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1 **LIFE CYCLE ASSESSMENT TO SUPPORT DECISION-MAKING IN**  
2 **TRANSPORTATION PLANNING: A CASE OF FRENCH BUS RAPID TRANSIT**

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4  
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## 1       **ABSTRACT**

2  
3       This article discusses the potential of Life Cycle Assessment (LCA) as a support tool for  
4 decision-making in transportation planning.

5  
6       After summarizing the LCA method, it applies it to a bi-articulated Bus Rapid Transit  
7 system built around Fort de France, in Martinique, and a standard diesel bus rolling stock  
8 alternative. The system boundaries include operation, and the vehicle and infrastructure  
9 components. This case study forms the basis for discussions over the inclusion of LCA in  
10 project processes, the issues and impediments, and its incorporation into mandatory Cost-  
11 Benefit Analysis in France.

12  
13       The results show the project's contributions to environmental impacts, captured via a set of  
14 13 indicators. Bus fuel has a low impact on some indicators like solid waste or aquatic  
15 toxicities but a substantial impact (35 to 57%) on acidification, eutrophication, and climate  
16 change, demonstrating the importance of considering the entire system. With regard to  
17 infrastructure, hubs account for 25% of impact, while lighting can be substantial (up to 20%).  
18 Bi-articulated buses are a better option than standard diesel buses on most indicators under the  
19 assumptions of this study. However, modal environmental performances are highly context-  
20 sensitive. The impacts are normalized against those of the average passenger car, and  
21 compared with those of high-occupancy car modes.

22  
23       LCA could be used at every stage of project or policy design, with varying precision.  
24 However, its implementation is restricted by several factors, notably understanding and  
25 adoption by decision-makers, which are affected by issues such as results interpretation, extra  
26 workload and lack of dedicated tools.

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30       *Keywords:* Decision making support, Life Cycle Assessment, Transportation planning, Bus  
31                   Rapid Transit, Environmental alternative, rolling stocks, normalization  
32

# 1 INTRODUCTION

## 2 3 **Context**

4 Transportation is very valuable to territorial socioeconomic development. Urban  
5 populations are expected to go on rising in future decades, leading to a concentration of  
6 mobility needs in cities. The objective of transportation planning is to meet, anticipate and  
7 steer travel demand, through policy design and investment decisions. Standard selection  
8 processes use a range of established methods, common to much of the international  
9 community of transportation specialists. Cost-Benefit Analysis (CBA) in particular, also  
10 called socioeconomic analysis, offers simple indicators like Net Present Value (NPV) to  
11 assess project benefits.

12 Useful to society though it is, transportation is one of the biggest contributors to human  
13 environmental stresses on the planet. In France, for example, transportation accounts for 20%  
14 of greenhouse gas emissions (1). While some environmental impacts are taken into account in  
15 CBA, given the growing importance of ecological factors, their role and representativeness  
16 have to be addressed. In France, these effects encompass emissions of Greenhouse Gases  
17 (GHG) and atmospheric pollutants (e.g. NO<sub>x</sub>, PM<sub>2,5</sub>, VOCs and SO<sub>2</sub>) from operation, noise  
18 and, more recently, some of the energy consumption. However, CBA omits other issues such  
19 as resource depletion and waste, or damage to habitat (2). Moreover, the scope of CBA is  
20 typically restricted to operation. On the contrary, Life Cycle Assessment (LCA) is a  
21 multicriteria assessment methodology that takes into account broad-spectrum environmental  
22 performance as well as the full physical system and life cycle of transportation modes.

## 23 24 **Objective and background**

25 The objective of this paper is to borrow from LCA the elements missing from the CBA  
26 method of assessing the environmental performance of transportation modes in France, in  
27 order to make the latter more holistic. A LCA case study is conducted on a French Bus Rapid  
28 Transit project, to capture the impacts of infrastructure, vehicles, and operation. Two  
29 alternative rolling stock types are presented. The key parameter of passenger travel demand is  
30 discussed.

31 Applied to roads, LCA is now a fairly well-defined field ((3)), despite some difficulties (4).  
32 It has sometimes been applied from a consequential perspective, which considers the impact  
33 on operations of roadway condition or maintenance (4). Numerous LCAs have also been  
34 conducted comparing bus operations ((5), (6), (7), (8), (9), (10)), excluding the nonoperational  
35 components of vehicles. Very few Life Cycle Inventories (LCI) have been carried out on bus  
36 body frames. EcoInvent provides the LCI of “standard” bus body frame production in Europe,  
37 based on an Environmental Product Declaration for the Volvo 8500 bus, as well as standard  
38 bus maintenance and end-of-life LCIs (11). Chester and Horvath (12) developed LCIs of  
39 standard US buses, based on sales statistics. There are few references for LCAs on entire bus  
40 modes ((11), (12), (13)), though one has covered a real Bus Rapid Transit (14) system with a  
41 large perimeter, excluding end-of-life of infrastructure and vehicles. The bus body frame is  
42 adapted from EcoInvent LCIs.

43 This article begins by summarizing the LCA framework and its key steps. It then goes on  
44 to detail the case study of a French Caribbean BRT line by comparison with an alternative  
45 vehicle, followed by an application of the assessment methodology together with an  
46 explanation of the chosen set of 13 indicators. It then discusses the main findings of the case  
47 study, before tackling the broader question of LCA as a potential aid to decision-making in  
48 transportation planning.

49

## **LIFE CYCLE ASSESSMENT FRAMEWORK**

### **Overview**

LCA is a methodology used to estimate the material and energy flows – then the potential environmental impacts – of a system throughout its life cycle: extraction, transportation and processing of raw materials, system production, use/operation, maintenance, and end-of-life processing. It is covered by ISO standards 14 040 and 14 044 ((15), (16)). LCA results show the potential environmental impacts of the system from cradle to grave, in relation to a functional unit.

