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Environmental impact and cost price analysis of electric cargo bikes and electric vans for freight transport.

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ENVIRONMENTAL IMPACT AND COST PRICE ANALYSIS OF ELECTRIC CARGO BIKES AND ELECTRIC VANS FOR FREIGHT TRANSPORT

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List of abbreviations and acronyms

APR: Annual Percentage Rate

ADEME: French Agency for Ecological Transition

B2C: Business-to-Consumer

FTL: Full Truckload

GHG: Greenhouse Gas

GLEC: Global Logistics Emissions Council

GWP: Global Warming Potential

Kg: Kilogram

Km: Kilometre

LCA: Life Cycle Assessment

LCI: Life Cycle Inventory

LCIA: Life Cycle Impact Assessment

LF: Loading Factor
LTL: Less than Truckload or Less Than Load

SETAC: Society of Environmental Toxicology and Chemistry

TTW: Tank-To-Wheel

Wh: Watt-hour

WTT: Wheel-To-Tank

WTW: Well-To-Wheel

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1. Introduction

1.1. General context

Transport activities related to the production and distribution of products and services have been questioned for several years. According to Eurostat (2021b), emissions from transport are the main cause of air pollution. In a world where global warming is at the heart of the political and societal debate, it is sometimes absurd to see the number of transports poorly organised by certain industries and companies. Carrying out transport over thousands of kilometres with half loaded vehicles seems outdated, which is why many companies have started to set up "collaborative vehicle routing" systems. It consists in the joint planning of logistics operations of several companies through their collaboration. This cooperation allows to increase fleet efficiency, as well as to pursue ecological objectives.

The City Line project allows several companies to collaborate in order to share more ecological transport solutions. Indeed, it is a collaborative routing problem allowing partners to share vehicles, thus avoiding nearly empty loads. The solution represents a LTL (Less than Truckload or Less Than Load) shipping mode, which means that several small loads from different companies are combined in the same vehicle or in the same shipment, to avoid wasted space. The opposite system is referred to as FTL (Full Truckload), a shipping mode where one truck carries a single load, with goods belonging to only one company. This second version is therefore not feasible for the project's partner companies, as the quantities to be sent are too small. This actually makes the collaboration between these companies possible.

Moreover, the vehicles proposed by the transport partners Urbike, Coursier Wallon and Deliver-e are electric cargo bikes and electric vans, which at first sight are more environmentally friendly means of transport. This is, in fact, what the life cycle assessment will allow to determine.

- Deliver-e, based in Namur, is a project resulting from the desire of TNPS to revitalise its transport offer. TNPS is a pioneer in same-day parcel delivery in Belgium.

- Urbike, located in Anderlecht, is a cyclo-logistics cooperative that aims to improve the quality of life in the city by favouring the transport of goods by bicycle. Their aim is to gradually replace vans and light trucks with cargo bikes for the last kilometre of delivery.

- Coursier Wallon has two subsidiaries, one in Mons and one in Namur, and offers a bicycle delivery service in the city.

The City Line project was born out of a desire to reconnect transport activities with society's expectations. Several B2C (Business-to-Consumer) companies have joined the project, as they are concerned about the environmental impacts of their transport activities: eFarmz, Les Tartes de Françoise and Brasserie artisanale de Namur (La Houppe).

- eFarmz is a Belgian e-shop offering its customers organic, local and seasonal products as well as boxed meals, delivered at home or in a relay point. Their goal is to offer quality products for a healthy and sustainable diet.

- Les Tartes de Françoise offers its customers pies in no less than 22 workshops in Belgium, but also has an e-shop allowing the pies to be delivered directly to the customers.

- La Houppe is a brewery located in the heart of Namur. They also offer an e-shop for home delivery of beers.

These Belgian businesses have decided to change course regarding the organisation of their freight transport system and have therefore joined the City Line project in order to build a new reliable delivery model.

This project is part of a bigger challenge: Physical Internet. It is the translation of the internet to logistics. The idea is to transport the goods in special containers that are standardized and modular. The technology enables these containers to be filled in a such a way as to optimize space and facilitate the handling of goods. These small containers can be assembled and transported by electric vans, for example, thus combining products from different partner businesses, and can then be disassembled, for last-mile delivery. Electric cargo bikes can then take care of the delivery in the city centre, thus avoiding congestion and traffic problems, in addition to being more environment friendly.

Another objective is also to raise awareness among end-users to avoid the boycott of products routed through collaborative routing. Longer lead times may occur, so customers need to be aware of the reasons behind it. They should perceive collaborative routing as an improvement in the service quality because of the efforts made by companies to alleviate their negative impacts on the planet. For this reason, this study can be used for explanatory purposes in the marketing of various Belgian companies in order to address the final consumers. It is important to inform customers with precise figures and analyses so that they are aware of the benefits and limitations of this new modes of transport.

1.2. Objective of the thesis and research question

The aim of this thesis is to compare different vehicles from an environmental point of view, in order to deduce if the use of electric cargo bikes and electric vans represents a less polluting transport solution. A cost analysis will be carried out in parallel, in order to evaluate the relevance of using these vehicles. This master thesis will answer the following research question: "Is it more eco-friendly to use electric vehicles for the delivery of goods and what are the economic benefits?”

1.3. Thesis methodology

The first part of this thesis consists of a literature review to identify existing methods to assess the environmental impact of an activity, in this case freight transport.

In a second step, the selected method will be used in the framework of the City Line project, thanks to a dedicated software. The different steps will be carried out, with the aim of comparing five types of vehicles: an electric cargo bike, an electric van, a thermal van, a small truck and several cars of different sizes. As the electric vehicles are used in the project, this will allow them to be compared with more traditional means of transport, in order to analyse their competitive advantage.

Then a cost price analysis will be carried out to determine whether these solutions represent a financial burden or benefit. This will add a dimension to the analysis and allow to understand whether there is an ultimate benefit to our partners in having considered these vehicles.

Finally, the results obtained in the previous parts will be analysed and related. Conclusions and recommendations will be formulated, in line with the objectives pursued.

2. Literature review

This literature review summarises existing and relevant methods for assessing the environmental impacts of a transportation network. These methods will first be described, and then compared, in order to choose the most appropriate one for the City Line project.

2.1. Bilan Carbone®

2.1.1. Introduction

The Bilan Carbone® tool set up by ADEME (French Agency for Ecological Transition) is a calculation method using an Excel® spreadsheet. This tool is used to calculate the greenhouse gas emissions generated by all activities of a business. The goal of this implementation was to determine the dependence of companies on fossil fuels or climate constraints. ADEME has continued the work started by the ISO 14064 standard released in 2006 on carbon accounting. This norm is based on the GHG Protocol, a carbon accounting standard. It mainly focuses on direct emissions related to a company's activities and ADEME's idea was to account for indirect emissions as well. This is linked to their core business: promoting environmental transition via economic players such as local authorities and businesses (Le Breton & Pallez, 2017).

The Bilan Carbone® has three main objectives which can be described as steps in the completion of a carbon assessment.

2.1.2. Emissions calculation

There are many greenhouse gases: CO_2, O_2, CH_4, N_2, etc. Therefore, conversion factors, also called emission factors, are needed to express all results in "CO_2-equivalents". To do this, conventions are used to add up the different quantities of gases according to their warming power. For this purpose, the Base Carbone®, a public database of emission factors, can be used.

The direct and indirect CO_2 emissions of the activities are recorded, as for an inventory. A distinction is made between direct and indirect emissions.

- Direct emissions: these are the scope 1 emissions, related to the daily activities of a business or factory, its processes, and its vehicle fleet.

- Indirect emissions: these are the scope 2 and scope 3 emissions, indirectly caused by the company's activities. Scope 2 emissions are due to electricity usage as well as heat, while scope 3 emissions may include staff transport, raw materials extraction and transport, manufacture of semi-finished products by a supplier, etc.

2.1.3. Taking corrective actions

The Bilan Carbone® helps companies to set up action plans by determining their priorities in terms of emission reductions. This obviously depends on a company's commitment rate and its perceived responsibility. The analysis will enable companies to know which are their most polluting activities and to take action. It is a useful tool to facilitate decision-making.

2.1.4. Acknowledging economic fragility

The aim is the simultaneous reduction of both climate impacts and costs. The Bilan Carbone® allows companies to assess their dependence on variations in the cost of energy. They will then know to what extent their activities would be affected by an increase in the cost of fossil fuels or by the introduction of a carbon tax (French Ministry of Ecology, 2008). As a result, they can adopt strategies to reduce their vulnerability to the cost of energy.

2.2. Well-to-wheel (WTW) analysis

2.2.1. Introduction

This method consists of the accounting of all emissions related to a company’s operations and supply chain. The GLEC (Global Logistics Emissions Council) Framework describes the method and the main steps carried out.

2.2.2. Categorization of emissions

According to the Smart Freight Centre (2019), emissions are first split in three main categories:

- Scope 1 emissions: these are the direct emissions related to the assets owned by a company. Direct emissions are those generated by the combustion of liquid and solid fuels purchased for energy, heat, and steam production. Assets include not only the vehicle fleet but also the logistics infrastructure that a company has at its disposal.
- Scope 2 emissions: these are the indirect emissions related to the production and distribution of electricity, steam, and heat needed for the company's electricity-dependent assets and operations. They are also referred to as electricity emissions.
- Scope 3 emissions: these are also indirect emissions. They are due to the transportation of goods from the suppliers to the company and from the company to the customers. They are accounted at all stages of the supply chain: purchasing, product use and end-of-life. For this reason, they can also be called supply chain emissions.

2.2.3. Fuel life cycle

All the fuel emissions will be counted in the analysis, which is referred to as a WTW analysis. The whole fuel life cycle is considered, which means that all steps necessary to turn a resource into a fuel, as well as the ones required to bring that fuel to a vehicle are considered (Edwards et al., 2014).

The WTW is divided in two categories which are described hereunder.

1) *Well-to-tank (WTT)*

This part of the analysis gathers all the emissions related to fuel and produced between the well - the energy source- and the tank – the point of use. These emissions result from the following processes: fuel extraction, transportation, storage, and distribution. Therefore, they are referred to as scope 3 emissions. The combustion of the final fuel is not considered at this stage. It is also important to note that the emission values obtained may vary regarding the region, the production method, the transportation mode, etc.

2) *Tank-to-wheel (TTW)*

These are the emissions that result from the combustion of fuels that are necessary to feed scope 1 activities – the wheel. These fuels are used in the direct activities carried out by the company and, as a result, are reported as scope 1. The CO_2 emissions corresponding to their carbon content are calculated regardless of their origin (Edwards et al., 2014). TTW for electricity, hydrogen fuel cells and biofuels are zero, because the emissions are considered in WTT (Smart Freight Centre, 2019).

3) *Well-to-wheel (WTW)*

The WTW analysis corresponds to the addition of the WTT and the TTW. Contrary to the TTW, the origin of fuels is taken into account because the CO_2 equivalents of the ones of renewable origin are considered in a better way. *Figure 1* illustrates the fuel life cycle, as described by the GLEC Framework.

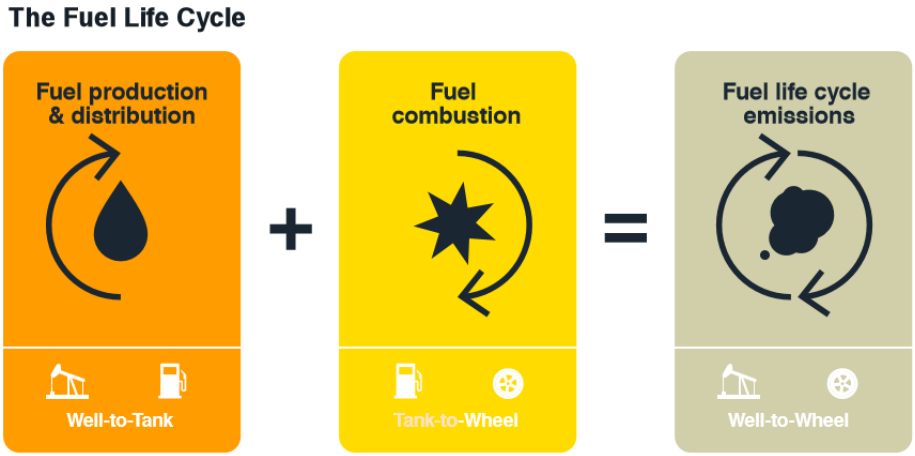


Figure 1: Accountability of fuel emissions (Smart Freight Centre, 2019)

2.2.4. Emissions calculation

1) *Setting boundaries and goals*

This first step corresponds to the study framework. Once the boundaries have been set, the goals of the study must be determined. These are the objectives that will shape the analysis and determine the type of data needed for the following steps.

2) *Scope 1 and 2 emissions*

Fuel and electricity data are converted into GHG emissions once they have been collected.

To do so, two types of conversion factors are used:

- Fuel emission factors are used to convert the fuels used by a company into CO_2 equivalents. They are expressed as the mass of CO_2 released for the fuel used.
- Electricity emission factors are used to convert the amount of electricity used by a company at all stages of its supply chain into CO_2 equivalents. They are expressed as the mass of CO_2 released for the electricity used (in kWh).

To obtain the total emissions for a year, a company can simply add up the emissions of all activities and it will therefore get an idea of its environmental impact.

3) *Scope 3 emissions*

This calculation step is a little bit more complicated. First, tonne-kilometres are used to translate freight transport activities. Tonne-kilometres consider the transport distance and weight. Secondly, factors are searched to estimate fuel use and emissions. Then, the tonne-kilometres are converted into GHG emissions thanks to these factors.

2.2.5. Interpretation

The results are gathered in a final step, referred to as reporting. The reporting is made according some protocols and standards. The objective is to track the evolution of a company's emissions throughout the years and to help decision-making.

In the final report, emissions are listed as follows:

- A total emissions value that record the total impact and its magnitude. Emissions are listed according to their scope and mostly expressed as CO_2 equivalents.
- An emission intensity value that transform emission data into a number to facilitate the analysis and the implementation of future actions and strategies. This value corresponds to the quantity of product transported.

