean meal: 81 %
  - Soy lecithin: 1 %
- Transesterification of soybean oil and beef tallow, on a mass basis:
  - Biodiesel: 90 %
  - Glycerine: 6 %
  - Soapstock: 4 %

Modelling Software and LCIA Methods

The inventory was modelled in openLCA with datasets version 2.4.5, applying three Life-Cycle Impact-Assessment (LCIA) methods:

- CML-IA baseline
- ReCiPe 2016 Midpoint (H)
- ReCiPe 2016 Endpoint (H)

Impact categories

- CML-IA baseline

Abiotic Depletion (elements), Abiotic Depletion (fossil fuels), Acidification, Eutrophication, Freshwater Ecotoxicity, Global Warming Potential (GWP 100 a), Human Toxicity, Marine Ecotoxicity, Stratospheric-Ozone Depletion, Photochemical Oxidation, Terrestrial Ecotoxicity.

- ReCiPe 2016 Midpoint (H)

Particulate-Matter Formation, Fossil Depletion, Freshwater Ecotoxicity, Freshwater Eutrophication, Climate Change, Human Carcinogenic Toxicity, Human Non-Carcinogenic Toxicity, Ionising Radiation, Land Use, Marine Ecotoxicity, Marine Eutrophication, Mineral Depletion, Ozone Formation (Human Health), Ozone Formation (Terrestrial Ecosystems), Stratospheric-Ozone Depletion, Terrestrial Acidification, Terrestrial Ecotoxicity, Water Consumption.

- ReCiPe 2016 Endpoint (H)

Particulate-Matter Formation, Fossil Depletion, Freshwater Ecotoxicity, Freshwater Eutrophication, Climate Change (Freshwater Ecosystems), Climate Change (Human Health), Climate Change (Terrestrial Ecosystems), Human Carcinogenic Toxicity, Human Non-Carcinogenic Toxicity, Ionising Radiation, Land Use, Marine Ecotoxicity, Marine Eutrophication, Mineral Depletion, Ozone Formation (Human Health), Ozone Formation (Terrestrial Ecosystems), Stratospheric-Ozone Depletion, Terrestrial Acidification, Terrestrial Ecotoxicity, Water Consumption (Aquatic Ecosystems), Water Consumption (Human Health), Water Consumption (Terrestrial Ecosystems).

INVENTORY ANALYSIS PHASE (LCI)

The inventories were compiled from the secondary sources cited in the references and therefore constitute a body of information that fulfils the requirements established during the Goal and Scope Definition Phase. For the two product systems considered, the following processes were included:

BX Product System (B7 and B15):

- Exploration, production, transport and distribution of B7
- Exploration, production, transport and distribution of B15
- Production and distribution of ARLA 32
- Use of B7
- Use of B15
- Vehicle production
- Vehicle maintenance

B100 Product System:

- Production, transport, and distribution of B100
- Production and distribution of ARLA 32
- Use of B100
- Vehicle production
- Vehicle maintenance

Thus, the inventories common to both product systems are: production and distribution of ARLA 32, vehicle manufacturing, and vehicle maintenance. Beyond the effects of the allocation procedures, these inventories also incorporate the distance assumptions associated with transport and distribution processes. A detailed discussion of these aspects lies outside the scope of the present text; their traceability is ensured through the cited references. Full inventories are provided in the annexes.

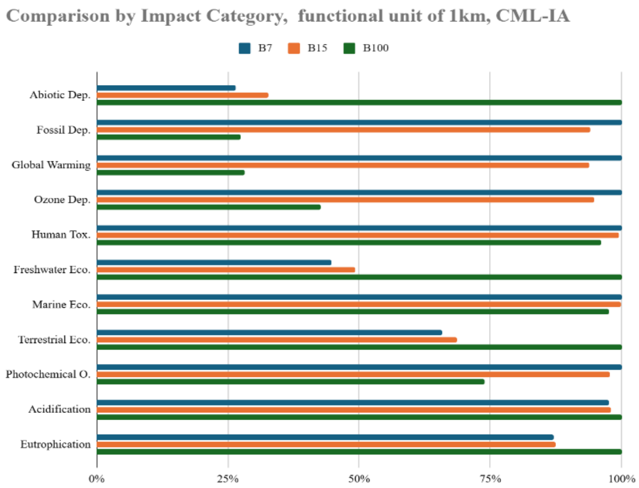
IMPACT ASSESSMENT PHASE (LCIA)

CML-IA Method

Table 1 and Figure 1 present the impacts for B7, B15, and B100 under the reference condition (50 % passenger load).