ISO standard 14040 defines the different steps in performing a LCA, which will be described later. Throughout this process and at each stage, the analyst needs to check, interpret, and monitor work in progress, in order to enhance the assessment and avoid mistakes.

### **Goal and scope**

The first step is to define the objective of the study, in order to develop the best methodology for a given question. This objective will help set the boundaries for the system assessment and to pre-select environmental indicators (impact categories, damage).

At this stage, a functional unit is defined in order to quantify the system's function so that it can be compared with another system. The function of a transportation system is to carry passengers a certain distance, so an appropriate functional unit is the passenger-kilometer.

### **Inventory analysis (17)**

Related to the functional unit, the inventory analysis is a quantitative description of inputs and outputs (emissions in the three different natural domains: water, air, and soil) going through the system, in the form of elementary material and energy flows. For generic processes, one can draw on Life Cycle Inventories (LCI) databases, for example 1 kWh LCIs for average electricity consumption in different locations. This means that a production inventory listing all quantified processes occurring during the life cycle of a system can be enough to conduct a LCA with an adequate LCI database.

Whether a LCI database is used or not, data collection is a long and unavoidable part of preparing a LCA.

### **Environmental impact assessment**

The purpose of this step is to link flow inventories to the potential environmental impacts associated with what happens to those flows. To do so, characterization methods have been developed, based on cutting-edge knowledge in the different disciplines.

There are 2 mandatory steps in a LCI Assessment (LCIA) process (15):

1. selection of impact categories and classification: choice of environmental impacts relevant to the specifics of the study, assignment of elementary flows to impact categories;
2. characterization: application of “characterization factors” to every flow in each category, e.g. application of an “impact score” with a common unit in order to calculate an indicator.

This stage can be followed by two optional steps: normalization and weighting.

### **Interpreting an impact assessment**

In addition to the analyst's continuous interpretation throughout the LCA process, the final step in the LCA is to interpret potential impacts, draw conclusions, and make

1 recommendations, in order to meet the initial goal. Caution is needed, as there are  
2 uncertainties at every stage of the LCA process, which can lead to uncertainty over impacts.

### 3 **CASE STUDY: THE BUS RAPID TRANSIT PROJECT IN FORT DE FRANCE,** 4 **MARTINIQUE**

#### 5 **Transportation planning context in Martinique**

6 The French island of Martinique is located in the middle of the Caribbean archipelago. Its  
7 administrative capital, Fort de France, is home to almost 25% of the population and, with the  
8 nearby town of Lamentin, accounts for half the island's employment (18).

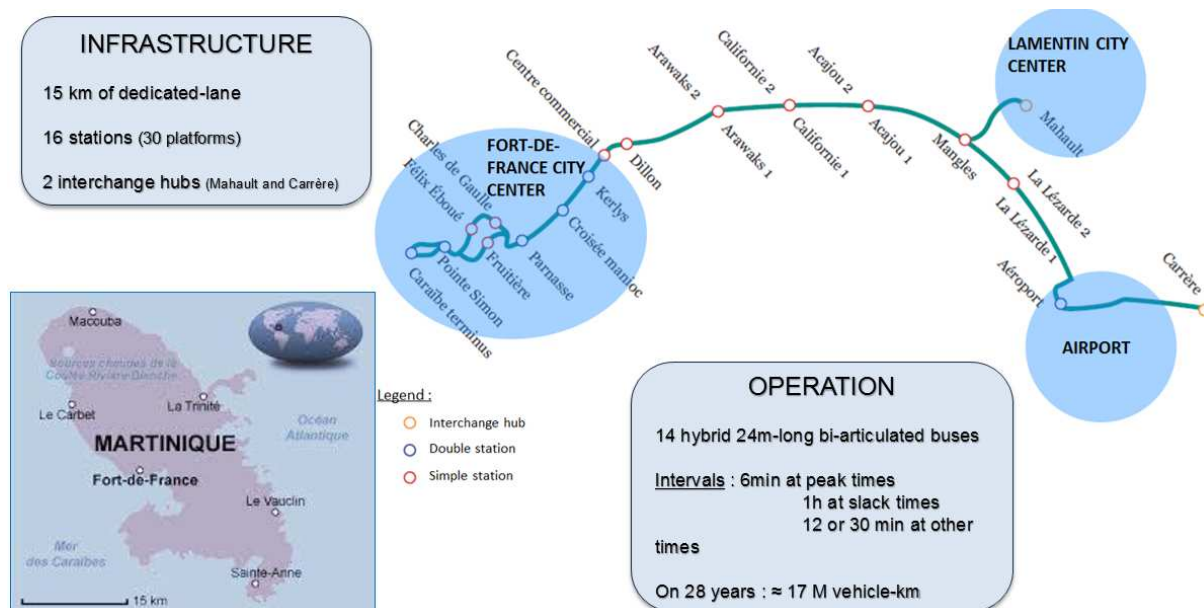
9 According to the Household Travel Survey (19), around 70% of passenger trips are made  
10 by car, rising to 83% in Fort de France. The occupancy rate of passenger cars is around 1.5  
11 people per vehicle. Walking is a more common mode than public transit (number of trips).  
12 As only 10% of people use public transit to commute, congestion has become a daily problem  
13 at peak hours, particularly around Fort de France, where the concentration of activities is high  
14 (20). This situation has prompted a number of transportation schemes, most recently the 2011  
15 regional reform of Martinique Transportation, which promotes the use of public transit and  
16 low environmental impact modes, the development of intermodality, and alternatives to single  
17 occupancy vehicles (20).