2.3. GHG Protocol Product Standard

2.3.1. Introduction

The GHG Protocol Product Standard- or Product Life Cycle Accounting and Reporting Standard- is a standard used by companies to assess and quantify the GHG emissions released during the complete life cycle of a product or service. The GHG Protocol's main goal is to create GHG accounting and reporting standards and mechanisms worldwide to reduce global GHG emissions. Thanks to this specific standard, action plans can be implemented.

There are several steps to conduct the analysis.

2.3.2. Scope and goal definition

This step consists in defining the main objective(s) of the study. It can be, for example: performance tracking, improving customer engagement, climate change management, etc. According to these objectives, the analysis will focus on different aspects and emissions.

Some principles must be respected to achieve standard compliance: relevance, accuracy, completeness, consistency and transparency (Bhatia et al., 2011).

For the product life cycle accounting, a product inventory must be carried out respecting some fundamentals. The scope of the product inventory must also be defined. This includes the product definition, the GHG emissions that are accounted for in the analysis, the functional unit for final products and the reference flow for intermediate products, etc.

2.3.3. Data collection

This step starts with the boundary settings, i.e. the limits of the product inventory. It includes the definition of all the life cycle stages and the associated processes, the time period, the boundaries for finished products, as well as the ones for a partial life cycle analysis when performed.

The data are collected according to the product inventory defined in the previous step. Data are collected in all processes of a company's activities.

The data quality is also at stake here. Indeed, companies must assess data quality by using quality indicators on activity data and emission factors (Bathia et al., 2011). They should report any actions taken to improve data quality, as well as data sources.

When needed, allocation rules are applied in order to record emissions and absorptions and reflect the contribution of products and services to the total emissions. This step is not always necessary and should be avoided when possible.

Uncertainty is also assessed at this level. It means that companies should be aware of the uncertain aspects of the surrounding environment. They should explain the methodological choices made to counter this uncertainty as much as possible: using profile, calculation models, allocation rules, etc.

2.3.4. Emissions calculation

This step allows the calculation of the inventory results. Emissions are multiplied by a GWP factor to be expressed in CO_2 equivalents. A global warming potential (GWP) factor is a metric used to transform and compare several GHG emissions (Bathia et al., 2011). The Product Standard uses a 100-year GWP factor because it is of common use and often considered as a median metric. This step corresponds to the impact assessment phase of an LCA.

The total inventory results must be quantified and reported once they have been translated into CO_2 equivalents. The amount of carbon released is considered and the amount of carbon contained (but not released) in finished and semi-finished products should also be reported.

2.3.5. Interpretation

This last step allows a company to track the performance of a product's GHG inventory over time and to set reduction targets for the future. The Product Standard enables the comparison between different products and competitors.

A company can decide to guarantee its results by taking a third-party insurance, which reduces the uncertainty that encompasses the analysis. This third-party must be independent of the organization and have no interest in it.

All the steps described previously, and all the results obtained during their completion are gathered in a document that must be published. This reporting phase is paramount to meet the Product Standard compliance.

2.4. Life cycle assessment (LCA)

2.4.1. Introduction

The LCA concept is defined as the analysis of all the potential and environmental impacts of a product or service from the acquisition of raw materials to the end of its life (Arvanitoyannis, 2008). All stages of production and distribution are considered, as well as waste disposal. For this reason, this method is also referred to as the "cradle-to-grave" approach.

According to SETAC, the LCA is divided into four stages:

1) Goal and scope definition
2) Inventory analysis
3) Impact assessment
4) Improvement assessment

ISO now standardizes life cycle assessment, through its international standards 14040 and 14044. However, the steps do not change from those identified by SETAC, except for the last one, now called "interpretation" instead of "improvement assessment".

The ISO standard also describes the more general framework of the LCA, which includes reporting, a critical review of the LCA, its limitations, the relationship between the different stages of an LCA and the conditions for the use of value choices and optional elements.

LCA considers all attributes or aspects of natural environment, human health, or resources by identifying an environmental issue giving cause for concern (ISO 14040, 2006a).

According to ISO 14040 (2006a), LCA can be used to:

- compare two or more products,
- identify opportunities to improve the environmental impacts of a product at all stages of its life cycle,
- highlight some indicators of environmental performance and measurement techniques that are relevant for the analysis,
- assist in decision-making as it allows to identify the stages at which environmental impacts are most problematic and to act accordingly,
- develop marketing strategies, (e.g., through the implementation of an eco-labelling scheme or by making an environmental product declaration).

2.4.2. Goal and scope definition

Any life cycle assessment begins with the definition of the goal and scope of the study. This step is probably the most important one to conduct an LCA because the standards defined by ISO are flexible and quite general. Therefore, it is useful to shape the analysis before it is performed. It will ensure the consistency of the analysis during its completion, but also when it is subject to peer review.

Defining the goal and scope enables to determine:

- The reasons why the study is being conducted.
- The subject matter.
- The depth and level of detail of the analysis: these factors may vary widely depending on the objectives pursued.
- The system boundaries: geographical, technical and time limits of the LCA.
- The intended use of the study.
- The target audience which will indicate the tone to be used throughout the study. It can have an internal purpose or be directed at the external public, politicians, etc.
- General rules and assumptions: the data-collection and allocation rules, for instance
- The functional unit: also called the reference function, which is a quantitative measure of the functions that the goods or services provide (Finnveden et al., 2009).

This is an arbitrarily chosen basis of comparison of product systems that provide the same or a remarkably similar function.

- Other characteristics or details relevant for the good completion of the analysis. This may involve the selection of the impact categories concerned, underlying indicators and models.

2.4.3. Inventory analysis

This step is often described as the most scientific part of an LCA.

The relevant and useful data is first collected to perform the inventory analysis. Two types of data should be considered:

- Specific or foreground data for production, distribution, waste removal, etc. that apply to a particular situation and that are supplied, for example, by a producer.
- Generic or background data that can be found in private or public data banks (e.g., energy production, transportation, emissions).

An input/output inventory is then carried out. According to Klöpffer (1997), all activities related to the production of one functional unit must be considered: raw material extraction, intermediate products, the product or service itself, the use phase and finally the waste removal. All products, materials and energy flows that enter a unit process are considered, including energy, transportation and auxiliary products. The outputs may include co-products, emissions to air, water and soil, waste-heat and solid wastes.

The result shows what resources were used and what emissions were generated during the life cycle of a product or service and constitutes the starting point for the life cycle impact assessment.

Sometimes, this step is sufficient to achieve the goal of the LCA performed. An interpretation of the results is required, and the analysis will be referred to as a Life Cycle Inventory (LCI) study.

The first two steps of an LCA - goal and scope definition and inventory analysis - are often referred to as the analysis phase of an LCA. Sometimes, only these steps are performed for benchmarking, improvement or to get a quick view of the complete analysis that will be performed later.

2.4.4. Impact assessment

The third phase of an LCA, also referred to as Life Cycle Impact Assessment (LCIA), aims to provide additional information to help assess the results of the LCI phase and to understand their environmental significance (ISO 14040, 2006a). It is also in this phase that the comparison of product systems is possible.

According to the literature, which is based on the ISO standards, the impact assessment can be divided into the following milestones. Note that the first three ones are mandatory to conduct an LCA, while the last two are optional.

1) *Selection of impact categories and classification*

The impact categories of interest are selected, as well as the indicators that relate to these impact categories and the underlying models. This selection is sometimes not performed at this stage because it may have already been done during the first step of the LCA, i.e., the goal and scope definition.

Then, the data obtained during the inventory phase will be assigned to the different impact categories selected according to the substances' ability to contribute to different environmental problems. The selected impact categories can be greenhouse gas emissions, climate change, stratospheric ozone depletion, human toxicity, acidification, noise, water use, land use, etc., with some more input-oriented categories ("resource depletion") and others more output-oriented ("pollution") (Klöpffer, 1997). In the previous research, these two stages are either considered separately or together.

According to the IMPACT 2002+ methodology, a distinction is made between two types of impact categories: midpoint and endpoint. *Figure 2* represents the link between the LCI results, the midpoint and the endpoint indicators.

- Midpoint categories describe emissions and resource consumption that contribute to the same impact. This impact is located somewhere between the emission and the damage. Examples of midpoint impact categories are human toxicity, land occupation, global warming or mineral extraction, for example.

- Endpoint categories, also called damage categories, are defined at the level of the areas of protection. The areas of protection are the entities that we want to protect by using the LCA (Finnveden et al., 2009). The endpoint categories correspond to human health, ecosystem quality, climate change and resources.

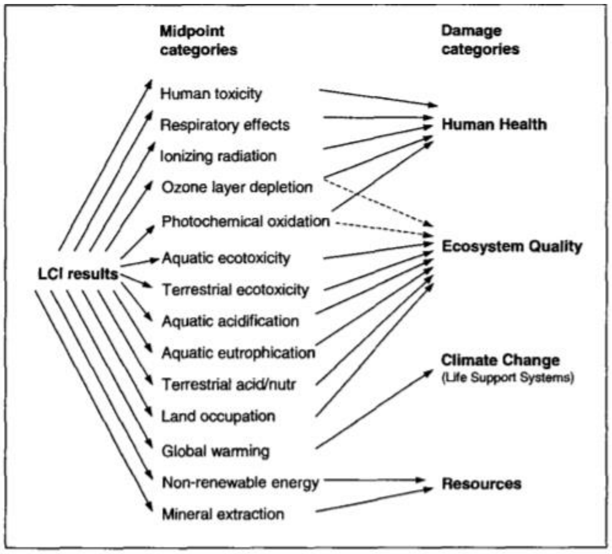


Figure 2: link between LCI results, midpoint and endpoint categories (Jolliet, 2003)

2) *Characterization*

This step is about the aggregation of the impacts within the impact categories. A number or indicator, which indicates the contribution of a product system per functional unit to an impact category, is used to transform the data (Klöpffer, 1997). For example, the indicator for the global warming impact category is the quantity of CO_2-equivalent.

Impact assessment provides information on their magnitude on ecological health, human health, and resource depletion for each impact category (Klöpffer, 2014).

3) *Normalization*

The results obtained in the characterization step are related to reference values to be interpreted more easily. All impact categories now have the same scale, and the impact scores are placed on this scale (Finnveden et al., 2009). This step is the response to disagreements that may occur regarding the characterization step.

4) Grouping

The grouping phase then allows impact categories to be assigned to one or more sets, to form for example regional and global sets. It shows qualitative similarities in the pattern of results contrary to the last phase, referred to as "Weighting", which will show quantitative similarities.

5) Weighting

Previously called *Valuation*, the final step of the impact assessment is about reflecting the importance of the impact scores and resource consumptions in the study conducted. This step is the most subjective one because the results obtained during the previous phases are aggregated together thanks to weighting factors in order to obtain a single score for the system studied, which will be interpreted according to a specific situation. The result may be a single number which could be misused (Klöpffer, 2014). In a comparative analysis, some impact categories may be more suitable for a system, and other categories may be better for another. The decision as to which system is best is case sensitive and this step is therefore often avoided.

2.4.5. Interpretation

This final step of the LCA summarizes the results obtained in the previous stages (LCI and LCA) and draw relevant conclusions. It constitutes the basis for decision-making and recommendations, while remaining consistent with the goal and scope definition established in the first step. An improvement analysis is performed, which gives an idea of the potential and future research to be carried out.

2.5. Comparison of the different methods

In order to determine the most appropriate method for the study carried out, a series of existing approaches were identified. These methods, as well as others, can be grouped into several sub-categories and can also belong to several of them.

2.5.1. Monocriteria vs multi-criteria

Monocriteria analyses	Multi-criteria analyses
Only one type of environmental impact is taken into account. This type of analysis does not allow for a comprehensive view of all the impacts related to a company's activities.	They record different sources of environmental impacts linked to a company's activities (global warming, eutrophication, ecotoxicity, etc.).
E.g.: Bilan Carbone®, which only records CO_2 emissions	E.g.: LCA

2.5.2. Product or service-oriented vs organization-oriented

Product or service-oriented methods	Organization-oriented methods
They allow the comparison of products or services within the same company or competing ones.	The internal organisation of companies is the basis for comparison.
E.g.: LCA, product oriented Bilan Carbone®, Product Life Cycle Standard	E.g.: GHG Protocol, organization-oriented Bilan Carbone®

2.5.3. Quantitative vs qualitative

Quantitative methods	Qualitative methods
The data collected are processed to demonstrate and predict facts. The results are expressed numerically.	These are descriptive and interpretation-based studies. The results are expressed literally. They have not been studied in this literature review as they are of little interest for the City Line project.
E.g.: LCA, Bilan Carbone®, GHG Protocol	E.g.: ESQV, Ecodesign Pilot, a check-list system

2.5.4. Choice of a method

All these tools have remarkable potential and enable a company to make strategic and long-term decisions. They help identify the most polluting activities and may offer solution paths. However, these techniques are relatively new and often subjective. Defining precise hypotheses is essential during an environmental analysis and the results obtained during a study will be difficult- if not impossible-to transpose to another one. Lack of data can also be a hindrance to analysis, especially when they must be estimated.

For this study, the LCA has been selected as the most relevant method because it is both a multi-criteria and a quantitative method. It is a complete tool that considers the environmental impacts of the whole supply chain of a company. However, it is important to note that social and economic impacts are not directly addressed in an LCA.

A carbon assessment will also be carried out, to compare the two methods, their results and to add depth to the analysis.

3. Life Cycle Assessment

The life cycle assessment having been defined as the most appropriate method to analyse the environmental impacts of the City Line project, the different steps it includes will be carried out, starting with the goal and scope definition which allows to structure the analysis and to define its scope. The aim is to account for all potential environmental impacts linked to the transport activity of the City Line project, from the vehicle's construction, through its use, to its end of life.