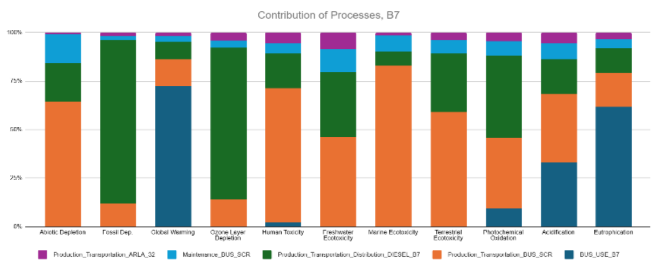
Impact Category	Unit	B7	B15	B100
Abiotic Dep.	kg Sb eq.	2,91E-07	3,59E-07	1,10E-06
Fossil Dep.	MJ	2,81E+01	2,64E+01	7,72E+00
Global Warming	kg CO2 eq.	1,67E+00	1,57E+00	4,69E-01
Ozone Dep.	kg CFC-11 eq.	9,72E-08	9,21E-08	4,14E-08
Human Tox.	kg 1.4-DB eq.	1,27E-01	1,26E-01	1,22E-01
Freshwater Eco.	kg 1.4-DB eq.	6,87E-03	7,57E-03	1,54E-02
Marine Eco.	kg 1.4-DB eq.	4,28E+02	4,27E+02	4,18E+02
Terrestrial Eco.	kg 1.4-DB eq.	5,14E-04	5,36E-04	7,80E-04
Photochemical O.	kg C2H4 eq.	1,69E-04	1,65E-04	1,25E-04
Acidification	kg SO2 eq.	4,10E-03	4,12E-03	4,20E-03
Eutrophication	kg $PO4^{3}$ eq.	5,63E-04	5,65E-04	6,46E-04

Table 1: Impacts for B7, B15, and B100 at 50 % passenger load, functional unit of 1 km travelled, CML-IA.

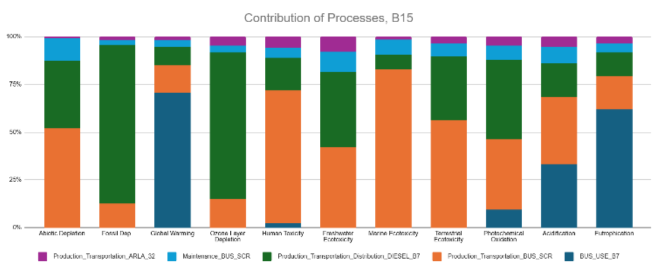


Graph 1: Impacts for B7, B15, and B100 at 50 % passenger load, functional unit of 1 km travelled, CML-IA.

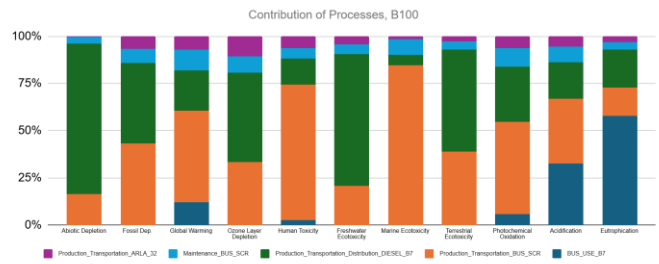
Similarly, Graphs 2, 3, and 4 present the contribution analysis for B7, B15, and B100, respectively, under the same condition.



Graph 2: Contribution analysis for B7.



Graph 3: Contribution analysis for B15.

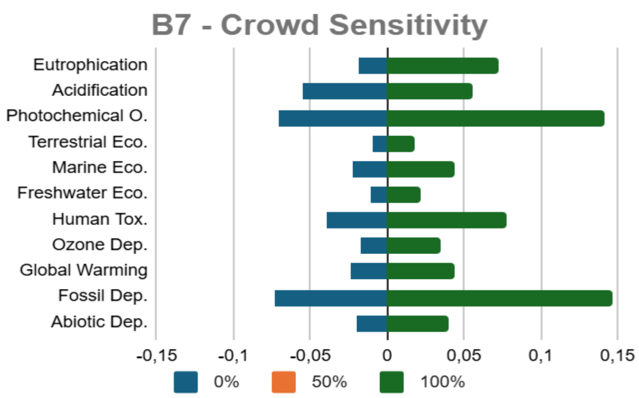


Graph 4: Contribution analysis for B100.

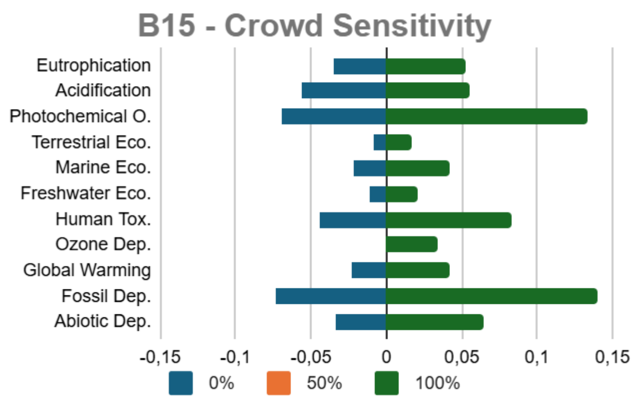
Based on the variation in consumption presented in Table 2, a sensitivity analysis was performed with respect to passenger load; see Graphs 5, 6, and 7.