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#### **The Bus Rapid Transit project in Fort de France**



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**FIGURE 1 Principal information on the assessed transportation project**

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This forking line, running along a dedicated corridor for a distance of 15 km, will link the center of Fort-de-France to the town of Lamentin and to the airport. It includes 16 stations and 2 interchange hubs, and will be served by 14 hybrid 24 meter-long bi-articulated buses with a capacity of 140 passengers each (see main specifications in FIGURE 1). The line was set to open at the end of 2015.

1 Whereas this article presents figures for an ex-post LCA with respect to physical  
 2 components, and an ex-ante LCA with respect to operations, it aims to compare the type of  
 3 vehicle chosen for this project with another type of rolling stock, as would have been possible  
 4 during the project process, for instance in concept or preliminary designs.

#### 6 *Bus vehicle alternative: standard diesel bus*

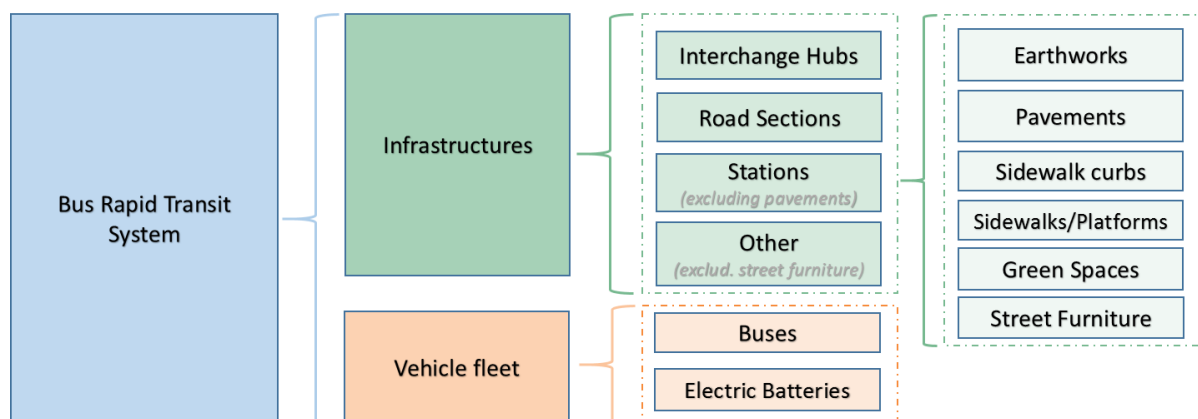
7 The alternative assessed is a 28 vehicle rolling stock of 13 meter long, standard diesel bus  
 8 weighing 11 tons, with a capacity of 70 passengers. They are assumed to have the same 14  
 9 year lifespan as the buses on the real line. This is low considering the potential mileage, but a  
 10 high level of comfort is expected. Usually, such rolling stock is then reused in the regions,  
 11 and then abroad, but these further leases of life are not considered here.

## 12 **METHODOLOGY**

13 This section provided a summary of the assessment methodology. Extensive details can be  
 14 found in de Bortoli et al (21).

### 16 **System boundaries**

17 FIGURE 2 presents the line as modeled in the study. A very wide range of infrastructure  
 18 has been considered, including green spaces, interchange hubs, and street furniture (including  
 19 lighting). Interchange hubs include parking lots. For the vehicle fleet, electric batteries have  
 20 been modeled separately.



22  
 23 **FIGURE 2 Description of the system studied: model per subsystem (column 3) and**  
 24 **per construction batch (column 4)**

26 The following elements were excluded in the absence of data: changing of lightbulbs,  
 27 cleaning and maintenance of streetlamps; management and maintenance of green spaces and  
 28 other street furniture like benches; incorporation of reclaimed asphalt pavement into new  
 29 mixtures, and maintenance of the sidewalk curbs.

### 31 **Database and software**

32 We used EcoInvent 2.1, the benchmark European multi-topic database. It contains  
 33 international industrial data from life cycle inventories on energy supply, resource extraction,  
 34 chemical products, metals, agriculture, waste management services, and transportation  
 35 services. LCIs have been reasonably adapted to the context of the project, in particular in  
 36 terms of the transportation of materials and electricity supply.

37 We chose the OpenLCA 1.3.1 open source software, which allows users to adapt existing  
 38 flows in EcoInvent. It has been particularly useful to create a specific process for the

1 operation of bi-articulated buses on the line, as consumption and emissions are completely  
2 different from those of the existing bus process in EcoInvent.

### 3 4 **Data collection and assumption**

#### 5 *Overview*

6 Data were collected through the participation of industrial companies involved in the  
7 project, verified and/or completed by literature review and estimates by sectoral experts.

#### 8 9 *Infrastructure*

10 This was assumed to be of entirely new construction, whereas in reality parts of the  
11 infrastructure were already built. Usage of materials and construction machinery, energy  
12 consumption and transportation are based on the Bill of Quantities and supplier information,  
13 for instance in the case of lighting or transportation. Bitumen and plasticizers are from Europe,  
14 whereas aggregates come from a quarry 3 km away.

#### 15 16 *Chosen vehicle fleet*

17 The bus body frame is modeled using the EcoInvent process, based on a Volvo 8500 Low  
18 Entry bus vehicle, including manufacturing of metal parts, engine production, and final  
19 assembly in Europe. The EcoInvent bus process excluding internal combustion engines has  
20 been scaled up to the mass of the VanHool bus. The calculation has been modified compared  
21 with de Bortoli et al (21) following a misinterpretation in the EcoInvent process description,  
22 which corresponds to an 11-ton bus, but gives data based on the 18.4 ton Volvo 8500.  
23 Moreover, the bus maintenance process has also been modified to match the Martinique  
24 context with regard to the electrical mix used in garages.