3.1. Goal and scope definition

The geographical scope of this study is Belgium, as all of the project's partners are located in Belgium and offer delivery within this country. The scope is therefore local but does not preclude transposition to other geographical areas. New hypotheses would have to be implemented, with other partners, and the results obtained will vary, but no reasonable doubt would prevent other pioneers in sustainable transport from carrying out a similar study. The scope is also limited in time, as new electric or sustainable vehicles are being developed. The City Line project is very topical but will evolve over time in order to adapt to the most advantageous solutions in the freight transport market.

The cargo bikes and electric vans of our transport partners will be compared with the most commonly used means of transport (i.e.: 3,5t trucks and thermal vans for the delivery of goods and cars for the collection of parcels by private individuals). This will allow the interpretation of the results and the conclusion of this study, that is to say whether these new modes of transport constitute a real competitive advantage in the context of green transport.

The aim of this analysis is not to discuss technical aspects of the different environmental impacts, but rather to provide an overview and critical aspect of a real project. For this reason, the analysis considers real data collected from transport partners and directly applicable to this situation, although several assumptions had to be made. The calculations have been conducted in a precise and objective manner. This study is primarily intended for private use, for the transport partners, but above all for the member companies, as they will be able to decide to what extent the City Line project meets their expectations. The cost analysis which is carried out in parallel in chapter 5 will add nuance to the results. This study is therefore not intended for scientific purposes and remains general in terms of quantifying environmental impacts. For example, details of the influence of chemical elements in the air will not be provided. The impacts studied will be mainly CO_2-equivalents emissions belonging to the global warming potential impact category, but this will be discussed further in section 3.3.

The data collection method is also decided at this stage. Data was collected from transport partners for the cargo bikes and electric vans. A questionnaire containing the information needed for the analysis was sent to Etienne de Clippele (Urbike), Jérôme Robert (Coursier Wallon) and Grégoire Trignon (Deliver-e). Where the information is missing, assumptions have been made and it was established that in this case, what applied to one carrier, applied to the others. This is the most appropriate way of dealing with the lack of data. Other important data about the processes were found in the databases used by each software, ecoinvent and thinsktep, for SimaPro and GaBi respectively. This applies as well for the cars and trucks, as none of the partners are willing to use these means of transport for the project.

The functional unit or reference function chosen is the kg.km, taking into consideration a notion of distance, the kilometre, but also a notion of mass, the kilogram. This is a quantitative measure of the properties of the product or service under study and will allow the comparison of results. In the case of this project, we therefore consider for freight transport that one parcel is transported over a distance of 1 km. The calculations made in SimaPro will also be given in km as the reference unit, in order to compare the two calculation results and to justify the choice of kg.km as the preferred functional unit.

Choice of an LCA software

Two life cycle assessment software packages were used in this study, namely SimaPro and GaBi. Firstly, SimaPro has been on the market for 30 years and is nowadays used in many industries and universities across 80 countries. It is a recognised and trusted tool that offers numerous functions, including an overview of the results not only at the end, but at all stages of the life cycle analysis. This tool has a high degree of transparency as all details of databases, supply networks and results from each impact source are accessible. The databases used to perfom an analysis are external: ecoinvent v3, Agri-footprint and ELCD. Ecoinvent 3.6 is the database that was used in the framework of this LCA. It is a very complete one that is frequently used, and that is based on scientific research. This database contains an important number of processes that are already created in SimaPro and that have been adapted to the City Line project. Justin Fraselle, chemical engineer at the University of Liege, provided access to the software but also provided his expertise in the use of the software. He made it possible to carry out the life cycle analysis for electric cargo bikes, electric vans, thermal vans, cars, and small trucks.

Then, GaBi was used to bring even more depth to the analysis. This is another software that has been widely used for 25 years in many industries and universities. It can be used as an LCA software, ecodesign tool, EPD generator or as a simple footprint calculator. It has many functions, allowing users to design their own system, without having to make many, sometimes inaccurate, assumptions. Another major advantage of GaBi is that many specific internal databases have been developed over the years and adapted to all sectors. It is however possible to use external and popular databases, such as ecoinvent. In this study, the GaBi database was used, as only the demonstration version of the software was offered to students for research purposes. This is the database developed by Sphera to calculate the ecological footprint of an organisation and referred to as thinkstep, abbreviated ts in the software, which is the former name of Sphera. This database source does not come from aging literature or laboratory research-based content, but from primary industry data collected in close cooperation with associations, providing a reliable environmental data foundation. The results of the LCA in GaBi can be directly integrated into the product design and the modelling of the processes is carried out in a quite simple way thanks to an interface that allows the user to make links using arrows between the processes. Transport by cars and trucks was analysed using this software, the other vehicles being unfortunately unavailable in the education version.

The decision to use two software packages with two different databases was taken because it allowed for a comparison of the power of the two software packages and their databases, and the extent to which they provide different answers to the research question.

The system is limited to the processes available in the two software packages. Typically, vehicle and road construction inputs are included (if available), as well as emissions from the transport activity itself, that is the use of vehicles. Maintenance is also considered. The end of life of vehicles is unfortunately not available and energy consumption is limited to transport, for vehicles running on the electrical grid. Otherwise, a fuel process is added, taking into account the extraction of minerals.

3.2.Inventory analysis

At this step of the LCA, the relevant data were collected. It includes the type of vehicles (model, brand...), net weight, maximal payload, etc. For electrical bicycles and vans, it was also important to know the types of batteries used, the capacity, the autonomy, and the recharging time of these batteries. As much information as possible about the City Line project was collected to ensure that the life cycle assessment was realistic.

Both types of data presented in the literature review were used. First, generic or background data were not collected directly for this project but were used from the databases of both GaBi and SimaPro. They concern energy production, transportation, and emissions. In a second step, specific or foreground data were collected from the project partners. These are specific data, which are not necessarily transposable and must therefore be used in the framework of this study. According to the literature, these data are for production, distribution, waste removal, etc. However, the focus here is on the transport activity itself, the other data having been collected as background data.

3.2.1. Electric cargo bike

The typical cargo bike model considered is the one used by Urbike, the DOUZE Cycles G4 with black box and a Brose S battery. The empty bicycle weighs approximately 150 kg, including the bike (30-35 kg), the battery, the driver (approximately 70-80 kg) and the trailer (30-40 kg). The maximum load on the bike itself is 80kg and usually 180-200kg on the trailer. However, if the trailer is loaded to the maximum, the load on the bike is generally limited to 50 kg. Therefore, a total load of 250 kg can be carried by a cargo bike. In total, this corresponds to a mass of 400 kg. In the SimaPro software, however, only the mass entered for the construction of the bicycle is taken into account (30 kg), and not that of the trailer. The maximum load of 250 kg was then used to calculate the autonomy of the bike via the Bosch website.

The battery of this bike has a capacity of 650 Wh, but 500 Wh is considered by SimaPro, with a weight of 2,6 kg. The bike has a lifespan of 15000 km and its battery needs to be replaced every 4000 km (so 3,75 times during the lifespan of the bicycle). A bike has an average speed of 19 km/h (Service Public de Wallonie, 2016). An average speed of 20 km/h was therefore taken into account for the analysis.

In SimaPro, the "Transport, freight, electric bicycle {BE-elec} - {RER-prod} | processing | Cut-off, U" process has been used as a basis for the analysis. The inputs from technosphere are the electricity, the construction and the maintenance of the cargo bike, as well as the road construction and maintenance. The outputs are the wear and tear of the bike and the decommissioned road. All these elements come from Europe (RER in the software), and the electricity from Belgium.

Table 1 indicates the consumption rates of a bicycle, whether it is running empty or full:

Loading factor	**Consumption**
SimaPro	
LF 0%	0,783 kWh/100 km
LF 100%	1,44 kWh/100 km

Table 1: Electricity consumption of an electric cargo bike

3.2.2. Electric van

For the electric van, the Nissan e-NV200, which the transport partner Deliver-e uses, was considered for the analysis. It has an autonomy of 200 km with a battery of 40 kWh and 262 kg. The maximum transportable load is 650 kg and the empty weight of the vehicle is 1539 kg.

The "Passenger car, electric {BE-elec} | processing | Cut-off, U " process was modified in SimaPro, being the closest to a van. The inputs are the electricity, the battery, the maintenance and construction of the vehicle, and the road construction. The outputs are road wear emissions, tyre wear emissions, and brake wear emissions. All these elements come from databases from the global world (GLO), except for electricity (BE).

The below consumption rates apply:

Loading factor	**Consumption**
SimaPro	
LF 0%	20 kWh/100 km
LF 100%	22,88 kWh/100 km

Table 2: Electricity consumption of an electric van

3.2.3. Thermal van

For the thermal van, it is not the electricity consumption, but the fuel consumption that applies. This is based on data from the database used in SimaPro, as a reminder Ecoinvent (data only available for a loading factor of 20%). The thermal van is slightly larger than the electric van, since the latter has a maximum load of 950 kg. The lifespan is approximately 218000 km, maintenance included.

In SimaPro, the "Transport, freight, light commercial vehicle {BE-elec} | processing | Cut-off, U" process is the one closer to a van. The inputs from nature are the same as for the electric van, except for electricity which has been replaced by fuel. The thermal van runs on a mix of gasoline and diesel, 81% of the vehicle running on diesel and 19% on gasoline, coming from Europe (except Switzerland). The construction of the vehicle is global (GLO).

The consumption of the thermal van is as follows:

Loading factor	**Consumption**
SimaPro	
LF 0%	
5.85 kg diesel	7.05 l/100km
1.36 kg petrol	1.82 l/100km
LF 100%	
7.02 kg diesel	8.45 l/100km
1.63 kg petrol	2.19 l/100km

Table 3: Fuel consumption of a thermal van

3.2.4. Truck

A small diesel truck was considered for the analysis, that is a truck used for transporting goods between 3.5 and 7.5 tonnes, as a larger truck would not represent the reality of the City Line project, which is aimed at urban transport for small and medium-sized enterprises. The same principle as for the thermal van was therefore applied. The assumption that the truck can carry up to 3500 kg was made as it is not representative to calculate for larger masses. The truck lifespan is 540 000 km, maintenance included.

In SimaPro, the "Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER-BE} | Cut-off, U" process has been adapted to the analysis. EURO classes are European emission standards, which indicate the maximum amount of pollutants that can be emitted by a vehicle. These include NO_x and carbon monoxide (CO). EURO 6 vehicles are currently the most recent and least polluting on the market, the EURO 7 being under development. The inputs from nature are diesel, truck construction, truck maintenance, road construction and maintenance. The outptus to technosphere are the same as for a van: road wear emissions, tyre wear emissions, brake wear emissions. All these components come from Europe, except for the construction of the truck which is global.

A truck of the same size was analysed (3.5-7.5t) in GaBi with similar characteristics. The process performed in GaBi can be observed in *Figure 3*. Two important modifications were made:

- A European mix of diesel was selected.
- A product or cargo of 1 kg "fits" in the truck process, so that this notion of transport is included in the analysis.
- A distance of 100 km was set as default, but this has been modified to take into account 1 km only.
- The mix of EURO 0-6 classes has been modified in order to represent only the EURO 6 class.

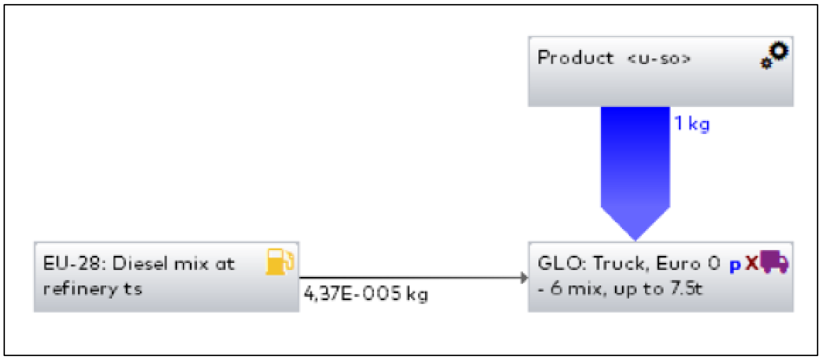


Figure 3: Truck process in GaBi software

The amount of diesel needed to transport a parcel of 1 kg over a distance of 1 km is 4.37×10^{-5} kg. Unfortunately, GaBi, or at least in its educational version, does not allow to include maintenance, road use, etc. in the process, while SimaPro does.

The different diesel consumptions calculated by the two software can be observed in *Table 4* below. The fuel consumption as a function of the loading factor is estimated in the same way as for the thermal van with a truck of a similar size in delivery mode. The fuel consumption varies this time by about 25% depending on whether a truck is empty or fully loaded.

Loading factor	**Consumption**
SimaPro	
LF 0% : 12.5 kg*	15.06 L / 100 km
LF 100% : 10 kg	12.05 L / 100 km
GaBi	
LF 100% : 15.3 kg	18.44 L / 100 km

*= fuel mass

Table 4: Fuel consumption of a 3.5t truck

The densities of gasoline and diesel considered are 745 kg/m³ and 830 kg/m³ respectively, for a temperature of 15°C. This is the density of the fuel, i.e., the weight of the product for a given volume (Total, 2020).

It can be observed directly that for a full truck carrying 3500 kilos, the fuel consumption according to GaBi is much higher. This can be explained by the fact that the initial process for the truck under consideration is a mix of the EURO 0 to EURO 6 classes, the classes below 5 requiring a very large amount of fuel and therefore negatively influencing this result.

3.2.5. Car

Three different types of cars of different sizes were used for the comparison, all of them EURO 5 class (EURO 6 not being available). Three petrol and three diesel cars were compared, with a lifetime of about 116,000 km for each model. The maximum loads are 300, 450 and 600 kg for the small, medium and large models respectively.

In SimaPro, the "Transport, passenger car, size, diesel, EURO 5 {RER}| Cut-off, U" processes have been chosen for the 3 identified sizes. The inputs and outputs are the same as for a truck and they are considered for Europe and the world.

In both programs, the use of the car cannot be modified as for the truck, for example, because it is considered a "passenger" means of transport and not intended for the delivery of packages. This is why three cars of different sizes were compared.