Consumption [km/l]			
Condition	**B7**	**B15**	**B100**
0% capacity	2,42	2,4	2,27
50% capacity	2,17	2,16	2,04
100% capacity	1,81	1,8	1,7

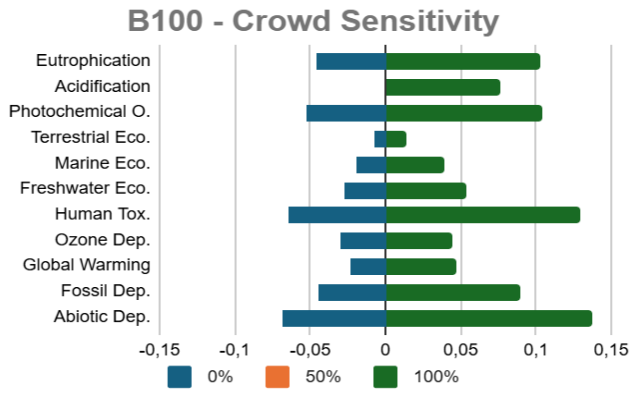
Table 2: Fuel consumption for B7, B15, and B100 under three passenger-load conditions.



Graph 5: Sensitivity to passenger load for B7.



Graph 6: Sensitivity to passenger load for B15.



Graph 7: Sensitivity to passenger load for B100.

The impacts estimated with the ReCiPe 2016 Midpoint (H) and Endpoint (H) methods are presented in Annexes 10 and 11.

RESULTS INTERPRETATION PHASE

CML-IA Method

When analysing the normalized impact categories in Figure 1, it was observed that none of the fuels offers exclusive benefits compared with the others. Fuels with a higher fossil-fuel content (B7 and B15) showed greater environmental impact in the following categories: Photochemical Oxidation, Marine Ecotoxicity, Human Toxicity, Stratospheric-Ozone Depletion, Global Warming Potential (GWP 100a) and Abiotic Depletion. In contrast, B100 exhibited higher impacts in Eutrophication, Acidification, Terrestrial Ecotoxicity, Freshwater Ecotoxicity and Abiotic Depletion. Although B7 and B15 displayed similar profiles across most categories in the presence of B100, a direct comparison between B7 and B15 reveals some differences attributable to their composition (B15 contains 8 % more biodiesel than B7). On average, B15 showed about a 5 % reduction in normalized impacts relative to B7, highlighting the advantage of a higher biodiesel share in the diesel blend. The contribution analysis indicated that B7 and B15 share similar profiles for all categories except Abiotic Depletion, where production and transport of B15 had a higher impact than B7. Comparing B7 and B15 with B100, the largest differences were found in Abiotic Depletion, Fossil Depletion, Global Warming (GWP 100), Stratospheric-Ozone Depletion and Freshwater Ecotoxicity. The Production, Transport and Distribution process for B100 naturally alters the contribution pattern of the other processes. Because they originate from common inventories, the processes for Bus Maintenance, ARLA 32 Production and Bus Manufacturing have identical absolute impacts across all categories. Bus Maintenance and ARLA 32 Production and Transport make small and similar contributions, each accounting for about 6 % of total impacts on all fuels. Bus Manufacturing, however, contributed significantly to most categories, particularly Abiotic Depletion, Human Toxicity, and Freshwater, Marine and Terrestrial Ecotoxicity. Likewise, fuel use was highly relevant for three categories: Acidification, Eutrophication and Global Warming. For the first two, this process showed slightly higher impacts for B7 and B15 compared with B100. For Global Warming, B7 and B15 each accounted for around 70 % of the category's total impact. Moreover, for B7 and B15, fuel production contributed to the most impact categories—especially Stratospheric-Ozone Depletion and Fossil Abiotic Depletion—representing roughly 80 % of the total in these categories. For B100, the principal impact was Abiotic Depletion. Finally, the sensitivity analysis showed that, for all fuels, operating at maximum passenger load (100 %) increased impacts in every category compared with the reference (50 %) and empty (0 %) conditions. The magnitude of the increase at full load was greater than the magnitude of the decrease at zero load, indicating higher sensitivity in the fully loaded condition. Under this aspect, B100 proved even more sensitive than B7 and B15.

ReCiPe 2016 Midpoint (H) Method

In this analysis, the impact categories Water Consumption, Ionising Radiation, and Land Use were excluded because they showed no significant impact. The full results are compiled in Annex 10, which confirms that the Bus Maintenance and ARLA 32 Production processes make the smallest contributions for all three fuels (average variation of about 6 %). The Fuel Production process accounts for an average of 22 % of the normalized impact for B100 and 17 % for B7 and B15—a finding that is not intuitive, since one might initially assume that producing B100 would entail lower impacts than producing B7 or B15. Conversely, B100 exhibits lower total impacts than B7 and B15 in the categories Terrestrial Ecotoxicity, Stratospheric-Ozone Depletion, Human Carcinogenic Toxicity, Climate Change, and Fossil Resource Use. Bus Manufacturing, common to all three fuels, shows an average normalized impact of 34 %, underscoring its importance in the overall impact profile, particularly for Mineral Resource Scarcity, Human Carcinogenic Toxicity, Freshwater Eutrophication, and Freshwater Ecotoxicity. Finally, the Use phase contributes an average of 22 % to normalized impacts, with especially high values in specific categories such as Stratospheric-Ozone Depletion, Tropospheric Ozone Formation – Terrestrial Ecosystems, Tropospheric Ozone Formation – Human Health, and Climate Change (for B7 and B15).