25 The transportation of buses from Europe includes the 450 km from the manufacturing plant  
26 in Koningshooikt, Belgium, to the Port of Le Havre in France, then 7000 km to the Port of  
27 Fort-de-France by sea (EcoInvent process : “*operation, transoceanic freight ship*”).

28 Operation is modeled using the “*operation, regular bus, CH, [vkm]*” process, which  
29 represents the operation of an average Swiss regular bus, modified with manufacturer’s data  
30 based on consumption measured on a SORT cycle of 56L/100 km and NO<sub>x</sub>, CO<sub>2</sub> and CO  
31 emissions measured by the World Harmonized Stationary Cycle procedure

32 Batteries have been modeled on the basis of EcoInvent lithium-ion cells, and a package  
33 extrapolated from Li et al (22).

#### 34 35 *Alternative vehicle fleet*

36 The LCIs for these standard buses have been put together directly with EcoInvent  
37 processes, excluding transportation and maintenance.

38 Buses run 200 km from the Volvo manufacturing plant in Säffle, Sweden, to the Port of  
39 Gothenburg, then 7900 km to the Port of Fort-de-France by sea.

40 The electricity mix in the maintenance process has been modified.

### 41 42 **Selection of environmental criteria**

43 Hundreds of indicators can be calculated using LCA. As decision-making is harder the  
44 more indicators there are, the set of indicators chosen in this study is presented briefly, with a  
45 policy approach to the categorization proposal.

#### 46 47 *Climate and energy*

48 **Energy consumption** Energy resource management is a fundamental environmental issue  
49 for the 21<sup>st</sup> century. In this study, primary energy consumption is calculated in megajoule



1 equivalents, using the Cumulative Energy Demand method and combining all sources: wind,  
2 fossil, water, primary forest, solar, biomass, geothermal and nuclear energies.

3 **Climate change** As this is a major environmental concern, the indicator selected uses the  
4 2001CML characterization method (Institute of Environmental Sciences - Leiden university),  
5 based on the Intergovernmental Panel on Climate Change's global warming potentials for a  
6 100-year time horizon, in CO2 equivalents.

7 **Stratospheric ozone depletion** Stratospheric ozone works as a shield that reflects a  
8 proportion of ultraviolet radiation (UVR) away from the Earth: it reduces global warming and  
9 protects people from the harmful effects of UVR. The transportation sector is responsible for  
10 a significant proportion of depletion through air conditioning and refrigerating systems. The  
11 CML method provides an indicator for calculating stratospheric ozone depletion expressed in  
12 kilograms equivalent of Freon-11 (CFC-11).

#### 13 *Resources and waste*

14 **Depletion of abiotic resources** Rapid societal development is leading to a shortage of  
15 abiotic resources. Aggregates are already scarce in some French regions. Reducing resource  
16 consumption is a priority for sustainable development, and is expressed with a CML indicator  
17 in kilograms equivalent of antimony.

18 **Solid and radioactive waste** In a context of increasing resource consumption, reducing  
19 waste by repurposing is important. An indicator for solid waste production is calculated using  
20 the EDIP characterization method and adding different landfill waste masses: bulk waste, slag  
21 and ashes, as well as hazardous waste. A special indicator on radioactive waste is also  
22 calculated directly with EDIP, as energy pathways are of interest in current policies and relate  
23 to transportation policy choices.

#### 24 *Health and ecosystems*

25 **Human toxicity** Increases in toxicity in the human environment is a public health issue  
26 that requires evaluation. A CML indicator on human toxicity is selected, expressed in  
27 kilograms equivalent of 1,4-DCB on a time horizon of 100 years.

28 **Photochemical oxidation** Occurring as summer smog, photochemical oxidants are  
29 secondary air pollutants that cause damage to plants (23) and as well as a range of human  
30 health disorders (24). Since their complex chemical formulae include nitrogen oxides and  
31 reactive hydrocarbons, they are an obvious indicator for transportation assessment. A CML  
32 indicator (high NOx) in kilograms equivalent of ethylene is proposed.

33 **Ecotoxicity** Three indicators for ecosystem toxicity are proposed, based on the CML  
34 method and using the same units as for the human toxicity indicator: terrestrial, marine  
35 aquatic and freshwater aquatic ecotoxicities. This choice represents toxicity of soil and waters.

36 **Eutrophication potential** Excessive discharges of rich nutrients into a body of water can  
37 lead to excessive plant growth, which destroys ecosystems by consuming sunlight, space, and  
38 oxygen. As this can totally devastate ecosystems and have a direct effect on toxicity (even for  
39 humans), a CML indicator has been selected, for a generic location, in kilograms equivalent  
40 of phosphate.

41 **Acidification potential** This encompasses potential acidity increases in water as well as in  
42 soil caused by the deposit of atmospheric acids mainly through rainfall. The main sources of  
43 acidification are industries, vehicle traffic, and power plants. The CML indicator for generic  
44 location has been used in this case study, in kilograms equivalent of sulfur dioxide.