In GaBi, EURO 5 cars were also analysed. As inputs, diesel or petrol can be find, depending on the type of car, as well as an input specific to the construction of the car (material type). For fuel, the data for the EU28 were considered, as specific data for Belgium were not available. At the output level, the vehicle itself is available, and a notion of distance in kilometres. Again, data regarding the construction of the vehicle, its maintenance, the road, etc. are missing.

The small, medium and large car models considered in GaBi refer to engine sizes. The three categories are defined as follows: up to 1,4l, 1.4-2l, and 2l.

The following fuel consumption rates apply:

Type of car	**Consumption**
SimaPro	
Diesel car	
Small : 4.34 kg*	5.22 L / 100 km
Medium : 5.56 kg	6.70 L / 100 km
Large : 6.96 kg	8.39 L / 100 km
Petrol car	
Small : 4.94 kg	6.63 L / 100 km
Medium : 6.09 kg	8.17 L / 100 km
Large : 7.24 kg	9.72 L / 100 km
GaBi	
Diesel car	
Small : 3.26 kg	3.93 L / 100 km

Medium : 4.27 kg	5.73 L / 100 km
Large : 5.67 kg	6.83 L / 100 km
Petrol car	
Small : 4.41 kg	5.92 L / 100 km
Medium : 5.31 kg	6.34 L / 100 km
Large : 7.53 kg	10.11 L / 100 km

*= fuel mass

Table 5: Fuel consumption of a passenger car

Generally speaking, the fuel consumptions considered in GaBi are slightly lower than those considered in SimaPro, for quite equivalent car models.

3.2.6. Other data

Data on the number of kilometres driven per year for each type of vehicle as well as data regarding the direct and indirect costs generated by this activity were also collected at this step and will be discussed in the *Cost price* section.

3.2.7. Additional modifications

As mentioned before, some general modifications were made in the SimaPro software for all the vehicles' processes in order to fit the project. Here are some of them:

- Modification of the initial electricity mix (international, European, Swiss...) into the Belgian electricity mix for the consumption of electric vehicles (electricity mix calculated using the "IEA World Energy Statistics and Balances" statistics of 2016).

- Modification of the electricity mix into the Belgian electricity mix (2016) also for the vehicle maintenance and road construction and maintenance inputs.

- Change in the "discharges to the technosphere" from the global mix to the European mix.

- Change in fuel/electricity consumption depending on the load, the vehicle, and the functional unit.

- Change in vehicle mass where data is available, e.g., for the electric van.

The calculations were carried out on the different types of vehicles taking into account different loading factors, which correspond to the percentage of a vehicle's load, in terms of mass. For example, a cargo bike can carry a maximum load of 250 kg, which corresponds to a loading factor of 100%. If it carries 25 kg, then its loading factor is 10%. The following equation is used:

$$\frac{Load\ carried}{Maximum\ load} \times 100$$

Where $Maximum\ load$ = 250 kg for a cargo bike.

In both software, the calculations are made directly in kg.km or sometimes in t.km. In GaBi, no changes have been made, as it is directly possible to change the loading factor with the free parameter "utilization", by directly indicating whether the truck is used at 10, 20, 30 %, etc. The fuel consumption then changes with this value. In SimaPro, however, it was necessary to transform the t.km into kg.km by simply dividing the parameters by 1000. To vary the loading factor, all process inputs and outputs had to be transformed to vehicle-specific parameters, that is according to the maximum load and fuel consumption. For a loading factor of 100%, all elements were divided by the maximum load, e.g., 250 kg for the cargo bike. The “electricity” (or fuel) input was allocated according to the consumption calculated in the next section.

3.2.8. Electricity and fuel consumption

The Bosch website was used to calculate the electricity consumption of the bike. As it does not allow for a mass greater than 300kg, the consumption figures for higher masses have been estimated by extrapolation. In *Table 6* is a list of the parameters chosen:

Parameters	
Speed	20 km/h
Mode	Turn
Weight	Variable
Pedalling frequency	60 rpm (revolutions per minute)
Support	Cargo line
Battery	Powerpack 500
Bike	Cargo bike

Tyres	Urban bicycle tyres
Transmission	Derailleur
Type of land	Isolated coastlines
Soil type	Good
Wind	Light
Season	Summer
Start-up frequency	3 out of 5

Table 6: Parameters from the Bosch website

The autonomy of the bike in km is generated by the Bosch website. Then, the load-dependant autonomies were interpolated by a second-degree curve of equation:

$$y = 0{,}0004x^2 - 0{,}3371x + 105{,}39$$

The electricity consumption in Wh/km and Wh/(kg.km) is then calculated as follows, for a loading factor (LF) of 0% up to an LF of 100% in 10% steps.

$$\text{Wh / km} = \frac{battery\ capacity}{autonomy\ (in\ km)}$$

$$\text{Wh/(kg.km)} = \frac{Wh\ /\ km}{maximum\ laod * \ LF}$$

Similar calculations have been made for the electric van, and it was then estimated that the electricity consumption of the vehicle varied by about 14% whether the vehicle is running empty (LF of 0%) or fully loaded (LF of 100%). This variation is considered to be linear.

According to data from the Treeze website, which calculates the different fuel consumption depending on the driving mode, it is estimated that fuel consumption varies by 20% whether a thermal van is driving empty or full and by 25% whether a truck is driving empty or full. The calculation has not been made for cars because the loading factor does not vary. Indeed, cars are studied individually, and the effect of mass transport on fuel consumption is considered as neglectable in this case.

3.3.Impact assessment

3.3.1. Selection of impact categories and classification

As explained in the literature review, these two stages can be performed separately or together, with the second option being preferred for this study.

In order to perform the Life Cycle Impact Assessment (LCIA), the impact categories have been selected, as well as the indicators that relate to these impact categories.

In the literature review, a difference was made between midpoint and endpoint impact categories, which respectively describe resource consumption situated at the impact level or directly at the damage level.

For the purpose of this study, the ReCiPe 2016 Midpoint (H) methodology has been selected because it describes indicators at both levels: midpoint and endpoint.

First, it gathers eighteen midpoint-oriented impact categories that focus on a single environmental problem:

Global Warming
Stratospheric ozone depletion
Ionizing radiation
Ozone formation, Human health
Fine particulate matter formation
Ozone formation, Terrestrial ecosystems
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Human carcinogenic toxicity
Human non-carcinogenic toxicity
Land use

Mineral resource scarcity
Fossil resource scarcity
Water consumption

Table 7: ReCiPe 2016 Midpoint impact categories

Impact-oriented indicators can be converted into damage-oriented indicators. This makes them more interpretable, but the conversion leads to a loss of precision. The different categories make it possible to avoid a transfer of impacts from one category to another, as the allocation of an emission is not the same for each class. Reverse effects could for example cancel each other out. The three endpoint-oriented impact categories covered by the ReciPe methodology are:

- Human health
- Ecosystem diversity
- Resource accessibility

For this study, the focus was made on the global warming potential (GWP) midpoint category, which quantifies the integrated infrared radiative forcing increase of a greenhouse gas (GHG) (Huijbregts, 2017). According to the classification stage, the results are expressed in kilograms of CO_2-equivalents, which is the indicator associated with the GWP. The results are then all expressed in this measurement unit in order to allow the comparison. This category is more output oriented, as it focuses on pollution caused by emissions to air and is indeed contributing to the “climate change” endpoint category. A second midpoint category that is of interest for this study is the ozone formation, also referred to as human health because it is expressed in kilograms of NO_x-equivalents, which can have important effects on health and ecosystems. Indeed, they are involved in the formation and destruction of ozone and in the formation of secondary fine particles (Weireld, 2014). Automobile exhausts and in particular diesel vehicles account for a significant proportion of NO_x air pollution.

Even though they represent the same thing, these two midpoint categories are presented under two slightly different names in the GaBi software: climate change in kilograms of CO_2-equivalents and photochemical ozone formation in kilograms of NO_x-equivalents. As explained, climate change is in fact the name of the endpoint category associated with the global warming potential and to which it alone contributes, so both names are sometimes used in the literature. As for the second midpoint category “ozone formation”, it is part of the human health damage endpoint category, which is why the SimaPro software also associates the two names.

3.3.2. Characterisation

As its name indicates, this step allows to apply characterisation factors to the data collected during the inventory step, data also referred to as “flows”. These factors are defined in the scientific literature on the basis of models and can slightly vary according to the type of life cycle assessment carried out. The total result for an impact category is then obtained as follows: each flow is multiplied by its associated characterisation factor and all impacts are then added together to obtain the total.

$$Total\ impact = \sum (flux\ \times characterization\ facor\ )$$

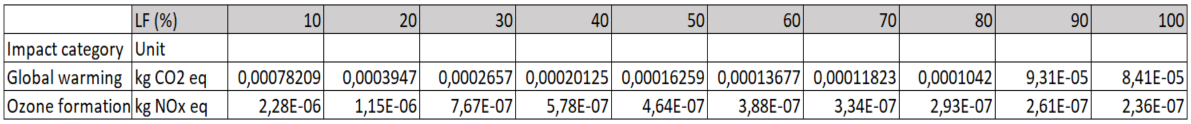
Characterisation factors are available for each impact category and for each substance. For example, for the LCIA ReCiPe 2016 Midpoint (H) and for the GWP impact category, methane (CH_4) has a characterisation factor of 34 kg CO_2-equivalents. This means that methane has an impact 34 times greater than CO_2 itself. Ditrogen monoxide (N_2) has a characterisation factor of 298 kg CO_2.

The next three steps of the life cycle assessment, i.e., normalisation, grouping and weigthing, will not be carried out as they are of little interest for this study and are not mandatory for the performance of an LCA. Normalisation allows the results to be transformed into a common unit of measurement across all impact categories. For this project, only two categories have been highlighted, and they are easily interpreted as such. The grouping step allows impact categories to be assigned to one or more sets. Finally, the weighting step allows to obtain a single score for the system studied. The interest of such a result for the City Line project has not been mentioned, as the chosen impact categories provide sufficiently satisfactory results. These last steps are more subjective, based on value choices, and can make the results vary greatly depending on the systems chosen, this is the reason why they have been omitted.

3.3.3. <u>Results</u>

The Simapro results are first presented in kg.km and then in km. This will allow the impact of the functional unit on the results to be analysed, hence the importance of choosing it carefully. Next, the GaBi results are presented for trucks and cars.

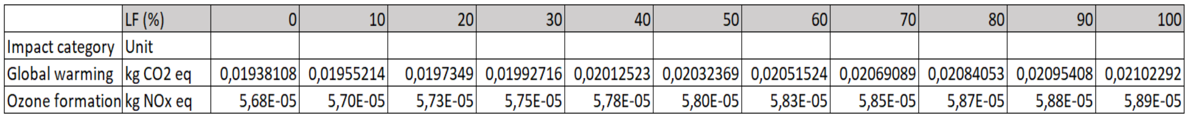
Electric cargo bike



	LF (%)	10	20	30	40	50	60	70	80	90	100
Impact category	Unit										
Global warming	kg CO2 eq	0,00078209	0,0003947	0,0002657	0,00020125	0,00016259	0,00013677	0,00011823	0,0001042	9,31E-05	8,41E-05
Ozone formation	kg NOx eq	2,28E-06	1,15E-06	7,67E-07	5,78E-07	4,64E-07	3,88E-07	3,34E-07	2,93E-07	2,61E-07	2,36E-07

Table 8: SimaPro results in kg.km for an electric cargo bike

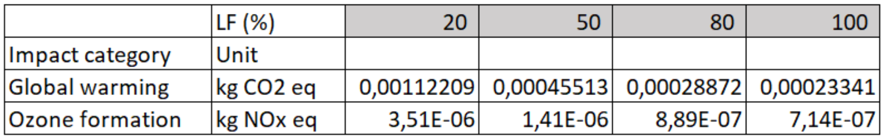
In kg.km, it is not possible to perform the calculations for a loading factor of 0%, because the equation system is then wrong. This is because the software divides the results by this LF, and division by zero gives an impossible result. In km, however, this problem does not occur. This comment applies for all vehicles.



	LF (%)	0	10	20	30	40	50	60	70	80	90	100
Impact category	Unit											
Global warming	kg CO2 eq	0,01938108	0,01955214	0,0197349	0,01992716	0,02012523	0,02032369	0,02051524	0,02069089	0,02084053	0,02095408	0,02102292
Ozone formation	kg NOx eq	5,68E-05	5,70E-05	5,73E-05	5,75E-05	5,78E-05	5,80E-05	5,83E-05	5,85E-05	5,87E-05	5,88E-05	5,89E-05

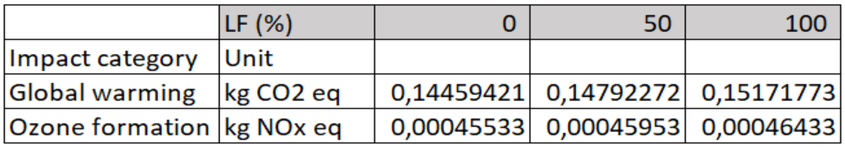
Table 9: SimaPro results in km for an electric cargo bike

Electric van



	LF (%)	20	50	80	100
Impact category	Unit				
Global warming	kg CO2 eq	0,00112209	0,00045513	0,00028872	0,00023341
Ozone formation	kg NOx eq	3,51E-06	1,41E-06	8,89E-07	7,14E-07

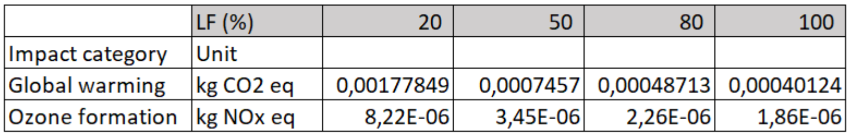
Table 10: SimaPro results in kg.km for an electric van



	LF (%)	0	50	100
Impact category	Unit			
Global warming	kg CO2 eq	0,14459421	0,14792272	0,15171773
Ozone formation	kg NOx eq	0,00045533	0,00045953	0,00046433