ReCiPe 2016 Endpoint (E) Method

In this analysis, the impact categories Ionising Radiation, Land Use, Water Consumption (Aquatic Ecosystems), Water Consumption (Human Health), and Water Consumption (Terrestrial Ecosystems) were excluded because they showed no relevant contributions. Expanded results are compiled in Annex 11, from which it can be seen that, for B100, the lowest impacts occur in the categories Terrestrial Ecotoxicity, Stratospheric-Ozone Depletion, Human Carcinogenic Toxicity, Climate Change (three sub-categories), and Fossil Resource Scarcity. The last two exhibit particularly large reductions, which supports the adoption of this biofuel in decarbonization and carbon-footprint-reduction strategies. Conversely, B100 shows higher impacts than B7 and B15 in Marine Eutrophication, Human Non-Carcinogenic Toxicity, and Freshwater Eutrophication, owing to the Fuel-Production process. The Bus-Maintenance and ARLA 32 Production processes make only minor contributions for all three fuels, with an average normalized impact of about 6 %. The Bus-Production process—common to all fuels—accounts for an average normalized impact of 32 %, with notable contributions to Mineral Resource Scarcity and Human Carcinogenic Toxicity. The Fuel-Production and Transport process yields an average normalized impact of 18 %, driving particularly high values for Marine Eutrophication in B100 and for Fossil Resource Scarcity in B7 and B15. Finally, the Use phase shows an average normalized impact of 25 %, with significant contributions to Stratospheric-Ozone Depletion, Tropospheric Ozone Formation (both sub-categories), and the three Climate-Change sub-categories—especially for B7 and B15.

CONCLUSIONS

The comparative Life-Cycle Assessment showed that adopting blends with higher biodiesel content entails significant environmental trade-offs. B100 consistently reduced the global-warming potential and lowered dependence on fossil resources, aligning well with national decarbonization targets and energy-security goals. Conversely, its higher impacts in eutrophication, acidification, and ecotoxicity point to the need for agricultural policies and technological pathways that curb emissions and effluents along the biodiesel supply chain. For the B7 and B15 blends, an almost identical environmental profile was observed, with marginal advantages for B15 in aquatic ecosystems and abiotic depletion; however, both remain more greenhouse-gas-intensive than B100. Sensitivity analysis revealed that vehicle load influences impact more strongly than the differences between B7 and B15, and that B100 is more susceptible to load variations, highlighting the importance of optimized fleet operation. Operationally, bus manufacturing and in-use fuel consumption accounted for substantial shares of the impacts, indicating that strategies to extend vehicle service life and improve energy efficiency may yield greater absolute reductions than merely switching fuels. In short, no single fuel maximizes all environmental benefits. Fuel choice must therefore be prioritized according to public-policy objectives: if greenhouse-gas mitigation is paramount, B100 is favored; if protection of aquatic and terrestrial ecosystems is emphasized, intermediate blends or upstream agricultural controls may be more appropriate. Future studies should explore second-generation biodiesel pathways, update regional inventories, and assess carbon-credit schemes to inform more refined decision-making for urban public transport.

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ANNEXES

Inputs			
Flow	**Category**	**Amount**	**Unit**
Bromine	Elementary flows/Resource/unspecified	8,11E-06	kg
Gas, mine, off-gas, process, coal mining	Elementary flows/Resource/unspecified	5,30E-01	m3
Iodine	Elementary flows/Resource/unspecified	1,55E-06	kg
Oil, crude, in ground	Elementary flows/Resource/unspecified	7,70E-01	kg
Sulfur	Elementary flows/Resource/unspecified	2,76E-04	kg
Outputs			
Flow	**Category**	**Amount**	**Unit**
Aldicarb	Elementary flows/Emission to soil/unspecified	7,28E-09	kg
Barium	Elementary flows/Emission to water/unspecified	1,29E-05	kg
Benzene	Elementary flows/Emission to air/unspecified	1,53E-05	kg
Carbon dioxide, fossil	Elementary flows/Emission to air/unspecified	2,69E-01	kg
Carbon monoxide, fossil	Elementary flows/Emission to air/unspecified	3,45E-03	kg
COD, Chemical Oxygen Demand	Elementary flows/Emission to water/unspecified	1,43E-03	kg
Cypermethrin	Elementary flows/Emission to soil/unspecified	3,37E-10	kg
Formaldehyde	Elementary flows/Emission to water/unspecified	8,45E-07	kg
Hydrogen fluoride	Elementary flows/Emission to air/unspecified	1,47E-06	kg
Mercury	Elementary flows/Emission to air/unspecified	9,32E-09	kg
Methane, bromotrifluoro-, Halon 1301	Elementary flows/Emission to air/unspecified	1,37E-08	kg
Methane, fossil	Elementary flows/Emission to air/unspecified	2,23E-03	kg
Nickel	Elementary flows/Emission to air/unspecified	1,71E-07	kg
Nitrogen oxides	Elementary flows/Emission to air/unspecified	8,69E-04	kg
Phenol	Elementary flows/Emission to water/unspecified	3,14E-06	kg
Phosphate	Elementary flows/Emission to water/unspecified	1,03E-05	kg
Production_Transportation_BIODIESEL_B7		**1,00E+00**	**l**
Sulfur dioxide	Elementary flows/Emission to air/unspecified	9,75E-04	kg

Annex 1: Inventory (kg) for production, transport, and distribution of 1 liter of B7.