## EVALUATION RESULTS

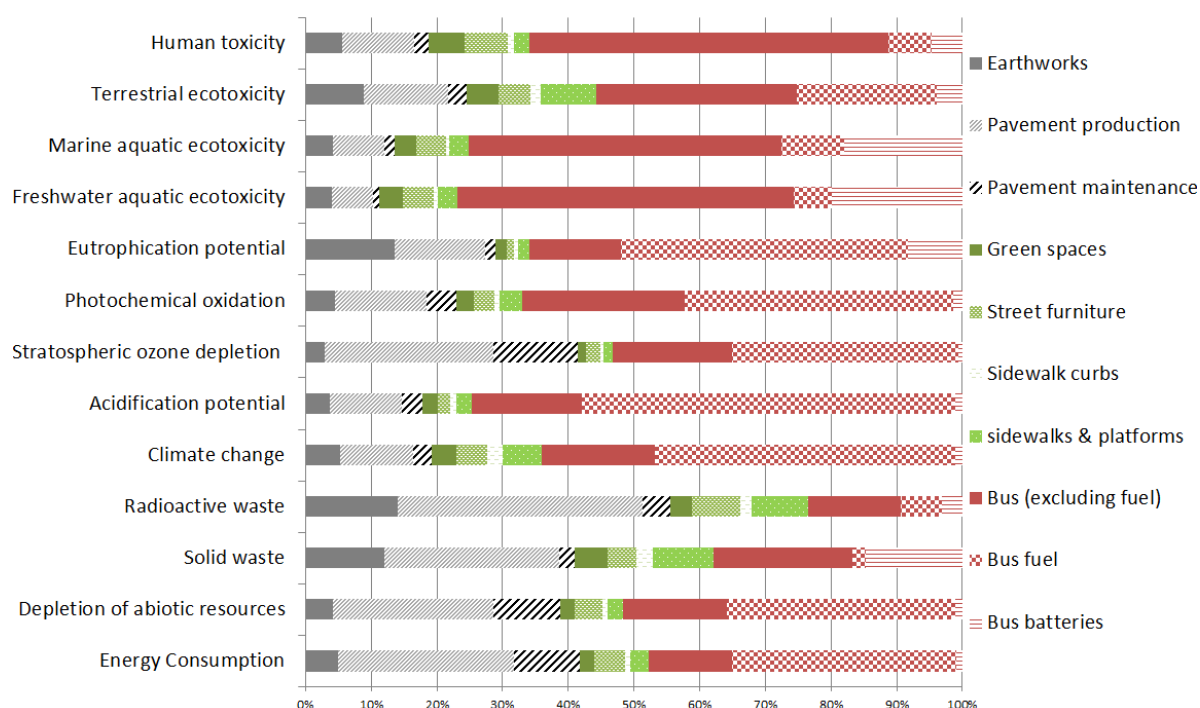
### Potential environmental impacts of the real transportation service

#### Complete system

As shown in FIGURE 3, the majority of environmental impacts are due to bus life cycles:

- especially toxicity impact from nonoperational bus components, which account for between 30 and 55% of total impacts. These are primarily caused by aluminum, chromium, copper, and motor resistors;
- fuel accounts for between 35 and 57% of eutrophication (mostly due to nitrogen oxides), photochemical oxidation (50% due to atmospheric emissions of sulfur dioxide, formaldehyde, and acetaldehyde), stratospheric ozone depletion (99% due to bromotrifluoromethane atmospheric emissions), acidification (80% due to nitrogen oxides), climate change (95% from carbon dioxide emissions), abiotic resources (92% from crude oil), and energy consumption

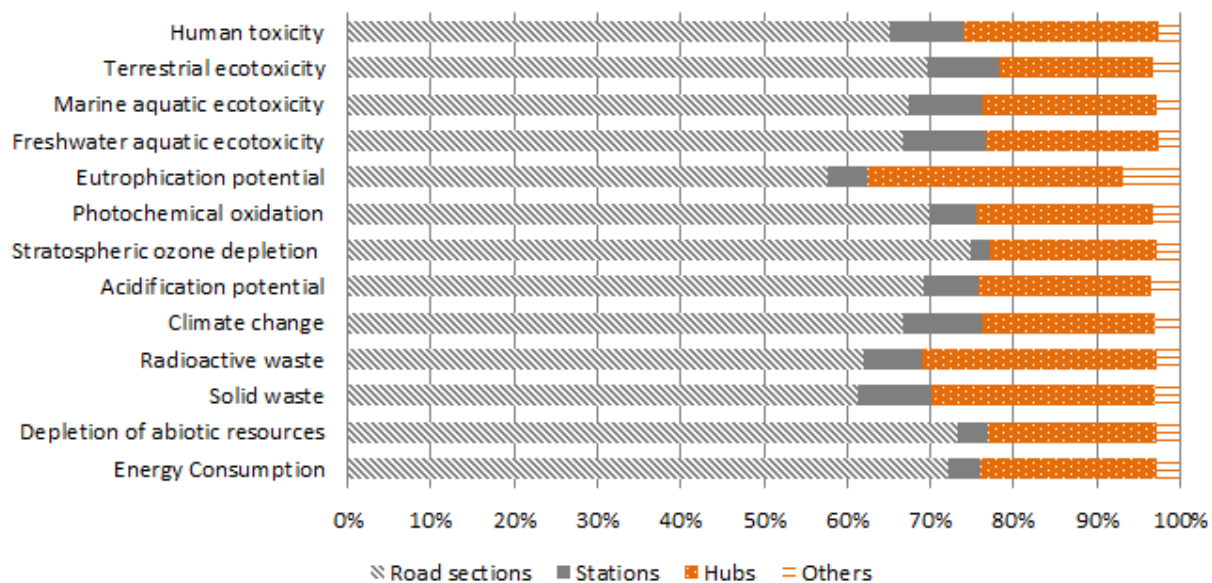
Nevertheless, infrastructure (including green spaces) contributes substantially to environmental burden, from 20% for aquatic toxicities to 75% for radioactive waste. The impact of pavement is particularly high, but components that typically lie outside the scope of LCA, such as green spaces, street furniture, sidewalks, and platforms, are not insignificant, accounting for between 5% (stratospheric ozone depletion) and 20% (terrestrial ecotoxicity) of impacts.