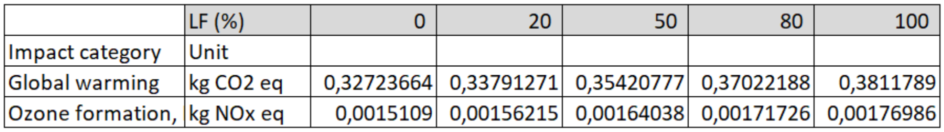
Table 11: SimaPro results in km for an electric van

Thermal van



	LF (%)	20	50	80	100
Impact category	Unit				
Global warming	kg CO2 eq	0,00177849	0,0007457	0,00048713	0,00040124
Ozone formation	kg NOx eq	8,22E-06	3,45E-06	2,26E-06	1,86E-06

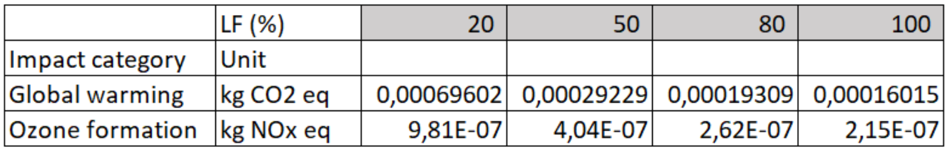
Table 12: SimaPro results in kg.km for a thermal van



	LF (%)	0	20	50	80	100
Impact category	Unit					
Global warming	kg CO2 eq	0,32723664	0,33791271	0,35420777	0,37022188	0,3811789
Ozone formation,	kg NOx eq	0,0015109	0,00156215	0,00164038	0,00171726	0,00176986

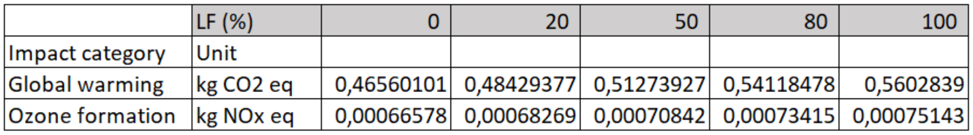
Table 13: SimaPro results in km for a thermal van

Truck (3.5t)



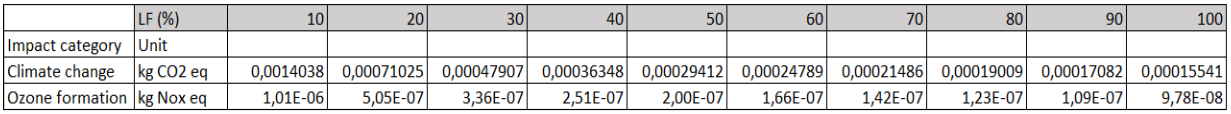
	LF (%)	20	50	80	100
Impact category	Unit				
Global warming	kg CO2 eq	0,00069602	0,00029229	0,00019309	0,00016015
Ozone formation	kg NOx eq	9,81E-07	4,04E-07	2,62E-07	2,15E-07

Table 14: SimaPro results in kg.km for a truck



	LF (%)	0	20	50	80	100
Impact category	Unit					
Global warming	kg CO2 eq	0,46560101	0,48429377	0,51273927	0,54118478	0,5602839
Ozone formation	kg NOx eq	0,00066578	0,00068269	0,00070842	0,00073415	0,00075143

Table 15: SimaPro results in km for a truck



	LF (%)	10	20	30	40	50	60	70	80	90	100
Impact category	Unit										
Climate change	kg CO2 eq	0,0014038	0,00071025	0,00047907	0,00036348	0,00029412	0,00024789	0,00021486	0,00019009	0,00017082	0,00015541
Ozone formation	kg Nox eq	1,01E-06	5,05E-07	3,36E-07	2,51E-07	2,00E-07	1,66E-07	1,42E-07	1,23E-07	1,09E-07	9,78E-08

Table 16: GaBi results in kg.km for a truck

The main observation is that the results are very similar, depending on the software used, despite the fact that the inputs and outputs taken into account by the two programs are pretty different. This is due to the fact that the trucks observed have the same technical characteristics: load, EURO class, weight, type of fuel, etc. It can therefore be concluded that for similar vehicles, or at least for similar trucks, the software packages offer results of the same magnitude.

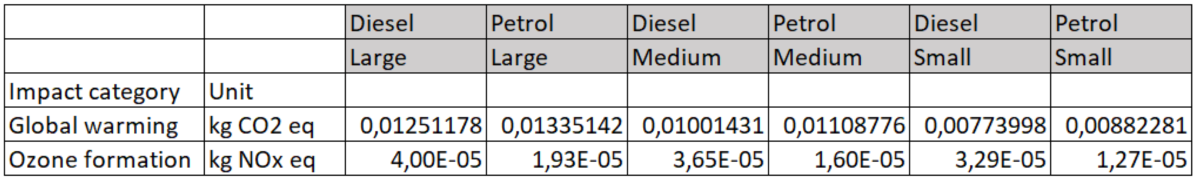
Cars

The analysed cars represent a different category of vehicle from the others, as they are not considered in delivery mode, but for the collection of parcels by private individuals themselves.

Therefore, it was assumed that the transport of the parcel does not affect the fuel consumption of the vehicle, as it is less than the total weight of the car. For the calculations in kg.km, an average parcel of 30 kg was used for the analysis.

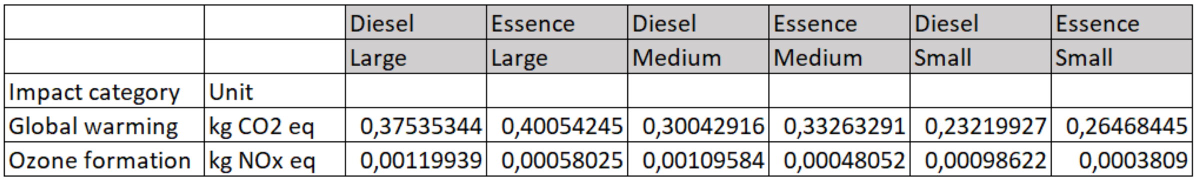
The loading factor is calculated by relating this 30 kg mass to the maximum load of the three types of cars studied: small, medium and large. The maximum loads are 300, 450 and 600 kg, respectively. This gives loading factors of 10%, 6.6% and 5%, and these will not be changed as no other scenario is considered for this type of vehicle.

The results obtained are as follows:



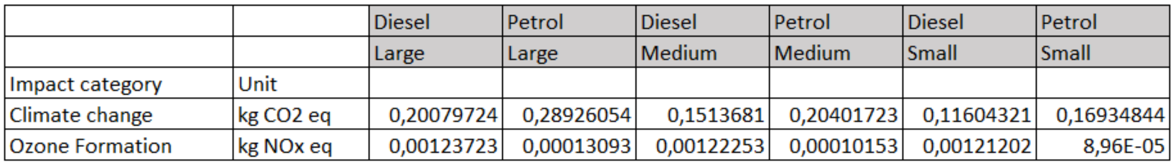
		Diesel	Petrol	Diesel	Petrol	Diesel	Petrol
		Large	Large	Medium	Medium	Small	Small
Impact category	Unit						
Global warming	kg CO2 eq	0,01251178	0,01335142	0,01001431	0,01108776	0,00773998	0,00882281
Ozone formation	kg NOx eq	4,00E-05	1,93E-05	3,65E-05	1,60E-05	3,29E-05	1,27E-05

Table 17: SimaPro results in kg.km for different cars



		Diesel	Essence	Diesel	Essence	Diesel	Essence
		Large	Large	Medium	Medium	Small	Small
Impact category	Unit						
Global warming	kg CO2 eq	0,37535344	0,40054245	0,30042916	0,33263291	0,23219927	0,26468445
Ozone formation	kg NOx eq	0,00119939	0,00058025	0,00109584	0,00048052	0,00098622	0,0003809

Table 18: SimaPro results in km for different cars



		Diesel	Petrol	Diesel	Petrol	Diesel	Petrol
		Large	Large	Medium	Medium	Small	Small
Impact category	Unit						
Climate change	kg CO2 eq	0,20079724	0,28926054	0,1513681	0,20401723	0,11604321	0,16934844
Ozone Formation	kg NOx eq	0,00123723	0,00013093	0,00122253	0,00010153	0,00121202	8,96E-05

Table 19: GaBi results in kg.km for different cars

Different magnitude results can be observed when using GaBi or SimaPro for the functional unit kg.km, although the analysed cars have similar characteristics (size, EURO class, etc.). The assumption that the two software packages offer similar results for similar vehicles is therefore not verified here. The difference can be explained by the fact that different inputs and outputs are taken into account. The road is not considered in GaBi, nor is the construction or maintenance of the car. It seems that the emission generated by the fuel consumption is more widely considered.

3.4. Interpretation

In this step, the results obtained in the previous section will be analysed in general, and then more specifically for each vehicle.

When kg.km is used as the functional unit, the impact decreases with the loading factor. Indeed, the most loaded vehicles have the lowest results because the impacts are allocated to more parcels (despite the increase in fuel or electricity consumption). The more the vehicle is loaded, the lower the emission allocated to a kilo transported, as it is less polluting to make full journeys than to transport a single parcel over a long distance. However, when calculations are made in km, the opposite effect occurs. Emissions increase with the load because this notion of filling is not considered. The software then considers that transporting more mass generates more emissions, without calculating the share allocated to each additional package. This second calculation is mainly for information purposes but is less interesting than the first one. For this reason, GaBi's results are only presented in kg.km. As mentioned before, only trucks and cars could be analysed in this software.

For the analysis of the results, cars were not directly compared to other means of transport, because they do not have the same utility. As a reminder, they are not used in delivery mode and therefore do not fit exactly with the reality of the City Line project. They have been studied for information purposes and their inclusion in the comparison would therefore distort the results.

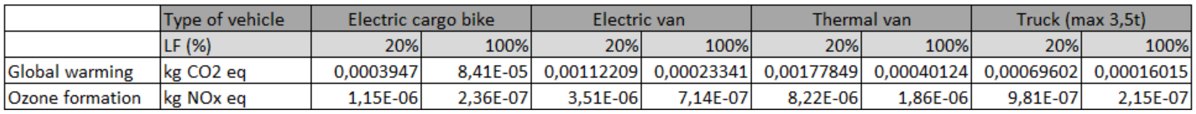
Summary tables of the results for each vehicle type and for the two impact categories defined in section 1.3. are available below for SimaPro. It would not be realistic to compare GaBi's processes directly with SimaPro's ones for different vehicles, as they do not account for the same inputs and outputs. GaBi focuses on the transport activity, whereas SimaPro takes into account the construction of the vehicle, its impact on the road, etc. It can therefore be concluded that SimaPro's results are closer to the objective of life cycle assessment, which is also called "cradle-to-grave" analysis and which aims to include all elements related to a service activity, from the extraction of raw materials to the complete disposal of materials. Unfortunately, SimaPro does not include end-of-life vehicle waste in its processes either, but it is still more complete. Two loading factors are compared, 20 and 100%, in order to analyse the situation of an underfilled or completely full vehicle.

The results with cars are available in

Appendices I and II. It can be observed that cars have much larger impacts, as they are not considered in delivery mode and carry a single parcel. This is why they have been set aside below, so as not to distort the results. These are presented first in relative numbers and then in percentages. The vehicle with the highest fuel consumption, and therefore the most polluting one, is allocated 100% for each loading factor and category. The results for all LF categories are available in

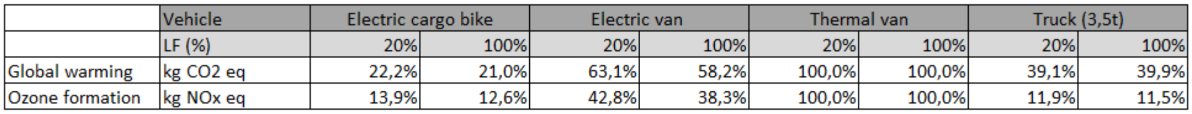
Appendices *III*. The other results can then be directly compared and the impact size is then easily observable. The graphs associated with these results can be seen in

Appendices *IV and V* and allow the situation to be visualised directly.



	Type of vehicle	Electric cargo bike		Electric van		Thermal van		Truck (max 3,5t)	
	LF (%)	20%	100%	20%	100%	20%	100%	20%	100%
Global warming	kg CO2 eq	0,0003947	8,41E-05	0,00112209	0,00023341	0,00177849	0,00040124	0,00069602	0,00016015
Ozone formation	kg NOx eq	1,15E-06	2,36E-07	3,51E-06	7,14E-07	8,22E-06	1,86E-06	9,81E-07	2,15E-07

Table 20: Comparison of all vehicles, SimaPro results in kg.km, relative value



	Vehicle	Electric cargo bike		Electric van		Thermal van		Truck (3,5t)	
	LF (%)	20%	100%	20%	100%	20%	100%	20%	100%
Global warming	kg CO2 eq	22,2%	21,0%	63,1%	58,2%	100,0%	100,0%	39,1%	39,9%
Ozone formation	kg NOx eq	13,9%	12,6%	42,8%	38,3%	100,0%	100,0%	11,9%	11,5%

Table 21: Comparison of all vehicles, SimaPro results in kg.km, percentage value

If a loading factor of 20% is taken, the electric bicycle is the least polluting means of transport for the GWP impact category, followed by the truck. The same conclusion can be drawn for a loading factor of 100%.

The thermal van is the most polluting option, for both loading factors of 20 and 100%. This can be explained by the fact that this vehicle is not electric, and that it does not allow the transport of a sufficiently large quantity of goods to reduce the impact attributed to a parcel.

For the impact category “Human Toxicity”, however, the truck seems to be the least damaging alternative, followed by the electric cargo bike. The thermal van is still the least preferred option.

Nonetheless, it is important to qualify these results because the loading factors of 20% and 100% correspond to different situations depending on the vehicle considered. In fact, it is a question of 20% of the total transportable mass for each vehicle, which in reality is different. Therefore, loading factors do not correspond to similar masses. For example, it corresponds to a mass of 50 kg for a bike (total load of 250 kg), but to a mass of 700 kg for a truck (total load of 3500 kg). This is why these two options compete for the top spot in terms of emissions.

It can therefore be concluded that the electric cargo bike represents a new sustainable transport solution whose better impacts in terms of GWP and ozone formation offer good prospects.