Inputs			
Flow	**Category**	**Amount**	**Unit**
Bromine	Elementary flows/Resource/unspecified	1,74E-05	kg
Gas, mine, off-gas, process, coal mining	Elementary flows/Resource/unspecified	4,92E-01	m3
Iodine	Elementary flows/Resource/unspecified	3,32E-06	kg
Oil, crude, in ground	Elementary flows/Resource/unspecified	7,09E-01	kg
Sulfur	Elementary flows/Resource/unspecified	5,92E-04	kg
Outputs			
Flow	**Category**	**Amount**	**Unit**
Aldicarb	Elementary flows/Emission to soil/unspecified	1,53E-08	kg
Barium	Elementary flows/Emission to water/unspecified	1,39E-05	kg
Benzene	Elementary flows/Emission to air/unspecified	1,44E-05	kg
Carbon dioxide, fossil	Elementary flows/Emission to air/unspecified	2,58E-01	kg
Carbon monoxide, fossil	Elementary flows/Emission to air/unspecified	3,19E-03	kg
COD, Chemical Oxygen Demand	Elementary flows/Emission to water/unspecified	1,33E-03	kg
Cypermethrin	Elementary flows/Emission to soil/unspecified	7,02E-10	kg
Formaldehyde	Elementary flows/Emission to water/unspecified	1,80E-06	kg
Hydrogen fluoride	Elementary flows/Emission to air/unspecified	1,40E-06	kg
Mercury	Elementary flows/Emission to air/unspecified	8,77E-09	kg
Methane, bromotrifluoro-, Halon 1301	Elementary flows/Emission to air/unspecified	1,27E-08	kg
Methane, fossil	Elementary flows/Emission to air/unspecified	2,11E-03	kg
Nickel	Elementary flows/Emission to air/unspecified	1,61E-07	kg
Nitrogen oxides	Elementary flows/Emission to air/unspecified	8,70E-04	kg
Phenol	Elementary flows/Emission to water/unspecified	3,00E-06	kg
Phosphate	Elementary flows/Emission to water/unspecified	1,07E-05	kg
Production_Transportation_BIODIESEL_B15		**1,00E+00**	**l**
Sulfur dioxide	Elementary flows/Emission to air/unspecified	9,78E-04	kg

Annex 2: Inventory (kg) for production, transport, and distribution of 1 liter of B15.

Inputs			
Flow	**Category**	**Amount**	**Unit**
Bromine	Elementary flows/Resource/unspecified	1,16E-04	kg
Energy, from oil	Elementary flows/Resource/unspecified	8,30E-01	MJ
Gas, mine, off-gas, process, coal mining	Elementary flows/Resource/unspecified	9,09E-02	m3
Iodine	Elementary flows/Resource/unspecified	2,21E-05	kg
Oil, crude, in ground	Elementary flows/Resource/unspecified	6,30E-02	kg
Sulfur	Elementary flows/Resource/unspecified	3,95E-03	kg
Outputs			
Flow	**Category**	**Amount**	**Unit**
Aldicarb	Elementary flows/Emission to soil/unspecified	1,01E-07	kg
Barium	Elementary flows/Emission to water/unspecified	2,50E-05	kg
Benzene	Elementary flows/Emission to air/unspecified	4,55E-06	kg
Benzene	Elementary flows/Emission to water/unspecified	3,76E-06	kg
Carbon dioxide	Elementary flows/Emission to air/unspecified	2,45E-02	kg
Carbon dioxide, fossil	Elementary flows/Emission to air/unspecified	1,39E-01	kg
Carbon dioxide, land transformation	Elementary flows/Emission to air/unspecified	2,02E-02	kg
Carbon monoxide, fossil	Elementary flows/Emission to air/unspecified	4,29E-04	kg
Cypermethrin	Elementary flows/Emission to soil/unspecified	4,58E-09	kg
Formaldehyde	Elementary flows/Emission to water/unspecified	1,20E-05	kg
Hydrogen fluoride	Elementary flows/Emission to air/unspecified	6,01E-07	kg
Mercury	Elementary flows/Emission to air/unspecified	2,94E-09	kg
Methane, bromochlorodifluoro-, Halon 1211	Elementary flows/Emission to air/unspecified	6,87E-10	kg
Methane, bromotrifluoro-, Halon 1301	Elementary flows/Emission to air/unspecified	1,97E-09	kg
Methane, fossil	Elementary flows/Emission to air/unspecified	8,50E-04	kg
Methane, tetrachloro-, CFC-10	Elementary flows/Emission to air/unspecified	1,66E-08	kg
Methane, tetrachloro-, R-10	Elementary flows/Emission to air/unspecified	1,66E-08	kg
Methanol	Elementary flows/Emission to air/unspecified	5,65E-05	kg
Nitrate	Elementary flows/Emission to water/unspecified	9,21E-04	kg
Nitrogen oxides	Elementary flows/Emission to air/unspecified	8,85E-04	kg
Phosphorus	Elementary flows/Emission to water/unspecified	1,74E-05	kg
Production_Transportation_BIODIESEL_B100		**1,00E+00**	**l**
Sulfur dioxide	Elementary flows/Emission to air/unspecified	1,01E-03	kg

Annex 3: Inventory (kg) for production, transport, and distribution of 1 liter of B100.