**FIGURE 3 Subsystem contributions to potential environmental impacts**

#### Infrastructure

Among infrastructural subsystems, road sections account for the major proportion of the impacts, between 60 and 75%. Nevertheless, as authors have noted (14), other subsystems are not insignificant: while stations represent 2 to 10% of the impacts, hubs are substantial, accounting for 20 to 30% of environmental burdens.



1  
2 **FIGURE 4 Contribution of the different infrastructural subsystems to different**  
3 **impact categories**

4  
5 *Street furniture*

6 This item includes the production of the equipment in Europe, transportation to Fort de  
7 France, and electricity consumed by streetlamps and access barriers.

8 In Figure 3, only 20% of lighting impacts have been allocated to the BRT line, given that it  
9 also benefits users of adjacent mixed-traffic lanes. Otherwise, with one streetlamp every 50m,  
10 a lighting system can account for up to 20% of line impacts over 28 years in energy  
11 consumption, climate change, or natural resource depletion. These impacts largely depend on  
12 the electricity mix: the use phase is predominant, accounting for 45 to 95% of impacts in  
13 terms of electricity consumption alone.

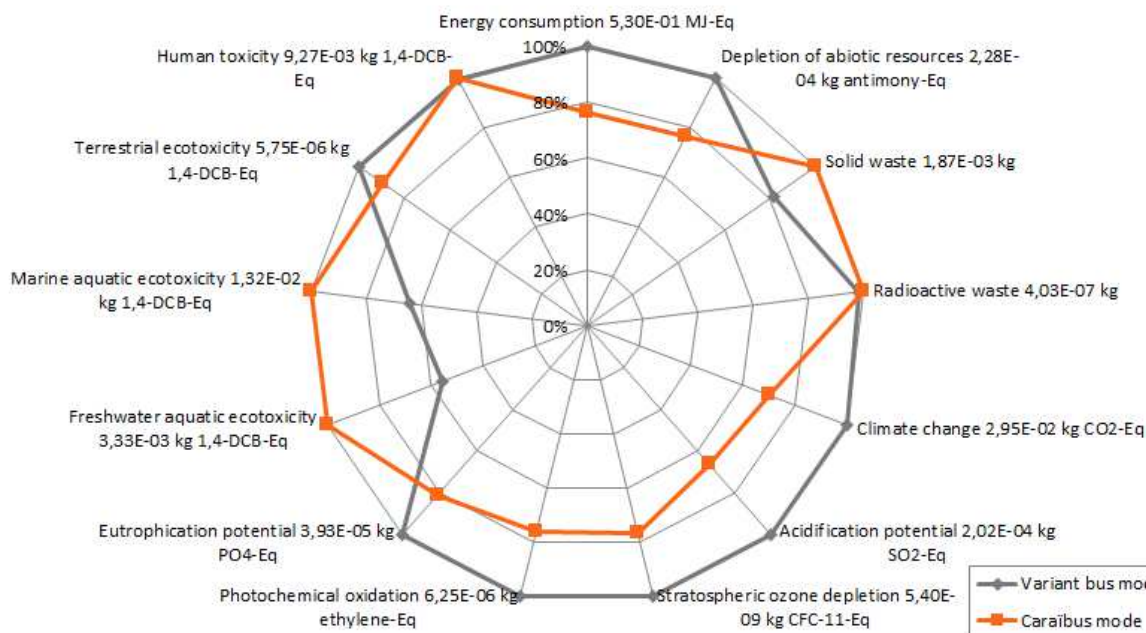
14 Although the street furniture comes from France, the overall impact of transportation is  
15 negligible.

16  
17 **Comparison of bi-articulated hybrid buses with standard diesel buses**

18 Based on 100% occupancy over 28 years, the best vehicle option depends on the indicator  
19 (FIGURE 5): bi-articulated buses are better on every indicator except marine and freshwater  
20 ecotoxicities, and solid waste. The two options are similar on radioactive waste and human  
21 toxicity performance.

22 As ecotoxicities are mostly related to metals, it would be of interest to refine the data  
23 collection and LCIs on propulsion systems.

24



1  
2 **FIGURE 5 Environmental impact comparison of bi-articulated hybrid bus mode**  
3 **with standard diesel bus variant mode**  
4

5 Even though the performance ranking per indicator remains the same when comparing the  
6 impacts of rolling stock life cycle and modes, relative impact differences tend to diminish  
7 compared with vehicle-only life cycle comparison. The infrastructure contribution for these  
8 bus modes is quite high compared with shared lane modes, where infrastructure accounts for  
9 only a few percent of the impacts on energy consumption and climate change (25). Indeed,  
10 dedicated-lane roads are less intensively used – Annual Average Daily Traffics (AADT) are  
11 between 54 and 72 buses for the Caraibus mode and between 108 and 144 for the alternative  
12 standard bus mode over 28 years – than shared roads used by an average passenger car mode,  
13 with AADTs ranging from the thousands to the ten thousands.

## 14 DISCUSSION

### 15 LCA for transportation systems: what challenges?

#### 16 *Assessment of complex systems: systemic approach and contextualization*

17 Assessing complex systems is difficult: capturing the interactions and feedbacks between  
18 subsystems may be hard, demands transdisciplinary research, and is globally time consuming.  
19 The partial or complete omission of interaction and subsystem feedbacks may lead to  
20 mistakes in quantifying environmental impact, and therefore to misleading input into  
21 decision-making.