It is important to note that this analysis shows that the EURO 5 truck is not a particularly bad means of transport, especially when fully loaded. One reason for this is that truck engines are generally subject to strict controls as they are used directly for freight transport, which is highly regulated in Europe because it has long been criticised for its heavy ecological footprint. Nevertheless, as it has been pointed out for the City Line project, it is less practical for urban freight transport.

There are many other benefits to using cargo bikes. Below is a non-exhaustive list:

- Cargo bikes make mobility easier, especially in the city centre. They avoid congestion problems, especially as more and more cities now have bicycle paths, which are perfectly suited to the use of electric cargo bikes. They also make it possible to avoid the weight restrictions imposed on certain large trucks. In addition to limiting congestion, speed is limited, and so is the risk of accidents.

- Parking problems are also eliminated with bicycles. Bicycles are light, space-saving and it is easy for any company to consider having deliveries made by bicycle, without the need for suitable delivery spaces. Bicycles have easy access to many places, compared to other vehicles. The same observation can be made with regard to transporters: it is much easier to store a fleet of bikes than a fleet of trucks. A small storage space is more than sufficient, as long as it is equipped with electrical charging stations.

- With the increase in the number of electric vehicles observed in recent years, the number of electric charging points, which used to be a problem, has increased. This means that it is no longer an issue to recharge your vehicle. Fuel costs are also reduced to zero.

- No specific license is required to drive a cargo bike, even for professional purposes. It is therefore easier to find drivers, who can also perform other functions within the company. The regulations governing transport are also lighter.

- This means of transport is more suited to the city: less polluting and without noise pollution. Some cities now have zones in which it is only allowed to travel with a less polluting vehicle (according to EURO classes).

- The security of the goods is ensured, thanks to a total locking system. The driver has the goods in sight during the whole journey. Moreover, as the routes are quite short, there is no need to take breaks in sometimes unsecured parking lots, where theft can easily occur. Also, since the routes take place in the city centre, the visibility of the bike dissuades burglars.

- Loading and unloading times are reduced, due to the fact that it is not necessary to park the truck and that manoeuvring is made easier, but also because the goods transported are specific to a company. It is not necessary to get into the truck to find out which packages belong to which company among its total cargo. The entire trailer can simply be delivered.

- A cargo bike may seem expensive at the time of purchase, but this budget is less than that of a car, van, or truck. In addition, several financial assistance options exist to facilitate the purchase, and subsidies can also be obtained. The cost structure will be discussed in more detail in the *Cost price* section.

The main disadvantage identified being the limitation of distances, this mode of transport is quite legitimate for the delivery of parcels in the city centre. It may then be possible for several companies to share larger vehicles such as trucks or even electric vans to a collection point on the outskirts of the city, where cargo bikes can then take care of the last-mile delivery. There are several containers available for delivery by bike: trailers, containers, bins, workboxes, etc. It is also possible to load up to 80 kilos on the front of the bike, but this will limit the load on the trailer.

Urbike has developed specific containers called "rack-à-back", the product sheet of which can be seen in

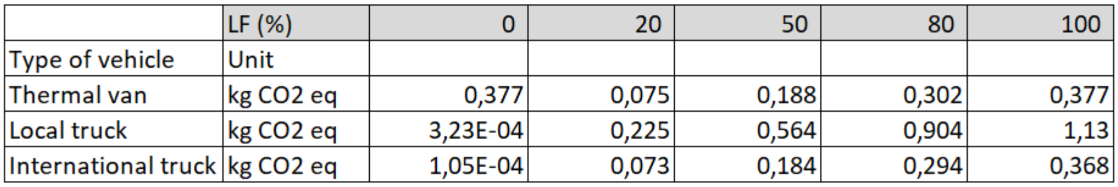
Appendices*VI*. These containers are suitable for delivery by bicycle, have wheels for easy movement, and their dimensions allow the transport of standard boxes and euro-pallets typically used for the transport and storage of goods. Containers from different companies can be combined in one truck and then divided for the last few kilometres by bicycle. Efficiency is maximised as the truck or van journey is made in LTL and the bicycle journey in FTL, or what might be called its bicycle equivalent.

Improvement analysis

For the future potential research to be carried out, it would be interesting to compare the different vehicles according to different loading factors in terms of percentage but corresponding to packages of equal weight. The loading factors currently taken into account correspond to different masses and are therefore valid for one type of vehicle only. It would then be beneficial to no longer speak in terms of LF but in terms of loaded parcels, and to see for example, which mode of transport is the least polluting for a cargo of 30 (as for cars), 100 or 200 kilos. Cars could also be studied more actively in this case. Furthermore, it could be analysed at what point, or at what mass, the van or the truck becomes a better alternative than the bicycle. Electric vans could be directly compared with trucks, and this would possibly lead to other results than the ones obtained previously.

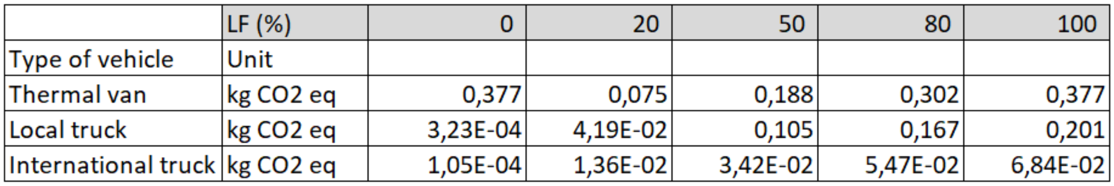
4. Carbon Footprint

As ADEME's Bilan Carbone® tool is not freely available, the AWAC (Agence Wallonne de l'Air et du Climat) carbon footprint calculator for small emitters was used. This is a tool designed for small companies and public institutions such as SMEs, independent in the tertiary sector, to calculate the greenhouse gas emissions generated by their daily activities. The interface is nevertheless weak for our analysis because it can just be used to calculate the impacts of a company's general activities (electricity consumption, heating, staff travel, goods transport, etc.), that is to say direct emissions, from scope 1. Scope 2 and 3 emissions are unfortunately neglected by the simulator. Only the "logistics" tab of the interface, referring to the delivery of goods, was used for this study. The results are available in kg of CO_2-equivalents for 3 types of non-electric vehicles: a thermal van, a local truck, and an international truck. In *Table 22*, it was assumed that the maximum loads accounted for are the same as in SimaPro, respectively 650 kg for the van and 3500 kg for the two types of truck. The loading factors for the van and the trucks therefore represent different masses, as in the LCA. In *Table 23*, however, the truck was modified to represent loading factors equal to those of a van, considering a maximum load of 650 kg as well. The results are available for the functional unit "km", this being the only one proposed by the simulator.



	LF (%)	0	20	50	80	100
Type of vehicle	Unit					
Thermal van	kg CO2 eq	0,377	0,075	0,188	0,302	0,377
Local truck	kg CO2 eq	3,23E-04	0,225	0,564	0,904	1,13
International truck	kg CO2 eq	1,05E-04	0,073	0,184	0,294	0,368

Table 22: AWAC calculator results in km



	LF (%)	0	20	50	80	100
Type of vehicle	Unit					
Thermal van	kg CO2 eq	0,377	0,075	0,188	0,302	0,377
Local truck	kg CO2 eq	3,23E-04	4,19E-02	0,105	0,167	0,201
International truck	kg CO2 eq	1,05E-04	1,36E-02	3,42E-02	5,47E-02	6,84E-02

Table 23: AWAC calculator results in km (same LF)

As for the life cycle assessment, the results in km increase with the load transported, as the impacts are not allocated to a single package, but to the whole cargo. It can be observed that the international truck is the least polluting means of transport, for both payloads analysed, followed by the local truck, for equivalent capacities (650 kg). This hypothesis is the most correct, although the description of a "local truck" is not given by the simulator, it can be assumed that it is a small truck for urban delivery, with a capacity equivalent to that of a van. Generally speaking, the analysis shows that a thermal van does not seem to be an advantageous option for a company wishing to reduce its carbon footprint.

If we compare these results with those obtained from the life cycle assessment, it can also be observed that they are much higher. We can conclude that the two methods do not take the same elements into account, as the extraction and construction inputs are not part of the AWAC's analysis, for example. This tool is in fact used for general analysis purposes, to make companies aware of their environmental impact and to help them make decisions, so it is naturally less powerful than software such as SimaPro or GaBi. The calculation made by AWAC to obtain these results is as follows: the transport activity is first transformed into t.km and then multiplied by the two emission factors below.

- A "fossil fuel use" emission factor for each vehicle type
- A "fossil fuel production" emission factor for each type of vehicle

Then the two results for each emission type are added together to obtain the total impact. The emission factors for each type of vehicle are available in *Table 24*.

Type of vehicle	Fossil fuel use	Fossil fuel production
Thermal van	$2{,}04 \times 10^{-4}$	$3{,}76 \times 10^{-4}$
Local truck	$5{,}881 \times 10^{-5}$	$2{,}64 \times 10^{-4}$
International truck	$7{,}524 \times 10^{-5}$	3×10^{-5}

Table 24: AWAC calculator emission factors

5. Cost price

The life cycle assessment evaluated the potential environmental impacts arising from the transport activity of the City Line project. It is therefore a life cycle assessment related to the proposal of a service. In order to assess the strategic strength of this project, it is important to also analyse its cost structure to determine the extent to which it represents a competitive advantage for the transport partners. The electric cargo bikes and vans provided for the project entail costs for the transport partners, which will ultimately be charged to potential customers. This element should thus be considered in the broader strategic strength analysis of the City Line project.

5.1. Introduction

The cost price is an economic term that refers to all the costs incurred by a company to produce a good or service. The calculation must take into account both direct costs and indirect costs, i.e., expenses that are not directly linked to the production of the product or service (advertising, rental of premises, salaries, etc.) (Blanc, 2017).

There are various methods to calculate the cost price of an object or service. These are detailed below.

Firstly, the variable cost approach or "direct costing" incorporates all the variable costs linked to the company's activities into the so-called direct costing. This term is therefore misleading, as no distinction between direct and indirect costs is made at this stage. As a result, this method makes it possible to calculate the direct cost of an object or service, based on a distinction between fixed costs, which cannot be controlled by an isolated decision-maker, and variable costs, which are more controllable by an isolated decision-maker.

Secondly, the semi-complete costing approach will incorporate fixed costs, which were not taken into account in the direct costing method, into the calculation. The direct costs as well as the indirect variable costs related to the manufacture and distribution of the cost object or service will be considered.

The last approach described in the literature is the full cost approach. It distinguishes between direct and indirect costs related to the consumption of a company's resources. In this way, all stages of the production, design and distribution of a product or service to the end customer are taken into account. It is therefore possible to calculate the full cost of goods sold by adding together the purchase cost, the distribution and the non-production costs of the products sold.

The trinomial formula is used to calculate the cost of a road transport operation. This is a mathematical formula that calculates the operating cost of a transport operation from the sender to the receiver, using 3 terms that are described in the next section.

5.2. Trinomial formula

In the case of road transport, the trinomial formula is used to calculate the cost price. It includes three main terms: the kilometre term, the daily term and the hourly term. The cost price from the sender to the recipient is then known. In this work, 1 km has been chosen as the unit of measurement and 1 kg is being transported, in order to be consistent with the life cycle analysis.

5.2.1. Kilometric term

This first element of the trinomial calculation allows to calculate the kilometric cost related to a transport. To do this, the following elements are taken into consideration:

- Amount of gasoline, diesel or electricity used, when using electric vehicles: the price of fuel per kilometre will be multiplied by the number of kilometres travelled. In the case of electric vehicles, the price per Watt-hour will be multiplied by the number of Wh.
- Tyre wear
- Repairs and maintenance operations to be carried out on the vehicle.
- Road tolls, which will not be considered for this project, since the transport is carried out in Belgium, where no road tolls are directly applicable.

These different expenses are included in the category of variable expenses, because they increase according to the number of kilometres covered for a transport.

5.2.2. Hourly term

The second element in the trinomial calculation is the hourly term, which makes it possible to calculate the driving loads. It includes:

- The driver's salary
- The employee contributions (ONSS, professional deduction, etc)
- The possible expense reports.

These charges are considered as fixed because they are not impacted by a variation of the number of kilometres driven.

5.2.3. Daily term

The last element is the daily term, which is used to calculate the daily charges. The following charges aplly:

- The purchase cost of the vehicles. The 21% VAT applicable to the purchase of the vehicles and batteries is not included in the cost price calculation because this VAT is deductible by the company.
- Depreciation, which is a sum set aside by the company to buy the same or a similar vehicle, back at the end of the duration of use.
- Insurance
- Taxes
- Structural costs

These are also fixed costs. They are the responsibility of the carrier, whether the vehicle is used or not, and do not change according to the vehicle usage rate.

5.2.4. Calculation

According to the trinomial formula, the cost price will therefore be equal to the sum of

$$C_k + C_h + C_j$$

Where,

C_k = Kilometric load

It is calculated as follows: Price per kilometre × number of kilometres.

C_h = Hourly charge

This is the service time multiplied by the price per hour.

The service time can be calculated by dividing the distance by the speed, and then adding the expected loading and unloading time.

C_j = Daily load

The service time is divided by the maximum daily service time to obtain the number of days the vehicle is used.

5.3. Application to the City Line project

The transport partners Coursier Wallon and Urbike provided a significant amount of information on the costs of acquiring and owning different vehicles. As far as Deliver-e is concerned, it is more complicated to carry out any cost price analysis, as the amount of information received is far too small and the number of assumptions and estimates to be made is high.

Nevertheless, the trinomial formula will be applied to all the project's transporters, Coursier Wallon, Urbike, and Deliver-e in order to assess the cost performance of the City Line Project. The following assumptions had to be made in order to proceed with the calculation.

Assumption 1 – electricity use: For electric vehicles, the calculation in Watt-hours will be used to determine the electricity consumption. A price of 0.2702 € /kWh is applicable, i.e. the price for household consumers, including taxes in BE for the second half of 2020 (Eurostat, 2021a).