Inputs			
Flow	**Category**	**Amount**	**Unit**
Manutenção_ÔNIBUS_SCR		8,47E-07	Item(s)
Produção_Transporte_ARLA_32		2,30E-02	l
Produção_Transporte_DIESEL_B7		4,60E-01	l
Produção_Transporte_ÔNIBUS_SCR		8,47E-07	Item(s)
Outputs			
Flow	**Category**	**Amount**	**Unit**
Carbon dioxide, fossil	Elementary flows/Emission to air/unspecified	1,19E+00	kg
Carbon monoxide, fossil	Elementary flows/Emission to air/unspecified	4,50E-04	kg
Dinitrogen monoxide	Elementary flows/Emission to air/unspecified	6,34E-05	kg
Methane	Elementary flows/Emission to air/unspecified	6,34E-05	kg
Nitrogen oxides	Elementary flows/Emission to air/unspecified	2,54E-03	kg
NMVOC, non-methane volatile organic compounds, unspecified origin	Elementary flows/Emission to air/unspecified	1,70E-05	kg
Particulates	Elementary flows/Emission to air/unspecified	2,16E-05	kg
Sulfur dioxide	Elementary flows/Emission to air/unspecified	7,15E-05	kg
USO_ÔNIBUS_B7		**1**	**km**

Annex 4: Inventory (kg) for the combustion of B7 per 1 km travelled.

Inputs			
Flow	**Category**	**Amount**	**Unit**
Maintenance_BUS_SCR		8,47E-07	Item(s)
Production_Transportation_ARLA_32		2,31E-02	l
Production_Transportation_BIODIESEL_15		4,63E-01	l
Production_Transportation_BUS_SCR		8,47E-07	Item(s)
Outputs			
Flow	**Category**	**Amount**	**Unit**
Carbon dioxide, fossil	Elementary flows/Emission to air/unspecified	1,09E+00	kg
Carbon monoxide, fossil	Elementary flows/Emission to air/unspecified	4,28E-04	kg
Dinitrogen monoxide	Elementary flows/Emission to air/unspecified	6,34E-05	kg
Methane	Elementary flows/Emission to air/unspecified	6,34E-05	kg
Nitrogen oxides	Elementary flows/Emission to air/unspecified	2,56E-03	kg
NMVOC, non-methane volatile organic compounds, unspecified origin	Elementary flows/Emission to air/unspecified	1,65E-05	kg
Particulates	Elementary flows/Emission to air/unspecified	1,98E-05	kg
Sulfur dioxide	Elementary flows/Emission to air/unspecified	7,15E-05	kg
USE_BUS_B15		**1,00E+00**	**km**

Annex 5: Inventory (kg) for the combustion of B15 per 1 km travelled.

Inputs			
Flow	**Category**	**Amount**	**Unit**
Maintenance_BUS_SCR		8,47E-07	Item(s)
Production_Transportation_ARLA_32		2,45E-02	l
Production_Transportation_BIODIESEL_B100		4,91E-01	l
Production_Transportation_BUS_SCR		8,47E-07	Item(s)
Outputs			
Flow	**Category**	**Amount**	**Unit**
Carbon dioxide, fossil	Elementary flows/Emission to air/unspecified	3,79E-02	kg
Carbon monoxide, fossil	Elementary flows/Emission to air/unspecified	2,47E-04	kg
Dinitrogen monoxide	Elementary flows/Emission to air/unspecified	6,34E-05	kg
Methane	Elementary flows/Emission to air/unspecified	6,34E-05	kg
Nitrogen oxides	Elementary flows/Emission to air/unspecified	2,74E-03	kg
NMVOC, non-methane volatile organic compounds, unspecified origin	Elementary flows/Emission to air/unspecified	1,11E-05	kg
Particulates	Elementary flows/Emission to air/unspecified	7,26E-03	kg
Sulfur dioxide	Elementary flows/Emission to air/unspecified	0,00E+00	kg
USE_BUS_B100		**1,00E+00**	**km**

Annex 6: Inventory (kg) for the combustion of B100 per 1 km travelled.