22 Moreover, context-specific data and modeling are particularly important in reducing the  
23 variability of results and providing environmental assessments relevant to decision-making  
24 (26). However, they are very time-consuming and a possible source of error when using  
25 generic LCI databases, characterization methods, and LCA software. Choosing the right  
26 characterization method is an important step toward contextualization, but is still tricky,  
27 particularly in very particular conditions, such as those of a Caribbean island.

#### 28 *A need for traffic microsimulation*

29 In ex-ante transportation appraisal, accurate traffic simulation forecasts are essential in  
30 order to quantify the occupancy rates for a functional unit. Here, a 100% occupancy rate has  
31 been considered, e.g. full capacity. In fact, as demand rises with higher frequency, demand on  
32 bi-articulated and standard buses is unlikely to be the same. Although other factors such as  
33

1 ticket price, modal image, or comfort also affect traffic demand, standard bus demand is  
 2 likely to be higher since frequency on the standard bus mode is twice as high as for the bi-  
 3 articulated bus mode. Defining occupancy rate scenarios is possible, even advisable, when  
 4 conducting comparative LCAs for transportation modes ((30), (21)). Nevertheless, this is not  
 5 sufficient in this case study, which requires traffic microsimulation.

6 Microsimulation would also be needed to assess the impact of doubling bus traffic on the  
 7 rest of the network. Indeed, as buses have priority at traffic signals, vehicles in other lanes are  
 8 affected, possibly increasing the total environmental burden. These side-effects can be  
 9 captured either by enlarging the system boundaries or by conducting a consequential LCA.

#### 10 *Other biases*

11 The alternative does not consider the impact of the vehicle type on infrastructural design  
 12 and maintenance, whereas pavement design is based on expected heavy vehicle axle loads,  
 13 using Burmister models.

14 Moreover, the impact of passenger load on fuel consumption has not been explored.

15 In addition, BRT systems entail a high level of service, meaning good passenger comfort.  
 16 In Martinique, capacity is only 140 passengers, whereas a 24m-long bus can accommodate  
 17 around 200 passengers. If demand is high, the BRT line would be more environmentally  
 18 efficient with fewer seats.

### 19 **LCA as a tool for supporting decisions on transportation planning**

#### 20 *Background*

21 LCA is only occasionally used as an aid to decision-making on transportation issues. In  
 22 recent years, eco-comparators have been developed in France to compare road pavements  
 23 based on a truncated LCA (28). They can be used in bidding processes if environmental  
 24 alternatives are allowed. Nevertheless, system boundaries miss out the key environmental  
 25 impacts relating to vehicle-pavement interaction (29). LCA-based tools are used by some  
 26 companies in Europe to improve the mobility practices of employees (13). Transportation  
 27 projects have been assessed by some authors, in particular in California ((30), (14), (27)).  
 28 Some decisions, though driven by environmental objectives, are taken without performing a  
 29 LCA, such as policies in favor of e-mobility. The case of Paris, which is planning to convert  
 30 its entire bus rolling stock to e-buses, is emblematic. Indeed, while e-mobility is currently  
 31 seen as an obvious way to reduce GHG emissions from transportation in France, a massive  
 32 change in electricity consumption – and therefore supply – might change this assumption, and  
 33 could be captured by a consequential LCA. LCA on alternative mass transit bus powertrain  
 34 solutions has already been used to produce recommendations, for instance in the United  
 35 States, relating to the electricity grid (9). Nevertheless, LCA is not sufficient for the  
 36 assessment of e-mobility, notably two of its main urban benefits, i.e. reducing air and noise  
 37 pollution. The latter is not yet assessed in LCA ((31), (32)).

#### 38 *At what stage(s) of transportation development?*

39 **At the project level** LCA can be used at each stage of the project process, with different  
 40 levels of precision, to aid decision-making on environmental performance. As illustrated in  
 41 this article, ex ante LCA can be performed to choose between technical options. Nevertheless,  
 42 it demands expertise as well as caution to model likely scenarios. Moreover, since it comes on  
 43 top of a tough appraisal process – including environmental impact assessment, CBA, and  
 44 other analyses – it can be perceived as additional workload. This is especially true with regard  
 45 to the current lack of LCA-based decision tools in the transportation field, by contrast with the  
 46 building sector which is significantly ahead in the development of sectoral tools.

1     **For policies** Before the start of projects, in the policy design phase, attention should be  
2 paid, as already said, to travel demand and occupancy rates, in order to avoid condemning or  
3 approving embryonic transportation modes without regard for the specifics of the context  
4 ((30)). In FIGURE 6, it is interesting to note that with three people in a car, a European  
5 passenger car mode is more efficient on most indicators than the two public transit modes in  
6 Martinique with a 50% occupancy rate. For a specific context, however, a systemic approach  
7 is called for, taking network effects into account, since multimodality is now standard in  
8 urban trips.

9  
10     *Adoption of multicriteria results by decision-makers*

11     One of the difficulties in using LCA results to support decision-making is the multicriteria  
12 aspect: teaching skills and communication are important when presenting a number of  
13 indicators over which there is some uncertainty. Indeed, climate change and energy resources  
14 are not the only environmental issues.

15     When it comes to visualizing results, questions arise, e.g.: are spider charts sufficiently  
16 comprehensive? Are histograms clearer? Are there better diagrams? How many indicators can  
17 reasonably be presented simultaneously? In the case of multiple indicators, should criteria be  
18 packaged by theme or ranking? Comparisons of multiple scenarios are even trickier for LCA  
19 analysts to present.