Assumption 2 – tyre wear: most bicycle tyres have a lifespan of between 2000 and 5000 km (Reynaud, 2021), depending on the load carried, the condition of the roads used, the tyre pressure, the ambient temperature and the driving style. For the purposes of this project, we therefore consider a lifespan of 5000km, with the load carried representing 1kg and the roads used considered in good condition (urban area). All tyre prices come from the French website Velobac.

Assumption 3: it is assumed that bicycles travel at an average speed of 19km/h (Service Public de Wallonie, 2016).

Assumption 4: A year is 200 working days, and a working day is 10 hours (according to the excel table CNR– Simulateur de coût de revient).

Assumption 5: the service time is estimated at 1 hour, including loading and unloading.

Assumption 6: the figures obtained are rounded to the nearest thousandth.

5.3.1. Coursier Wallon

The calculations are made on an eBullit 6100 electric cargo bike with a Shimano Steps 418Wh battery. The number of kilometres done per year by Coursier Wallon is estimated at 5000, according to the company.

Kilometric term	
Electrical use	
Battery capacity	418 Wh = 0.418 kWh
Price per kWh	0.2702 €
	0.418 × 0.2702 € = 0.113 €
Battery life / autonomy	90 km
Total	0.113 / 90 = **1.254 × 10^{-3} €/km**

Tyre wear	
Shwalbe marathon 20x1,75 (front)	22,90 €
Schwalbe marathon 26x1,75 (rear)	34 €
Lifespan	5000 km
Total	56,90 € / 5000 = **1.138 × 10^{-2} €/km**
Repairs and maintenance	
Annual budget	1000 €
Annual kilometres	5000 km
Total	1000 € / 5000 = **0.20 €/km**
TOTAL	**0.213 €/km**
Hourly term	
Driver's salary (gross wage)	12.046 €/h
Expense reports	/
TOTAL	**12.046 €/h**
Daily term	
Depreciation	
Purchase price	4575 €
Lifespan	4 years
Maintenance price over 1 year	1000 €
Annual kilometres	5000 km
Number ok km per hour	19 km
Annual kilometres (in hours)	5000 / 19 = 263.158 €
Total per hour	[4575 + 1000 * 4] / [263.158 * 100% * 4] = 8.1463 €/h
Total per day	8.1463 €/h × 10 = **81.463 €**
Insurance (per year)	
Omnium	98 €
Bicycle insurance	10.01 €
Total per day	108.01 € / 200 = **0.541 €**
Additional expenses (per year)	

Health service	450 €
Working clothes	500 €
Legal insurance	2500 €
Total per day	3450 € / 200 = **17.25 €**
TOTAL	**99.254 €/day**

Table 25: Trinominal formula - Coursier Wallon

For the chosen unit of measurement, i.e., a kilometre, the hourly and daily terms must be transformed to obtain:

Kilometric term	**0.213€/km**
Hourly term	12.046 €/h
Average journey of 19 km + 1 hour service	24.092 €/service
Total in km	24.092 €/19 = **1.268 €/km**
Daily term	99.254 €/day
Total per year	99.254 € × 200 = 19850.8 €
Total per km	19850.8 € / 5000 = **3.97 € /km**
COST PRICE	**5.451 €/km**

Table 26: Cost price – Coursier Wallon

5.3.1.1.Additional explanations and assumptions:

1) Kilometric term

- Electrical use: The Shimano Steps battery has a capacity of 418 Watt-hours and an autonomy of 90 km.

- Tyre wear: The eBullit 6100 electric cargo bike has two wheels with two Schwalbe Marathon tyres, 20 and 26 inches in diameter and 1.75 inches wide.

- Repairs: an average budget of €5000 per year is planned by Coursier Wallon for the maintenance of their 4 electric cargo bikes, their "standard" bike and their 3 trailers. It is therefore considered that the budget allocated to the maintenance of one electric cargo bike amounts to €1000 per year, the costs being more important for this type of vehicle than for a standard bike or a trailer.

2) Hourly term

- Expense reports: no expenses mentioned by Coursier Wallon.

3) Daily term

- Depreciation: straight-line depreciation for 3 years, with replacement planned every 3 to 5 years. On average, 4 years were thus considered. The formula below was communicated by Urbike and will be applied. This formula is expressed in hours and will hence be multiplied by 10 (*Assumption 4*) to be transformed in a daily term. The purchase price of a bike amounts €4575 exl. VAT (including €371 for the battery), and no credit has been granted to the company.

Cost (€/hour) for the rolling stock:

$$\frac{[\text{purchase price excl. VAT} + \text{maintenance price over the 4 years}]}{[\text{use (hours per year)} * \text{percentage of use (\%)} * \text{depreciation period (4 years)}]}$$

- Additional taxes and charges: Cohezio medical service (based on the year 2020), work clothes and Allianz law insurance. The law insurance is a compulsory insurance that every employer must subscribe to in order to insure his workers in case of accidents at work, on the way to work etc.

5.3.1.2.Conclusion

The price cost of an eBullit 6100 electric cargo bike is €5.451, with the daily term having the greatest influence on this figure. This is followed by the hourly term and then the kilometre term. The daily and hourly terms are fixed costs, which means that Coursier Wallon will assume them, whether its bicycles are currently in use or not. Owning the bikes actually costs more than using them. Depreciation is the most expensive factor, followed by the driver's salary and additional expenses.

5.3.2. Urbike

The calculations are made on a DOUZE Cycles G4 electric cargo bike with black box and Brose S battery. The number of kilometres done per year by Urbike is estimated at 12000.

Kilometric term	
Electrical use	
Battery's capacity	635 Wh = 0.635 kWh
Price per kWh	0.2702 €
	0.635 × 0.2702 € = 0.172 €
Battery life / autonomy	120 km
Total	0.172 / 120 = **1.429×10^{-3} €/km**
Tyre wear	
Shwalbe Big Ben Plus 20x2,15 (front)	26.90 €
Schwalbe Big Ben Plus 26x2,15 (rear)	32.90 €
Lifespan	5000 km
Total	59.80 € / 5000 km = **1.196×10^{-2} €/km**
Repairs and maintenance	
Bicycle	1200 €/bike
Trailer	200 €/trailer
Container	100 €/container

Annual budget (bicycle + trailer)	1400 €
Annual kilometres	12000 km
Total	1400 € / 12000 = **0.117 €/km**
TOTAL	**0.13 €/km**
Hourly term	
Driver's salary (gross wage)	20 €/h
Expense reports	/
TOTAL	**20 €/h**
Daily term	
Depreciation	
Purchase price	4322 €
Lifespan	2 years
Maintenance price over 1 year	1400 €
Annual kilometres	12000 km
Number ok km per hour	19 km
Annual kilometres (in hours)	12000 / 19 = 631.579 €
Total per hour	[4322 + 1400 * 2] / [631.579 * 100% * 2] = 5.6382 €/h
Total per day	5.6382 €/h × 10 = **56.382 €**
Insurance (per day)	**0.541 €**
Additional expenses (per year)	
Storage space	4 m^2, 10 €/m^2/month
Price per year	4 m^2 × 10 € × 12 = 480 €
Price per day	480 / 200 = 2.4 €
Electricity	2.5 €/bike
Price per year	30 €
Price per day	30 € / 200 = 0.15€
Parts	100 €/bike/year
Price per day	100 € / 200 = 0.5 €
Legal insurance	2500 € / 200 = 12.5 €

Total	**15.9 €**
TOTAL	**72.823 €/day**

Table 27: Trinominal formula - Urbike

For one kilometre, the following cost price is obtained:

Kilometric term	**0.13 €/km**
Hourly term	20 €/h
Average journey of 19 km + 1 hour service	40 €/service
Total in km	40 €/19 = **2.105 €/km**
Daily term	72.823 €/day
Total per year	72.823 € × 200 = 14564.6 €
Total per km	14564.6 € / 12000 = **1.214 € /km**
COST PRICE	**3.419 €/km**

Table 28: Cost price - Urbike

5.3.2.1. Additional explanations and assumptions

1) Kilometric term

- Electrical use: The Brose S battery has a capacity of 635 Watt-hours and an autonomy of 120 km.

- Tyre wear: The eBullit 6100 electric cargo bike has two wheels with two Schwalbe Big Ben Plus tyres, 20 and 26 inches in diameter and 2.15 inches wide.

- Repairs: an annual budget is allocated by Urbike for its bikes, trailers, and containers. It is allocated as follows: €1200 for 11 bikes, €200 for 6 trailers and €100 for 6 containers. A bicycle equipped with a trailer will be considered because it is the combination most likely to be used for this project.

2) Hourly term

- The driver's salary: approximately €20 gross per hour, including contributions.
- Expense reports: no expenses mentioned by Urbike.

3) Daily term

- Depreciation: 2-year depreciation period, linear. The same calculation as for Coursier Wallon applies, with a 2-year period, instead of 4. The purchase price of a bike amounts €4322 exl. VAT (including the price for the battery). No credit has been granted to Urbike for the purchase of its vehicles, a "BCKlet" subsidy, however, was obtained by the company, but this will not be taken into account as the amount is not known.

- Taxes and insurance: not mentioned by Urbike. The same insurance amount as for Coursier Wallon will therefore be used hypothetically.

- Structural costs: These relate to the storage space dedicated to cargo bikes and equipment, the electricity costs for this space and a "parts" budget covering the purchase of locks, bike racks, etc. The legal insurance mentioned by Coursier Wallon has also been integrated in the calculation as it is compulsory for all employers.

5.3.2.2.Conclusion

The price cost of a DOUZE Cycles G4 electric cargo bike amounts €3.419, with the hourly term having the greatest influence on this figure, followed by the daily term. It means that, as for Coursier Wallon, the costs incurred by the possession of a bike is greater than the costs incurred by its utilisation. The driver's salary is the most important charge per kilometre.

5.3.3. Deliver-e

Deliver-e uses the Nissan e-NV200 van. As no data was provided by the company, many assumptions had to be made, starting with the number of km done per year with an electric van, which was estimated to be 25,000, that is to say about twice as much as the number of kilometres made with a cargo bike by Coursier Wallon over a year.

Kilometric term	
Electrical use	
Battery’s capacity	40 kWh
Price per kWh	0.2702 €
	40 × 0.2702 € = 10.808 €
Battery life / autonomy	200 km
Total	10.808 / 200 = **0.54 €/km**
Tyre wear	
4 x 17" tyres	40 €
Lifespan	40000 km
Total	40 € / 40000 km = **1 × 10^{-3} €/km**
Repairs and maintenance	
Annual budget	2000 €
Annual kilometres	25000 km
Total	2000 € / 25000 = **0.08 €/km**
TOTAL	**0.621 €/km**
Hourly term	
Driver’s salary (gross wage)	20 €/h
Expense reports	/
TOTAL	**20 €/h**
Daily term	
Depreciation	
Purchase price	35470 €
Lifespan	5 years
APR	1.50 %
Maintenance price over 1 year	2000 €
Annual kilometres	25000 km
Number ok km per hour	70 km
Annual kilometres (in hours)	25000 / 70 = 357.143 €

Total per hour	[35470 * 1.015 + 2000 * 5] / [357.143 * 100% * 5] = 25.7611 €/h
Total per day	25.7611 €/h × 10 = **257.611 €**
Insurance	
Total per year	1000 €
Total per day	1000 / 200 = **5 €**
Additional expenses (per year)	
Storage space	
Price per year	500 €
Price per day	500 / 200 = 2.5 €
Legal insurance	2500 € / 200 = 12.5 €
Total	**15 €**
TOTAL	**277.611 €/day**

Table 29: Trinominal formula – Deliver-e

The cost price for one kilometre I then obtained as follows:

Kilometric term	**0.621 €/km**
Hourly term	20 €/h
Average journey of 19 km + 1 hour service	40 €/service
Total in km	40 €/19 = **2.105 €/km**
Daily term	277.6311 €/day
Total per year	277.611 € × 200 = 55522.2 €
Total per km	55522.2 € / 25000 = **2.221 € /km**
COST PRICE	**4.947 €/km**

Table 30 : Cost price – Deliver-e

5.3.3.1. Additional explanations and assumptions

1) Kilometric term

- Electrical use: the Nissan e-NV200 van has a 40-kWh battery, with an autonomy of 120 km.

- Tyre wear: 4 four-season tyres at market price, with a life span of approximately 40,000 km

- Repairs: an annual budget of €2000 is applicable, which is about twice the budget allocated for cargo bikes

2) Hourly term

- The driver's salary: same as for Urbike

- Expense reports: no expenses

3) Daily term

- Depreciation: 5-year depreciation period, linear. The same calculation as for the other transport partners apply. However, Deliver-e was certainly granted with a credit for the purchase of a van. An APR (Annual Percentage Rate) of 1.50% was therefore added. The purchase price of the van is €35470, for the "business" model.

- Taxes and insurance: an estimate was made, based on various Belgian insurers' websites

- Structural costs: an estimate was made for the storage and the same legal insurance as for the other partners apply.

5.3.3.2. Conclusion

The price cost of a Nissan e-NV200 amounts €4.947, with the daily term being the most important but being closely followed by the hourly term. Depreciation is having a strong influence, as well as the driver's salary.

5.4. Interpretation

It can be observed that the costs incurred by Coursier Wallon, Urbike and Deliver-e are of the same order of magnitude, close to €4-5. At first sight, the bikes owned by Urbike have a lower cost price and are therefore more advantageous. However, it is important to take a step back from the situation and analyse the cost elements responsible for this difference.

The assumptions expressed in section 1.3. were made objectively and apply to all carriers. Thus, it can hence be concluded that they do not positively influence the result of one carrier to the detriment of another.