Inputs			
Flow	**Category**	**Amount**	**Unit**
Cadmium	Elementary flows/Resource/unspecified	3,65E-01	kg
Chromium	Elementary flows/Resource/unspecified	1,54E+02	kg
Coal, hard	Elementary flows/Resource/unspecified	6,05E+04	kg
Coal, hard, unspecified, in ground	Elementary flows/Resource/unspecified	6,05E+04	kg
Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	Elementary flows/Resource/unspecified	2,25E+01	kg
Gas, mine, off-gas, process, coal mining	Elementary flows/Resource/unspecified	3,08E+04	m3
Lead	Elementary flows/Resource/unspecified	6,08E+00	kg
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	Elementary flows/Resource/unspecified	3,98E+02	kg
Oil, crude, in ground	Elementary flows/Resource/unspecified	1,57E+04	kg
Outputs			
Flow	**Category**	**Amount**	**Unit**
Barium	Elementary flows/Emission to water/unspecified	1,58E+01	kg
Benzene	Elementary flows/Emission to air/unspecified	4,38E+00	kg
Carbon dioxide, fossil	Elementary flows/Emission to air/unspecified	2,29E+05	kg
Carbon dioxide, land transformation	Elementary flows/Emission to air/unspecified	1,74E+04	kg
Carbon monoxide, fossil	Elementary flows/Emission to air/unspecified	3,90E+02	kg
Chromium VI	Elementary flows/Emission to air/unspecified	1,47E-02	kg
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Elementary flows/Emission to air/lower stratosphere + upper troposphere	3,79E-03	kg
Hydrogen fluoride	Elementary flows/Emission to air/unspecified	9,93E+00	kg
Mercury	Elementary flows/Emission to air/unspecified	1,04E-02	kg
Methane, bromochlorodifluoro-, Halon 1211	Elementary flows/Emission to air/unspecified	3,92E-04	kg
Methane, bromotrifluoro-, Halon 1301	Elementary flows/Emission to air/unspecified	8,75E-04	kg
Methane, fossil	Elementary flows/Emission to air/unspecified	7,16E+02	kg
Nickel	Elementary flows/Emission to air/unspecified	1,57E-01	kg
Nitrate	Elementary flows/Emission to water/unspecified	7,96E+01	kg
Nitrogen oxides	Elementary flows/Emission to air/unspecified	5,90E+02	kg
Phosphate	Elementary flows/Emission to water/unspecified	3,14E+01	kg
Production_Transportation_BUS_SCR		**1,00E+00**	**Item(s)**
Sulfur dioxide	Elementary flows/Emission to air/unspecified	1,17E+03	kg

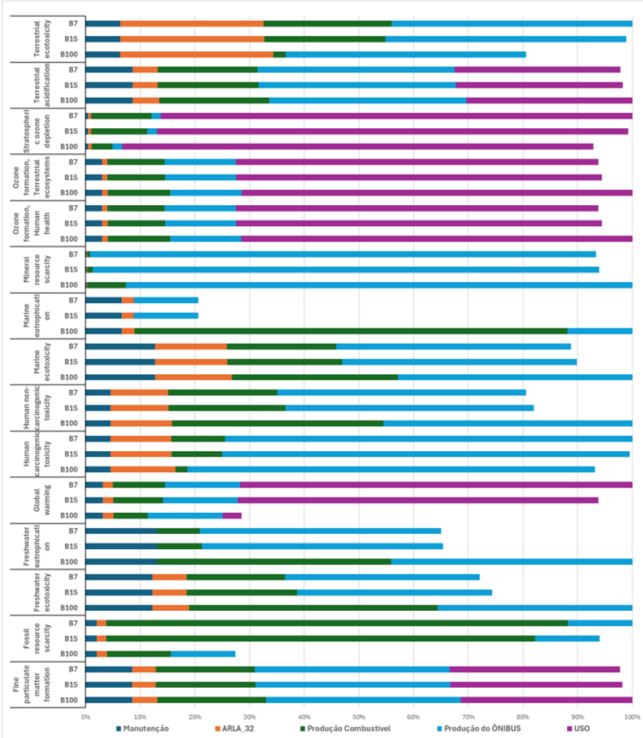
Annex 7: Inventory (kg) for the production and transport of one vehicle.

Inputs			
Flow	**Category**	**Amount**	**Unit**
Cadmium	Elementary flows/Resource/unspecified	1,72E-01	kg
Coal, hard	Elementary flows/Resource/unspecified	1,82E+04	kg
Gas, mine, off-gas, process, coal mining	Elementary flows/Resource/unspecified	6,02E+03	m3
Lead	Elementary flows/Resource/unspecified	2,86E+00	kg
Oil, crude, in ground	Elementary flows/Resource/unspecified	3,09E+03	kg
Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In, in ground	Elementary flows/Resource/unspecified	4,17E-03	kg
Outputs			
Flow	**Category**	**Amount**	**Unit**
Aldicarb	Elementary flows/Emission to soil/unspecified	4,30E-04	kg
Ammonium, ion	Elementary flows/Emission to water/unspecified	5,58E+00	kg
Barium	Elementary flows/Emission to water/unspecified	1,38E+00	kg
Benzene	Elementary flows/Emission to air/unspecified	4,51E-01	kg
Carbon dioxide, fossil	Elementary flows/Emission to air/unspecified	5,68E+04	kg
Chromium VI	Elementary flows/Emission to air/unspecified	5,84E-04	kg
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Elementary flows/Emission to air/lower stratosphere + upper troposphere	1,14E-03	kg
Hydrogen fluoride	Elementary flows/Emission to air/unspecified	9,67E-01	kg
Maintenance_BUS_SCR		**1,00E+00**	**Item(s)**
Mercury	Elementary flows/Emission to air/unspecified	1,25E-03	kg
Methane, bromochlorodifluoro-, Halon 1211	Elementary flows/Emission to air/unspecified	1,13E-04	kg
Methane, bromotrifluoro-, Halon 1301	Elementary flows/Emission to air/unspecified	2,07E-04	kg
Methane, fossil	Elementary flows/Emission to air/unspecified	1,72E+02	kg
Nickel	Elementary flows/Emission to air/unspecified	2,54E-02	kg
Nickel	Elementary flows/Emission to water/unspecified	1,09E-02	kg
Nitrate	Elementary flows/Emission to water/unspecified	2,56E+01	kg
Nitrogen oxides	Elementary flows/Emission to air/unspecified	1,35E+02	kg
Phosphate	Elementary flows/Emission to water/unspecified	9,30E+00	kg
Sulfur dioxide	Elementary flows/Emission to air/unspecified	2,82E+02	kg
Vanadium, ion	Elementary flows/Emission to water/unspecified	6,10E-02	kg