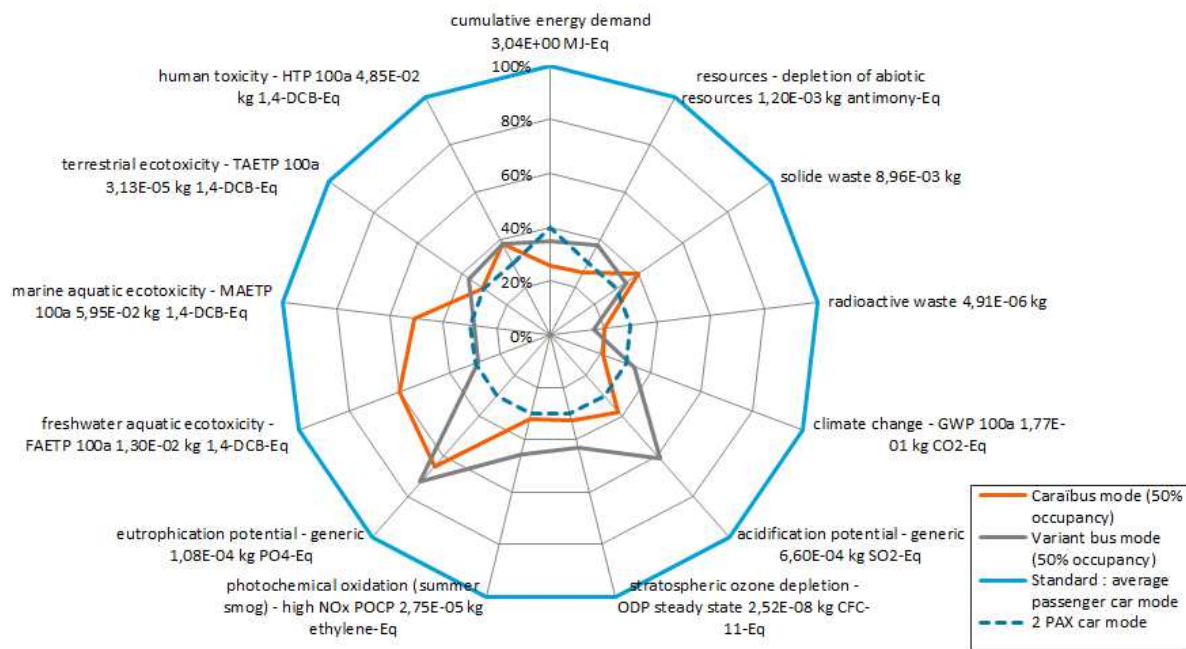
20  
21     *Interpretation of figures*

22     As there can be multiple indicators, with unfamiliar units, decision-makers can find the  
23 results hard to understand. On top of this, impact figures and their relative importance seem to  
24 be a hotspot.

25     One option in the LCA framework is to normalize results, i.e. to compare them with a  
26 standard, which gives the order of magnitude for the different impacts. In the transportation  
27 sector, where passenger car transportation is the dominant mode, normalized results are  
28 presented on the basis of the impacts of this mode (average occupancy 1.2), a standard that  
29 could also be spatialized to be more meaningful. Introducing this specific standard would be a  
30 positive way to encourage the use of LCA as a decision support tool, as the passenger car  
31 mode has the highest impact: alternatives would always be better.

32  
33  
34





1  
2 **FIGURE 6 Environmental comparison of the BRT mode (50% occupancy), the**  
3 **standard bus alternative mode (50% occupancy), and a proposed normalization**  
4 **standard: the European average passenger car mode**  
5

6 On the other hand, developing a more challenging standard, for instance including existing  
7 environmental transportation targets for every indicator in the normalization standard, would  
8 be more ambitious. Nevertheless, for some impacts there are no official targets.  
9

### 10 Use of LCA in the standard cost-benefit analysis

#### 11 *Monetization of LCA impacts*

12 Since performing LCA requires a significant investment of time, incorporating it into  
13 France's compulsory CBA could be a helpful compromise to achieve a better representation  
14 of environmental burdens in transportation assessments. CBA uses tutelary values to monetize  
15 every externality, whereas there are a dozen valuation methods for monetizing some LCA  
16 impacts, all based on different approaches (33). Integrating LCA into CBA would require to  
17 make coherent monetization methods as well as boundaries.  
18

#### 19 *Impact of weighting in decision-making*

20 The choice of tutelary values has a significant impact on results, because it entails a  
21 weighting process. In CBA for transportation projects, travel time cost effects are usually the  
22 dominant factor in the Net Present Value of projects. Carbon dioxide emissions are already  
23 taken partially into consideration, but are mostly insignificant with current tutelary values. If  
24 tutelary values do not show the environmental burden in NPV, there is no point in including  
25 LCA indicators in CBA.  
26

### 27 CONCLUSIONS

28 Even though environmental burden is a common component of decision-making processes,  
29 assessment practices rarely properly quantify it. In fact, CBA does not reflect ecological  
30 concerns. LCA could be used to clarify environmental performance, but remains a tool that is  
31 used only occasionally. In France, environmental alternatives are not always accepted in  
32 tendering processes. Some companies seem to be interested in LCA as a decision support tool,  
33 but regret the lack of public policy direction or incentives.

1       Moreover, the compulsory ministerial CBA process is already complex, and French  
2 practitioners are still working on the application of a new circular. In these circumstances, it is  
3 difficult to convey the importance of adding LCA criteria that are not addressed in the CBA  
4 appraisal protocol. Nevertheless, LCA can be seen as a way to achieve multi-stakeholder  
5 consensus, on account of the wide spectrum of environmental impacts it encompasses.

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14



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