The additional expenses incurred by Coursier Wallon are greater than those incurred by Urbike, but the two companies have not communicated the same types of expenses. The first scenario deals with working clothes and medical services, while the second deals with storage space and electricity. Consequently, these costs are not directly comparable even though they are in the same category. The batteries of the two bikes considered are different, and hence generate different costs. The purchase price of the bicycles and the budget for repairs is fairly similar, but is distributed differently, which results in a higher depreciation expense for Coursier Wallon, because their bicycles have a lower annual usage rate. Indeed, they achieve a rather low number of kilometres per year, 5000 km in comparison to 12000 for Urbike. Consequently, their annual charges cannot be distributed advantageously, and this results in a price difference of 2 euros, which is not neglectable. A considerable difference in salary can also be observed, as Urbike pays its drivers about €8 more in gross salary. This is obviously an estimation. Since Urbike did not communicate the amount of insurance the company has to pay, it was assumed that this amount is similar to the one paid by Coursier Wallon. However, it is possible that this budget represents a different charge.

For the electric vans, Deliver-e did not provide any information other than the vehicle model. Most of the assumptions were therefore made on the basis of the other transporters, even though they use completely different vehicles. The amounts have been increased but the price of €4.947 still needs to be analysed in more detail. Other additional charges are certainly borne by Deliver-e. The expenses for this type of vehicle are logically higher than for a cargo bike. If we compare this price with the one of Urbike, which is the most representative for a cargo bike because of the number of kilometres travelled, we can see a difference of €1.528. We can therefore deduce that owning a cargo bike is logically less expensive than a van.

Generally speaking, this analysis shows a cost price of around €4-5 for electric cargo bikes. This analysis must obviously be qualified, as it does not mean that the same prices are applicable to all companies owning electric cargo bikes. A variation in this figure can be observed depending on the number of kilometres that the bikes travel per year, the insurance and credit policies that companies have to deal with, but also the structural costs of the companies. It should be noted too that subsidies are sometimes granted to companies for the purchase of so-called less polluting vehicles.

Therefore, results obtained in this analysis cannot be directly transposed to all cases of acquisition and use of cargo bikes. This is a personal analysis, albeit an objective one, which has been conducted without value judgement.

It is also important to note that the results obtained in this analysis are highly dependent on the number of kilometres driven per year. These data are therefore valid for 2021 (based on 2020) and could change radically in the coming years if the partner companies develop their activities. The costs incurred could then be significantly reduced.

In general, it can be concluded that an electric cargo bike is both a more economical and less polluting option, thanks to the results obtained in the LCA and the cost analysis. The electric van, on the other hand, is more polluting and less interesting financially speaking.

6. Conclusion

In a context where ecological issues are at the heart of the societal debate, more and more companies are questioning their transport activity, which is highly polluting and often not regulated internally by companies. The "traditional" transport solutions present on the market, and particularly the truck, are still relevant, but are however gradually being replaced by more ecological solutions, especially in urban areas, where these vehicles do not allow for a user-friendly sharing of the roads. The City Line project aims to respond to this voluntary transition on behalf of several companies, through the use of electric vehicles, more specifically cargo bikes and vans, for the delivery of goods.

This thesis identified the bicycle as the least harmful means of transport for the global warming potential (in kg CO_2-equivalents) and ozone formation (in kg NO_x-equivalents) impact categories, thanks to a life cycle analysis carried out with two LCA software packages, SimaPro and GaBi. The electric cargo bike was compared with a thermal van, an electric van, a small truck (maximum load of 3.5t), and several car models. A quick carbon footprint was performed to further investigate the results and the relevance of the two methods. The analysis revealed that the LCA is still the most appropriate method when several impacts need to be identified. The results obtained kg CO_2-equivalents for the "GWP" impact category using SimaPro (in kg.km and with a loading factor of 100%) are $8{,}41\times10^{-5}$ for an electric cargo bike, $2{,}33\times10^{-4}$ for an electric van and $1{,}6\times10^{-4}$ for a small truck.

A cost price analysis was then carried out to further investigate these results and to add an economic dimension, in addition to the environmental one. The main result obtained is that transport by electric cargo bike is more interesting, with a cost price of around €4-5. It is less expensive than the other vehicles on the market, requires low-cost maintenance, and subsidies can also be obtained. However, the analysis must be taken with hindsight, as it is highly dependent on its use, an electric bike used to its full capacity being of course the most advantageous option.

The electric van is also a good solution, but unfortunately could not be analysed with project-specific data due to the lack of information obtained from the partners. As far as its environmental impact is concerned, it is still polluting, especially when lightly loaded.

Limitations and further research

This study is particularly valid for the City Line project and could be transposed to other contexts, provided that the assumptions made in the various stages apply as well. The vehicles analysed in the life cycle analysis are general processes and can therefore be transposed to similar research. Some of the vehicles were slightly modified to comply with the characteristics of this project, especially in terms of the maximum loads carried, but these modifications are minor and do not greatly influence the results obtained. However, the cost analysis is more specific to the data provided by the transport partners, especially for the electric cargo bikes. The number of assumptions that had to be made remains high, due to the lack of information obtained.

This study is limited in time, and geographically, as it provides a more sustainable solution for transport over short distances. Goods coming from other countries or from more distant regions still have to be transported to the city by traditional trucks or vans. In addition, new transport technologies are developing rapidly, and more cost-effective solutions may emerge in the next few years.

Only two impact categories have been analysed, but there are many other categories and factors that can be used to assess the environmental impacts of an activity. This thesis does not claim to offer a complete answer.

The loading factors analysed also correspond to different transported loads, which does not allow direct comparison for cargoes of similar masses. Furthermore, the volume of the package has not been taken into account, which could also add an interesting dimension to the analysis.

In conclusion, although the truck is still very present on the market, new electric and ever more ecological modes of transport are emerging to gradually replace it. Some companies are still reluctant, but the standards regulating transport are becoming stricter and the awareness and the need of users for sustainable solutions is becoming greater over time. Attitudes are changing and so is transport. Other advantages, specifically for the use of electric bicycles, are also to be mentioned, such as facilitating traffic, parking, avoiding congestion in the city centre, etc.

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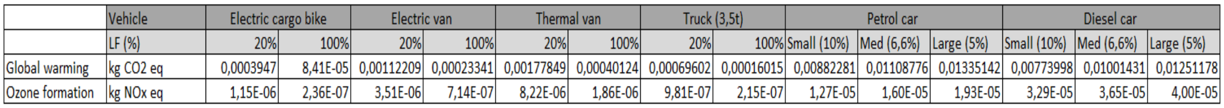
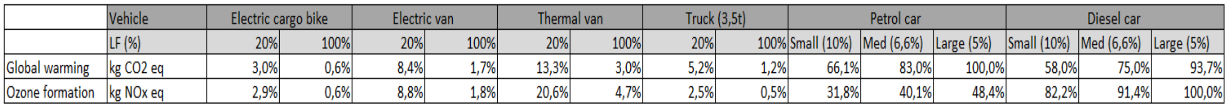
Appendices



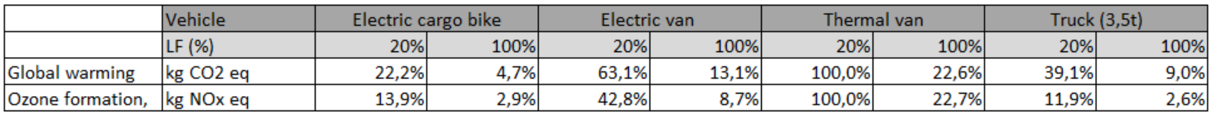
	Vehicle	Electric cargo bike		Electric van		Thermal van		Truck (3,5t)		Petrol car			Diesel car		
	LF (%)	20%	100%	20%	100%	20%	100%	20%	100%	Small (10%)	Med (6,6%)	Large (5%)	Small (10%)	Med (6,6%)	Large (5%)
Global warming	kg CO2 eq	0,0003947	8,41E-05	0,00112209	0,00023341	0,00177849	0,00040124	0,00069602	0,00016015	0,00882281	0,01108776	0,01335142	0,00773998	0,01001431	0,01251178
Ozone formation	kg NOx eq	1,15E-06	2,36E-07	3,51E-06	7,14E-07	8,22E-06	1,86E-06	9,81E-07	2,15E-07	1,27E-05	1,60E-05	1,93E-05	3,29E-05	3,65E-05	4,00E-05

Appendix I: Comparison of all vehicles (incl. cars), SimaPro results in kg.km, relative value



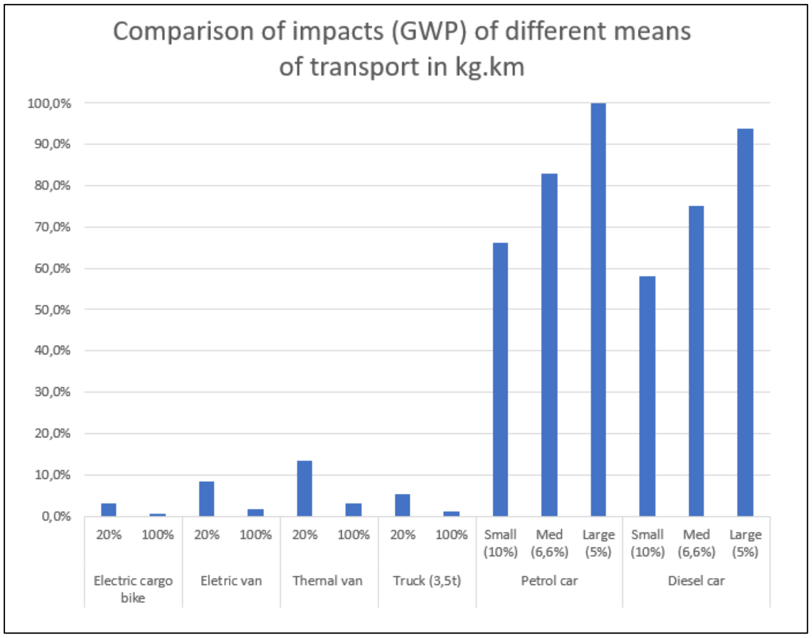
	Vehicle	Electric cargo bike		Electric van		Thermal van		Truck (3,5t)		Petrol car			Diesel car		
	LF (%)	20%	100%	20%	100%	20%	100%	20%	100%	Small (10%)	Med (6,6%)	Large (5%)	Small (10%)	Med (6,6%)	Large (5%)
Global warming	kg CO2 eq	3,0%	0,6%	8,4%	1,7%	13,3%	3,0%	5,2%	1,2%	66,1%	83,0%	100,0%	58,0%	75,0%	93,7%
Ozone formation	kg NOx eq	2,9%	0,6%	8,8%	1,8%	20,6%	4,7%	2,5%	0,5%	31,8%	40,1%	48,4%	82,2%	91,4%	100,0%

Appendix II: Comparison of all vehicles (incl. cars), SimaPro results in kg.km, percentage value

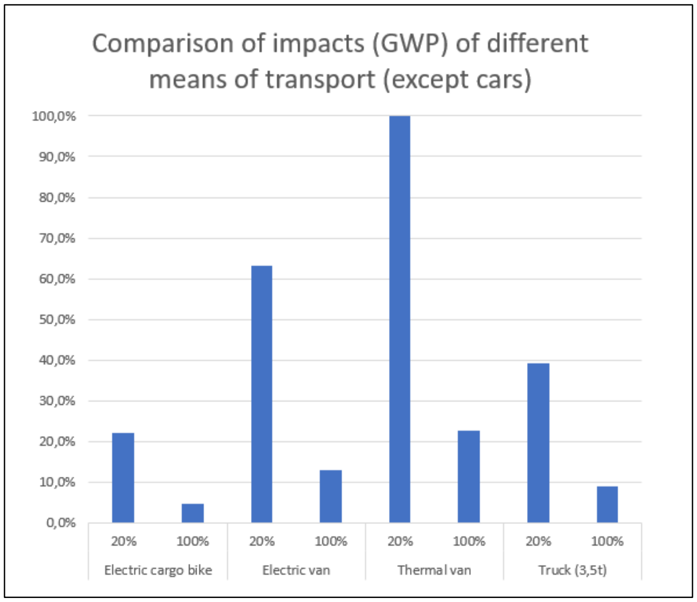


	Vehicle	Electric cargo bike		Electric van		Thermal van		Truck (3,5t)	
	LF (%)	20%	100%	20%	100%	20%	100%	20%	100%
Global warming	kg CO2 eq	22,2%	4,7%	63,1%	13,1%	100,0%	22,6%	39,1%	9,0%
Ozone formation,	kg NOx eq	13,9%	2,9%	42,8%	8,7%	100,0%	22,7%	11,9%	2,6%

Appendix III: Comparison of all vehicles, no distinction between LF, SimaPro results in kg.km, percentage value



Appendix IV: Graphical representation of the SimaPro results, kg.km (incl. cars)



Appendix V: Graphical representation of the SimaPro results, kg.km (excl. cars)

RACK À BACS

UN **CONTENEUR** SPÉCIALEMENT CONÇU POUR **LA LIVRAISON DE CAISSES ET BOÎTES STANDARDS**

- **Un rack à étagères polyvalent** sur roulettes
- Un grand volume avec **deux larges ouvertures**

BicyLift, une gamme de solutions brevetées, développée par FlexiModal
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Appendix VI: product sheet of a ''rack-à-back" from Urbike

Executive Summary

The aim of this thesis is to analyse the environmental impacts of transporting goods using different "traditional" means of transport, i.e., thermal vans and small trucks for the delivery of goods, and different types of cars for the collection of parcels by individuals. These vehicles will then be compared with more recent electric means of transport, namely cargo bikes and vans.

The first step of this thesis consists of a literature review to identify the most appropriate method to assess the harmful emissions related to the daily activities of a company. The Life Cycle Assessment (LCA) method was identified as such and was then used, once the most suitable software had been chosen. Two software packages, SimaPro and GaBi, were used, each with different features and offering a more in-depth analysis. A quick carbon footprint was also carried out, limited to the CO_2 emissions.

Secondly, an economic dimension was added by carrying out a cost analysis, for electric vehicles only, based on information collected from the transport partners of the City Line project, an urban logistics project for the "green" delivery of parcels in the city via electric vehicles.

The results of the two analyses, economic and environmental, were then compared to provide an overview of the benefits of cargo bikes and electric vans.

The last step is the conclusion, offering possible solutions but also setting out the limits of the study and proposing ideas for future research.