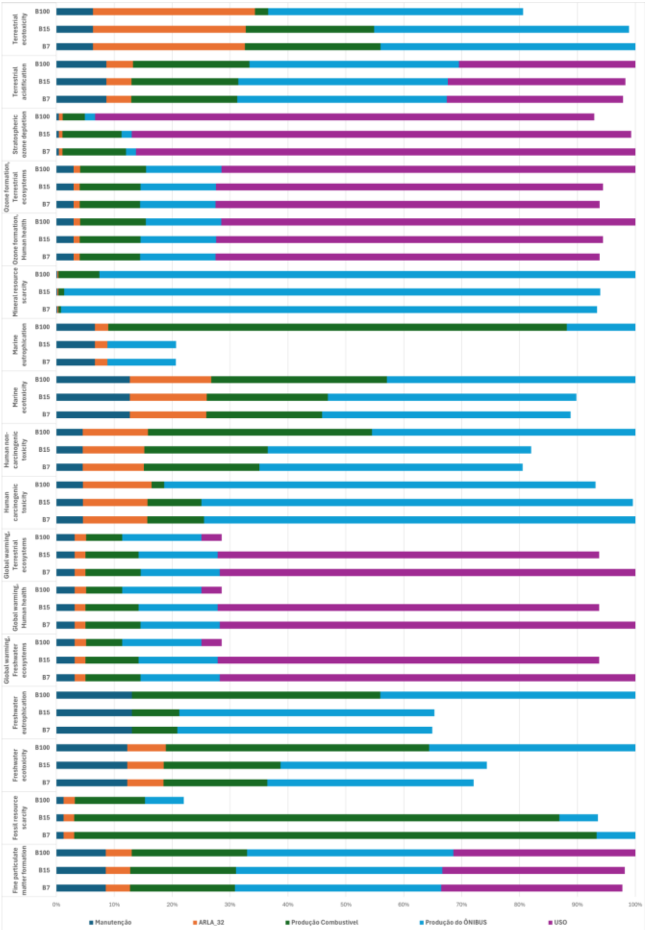
Annex 8: Inventory (kg) for the maintenance of one vehicle.

Inputs			
Flow	**Category**	**Amount**	**Unit**
Copper, 1.13% in sulfide, Cu 0.76% and Ni 0.76% in crude ore, in ground	Elementary flows/Resource/unspecified	5,02E-05	kg
Copper, Cu 3.2E+0%, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0% in ore	Elementary flows/Resource/unspecified	3,45E-05	kg
Gas, mine, off-gas, process, coal mining	Elementary flows/Resource/unspecified	3,42E-01	m3
Oil, crude, in ground	Elementary flows/Resource/unspecified	2,28E-01	kg
Outputs			
Flow	**Category**	**Amount**	**Unit**
Ammonia, BR	Elementary flows/Emission to air/unspecified	1,45E-03	kg
Ammonium, ion	Elementary flows/Emission to water/unspecified	1,56E-04	kg
Barium	Elementary flows/Emission to water/unspecified	9,92E-05	kg
Benzene	Elementary flows/Emission to air/unspecified	1,24E-05	kg
Cadmium	Elementary flows/Emission to air/unspecified	2,54E-07	kg
Carbon dioxide, fossil	Elementary flows/Emission to air/unspecified	1,26E+00	kg
Carbon monoxide, fossil	Elementary flows/Emission to air/unspecified	1,65E-03	kg
COD, Chemical Oxygen Demand	Elementary flows/Emission to water/unspecified	2,24E-03	kg
Hydrogen fluoride	Elementary flows/Emission to air/unspecified	4,01E-06	kg
Mercury	Elementary flows/Emission to air/unspecified	8,12E-09	kg
Methane, bromochlorodifluoro-, Halon 1211	Elementary flows/Emission to air/unspecified	1,98E-09	kg
Methane, bromotrifluoro-, Halon 1301	Elementary flows/Emission to air/unspecified	1,38E-08	kg
Methane, fossil	Elementary flows/Emission to air/unspecified	2,81E-03	kg
Nickel	Elementary flows/Emission to air/unspecified	5,06E-06	kg
Nitrogen oxides	Elementary flows/Emission to air/unspecified	1,75E-03	kg
Production_Transportation_ARLA_32		**1,00E+00**	**l**
Sulfur dioxide	Elementary flows/Emission to air/unspecified	5,41E-03	kg

Annex 9: Inventory (kg) for the production and transport of 1 liter of ARLA 32.



Annex 10: Life-Cycle Impact Assessment using ReCiPe Midpoint.



Annex 11: Life-Cycle Impact Assessment using ReCiPe Endpoint.