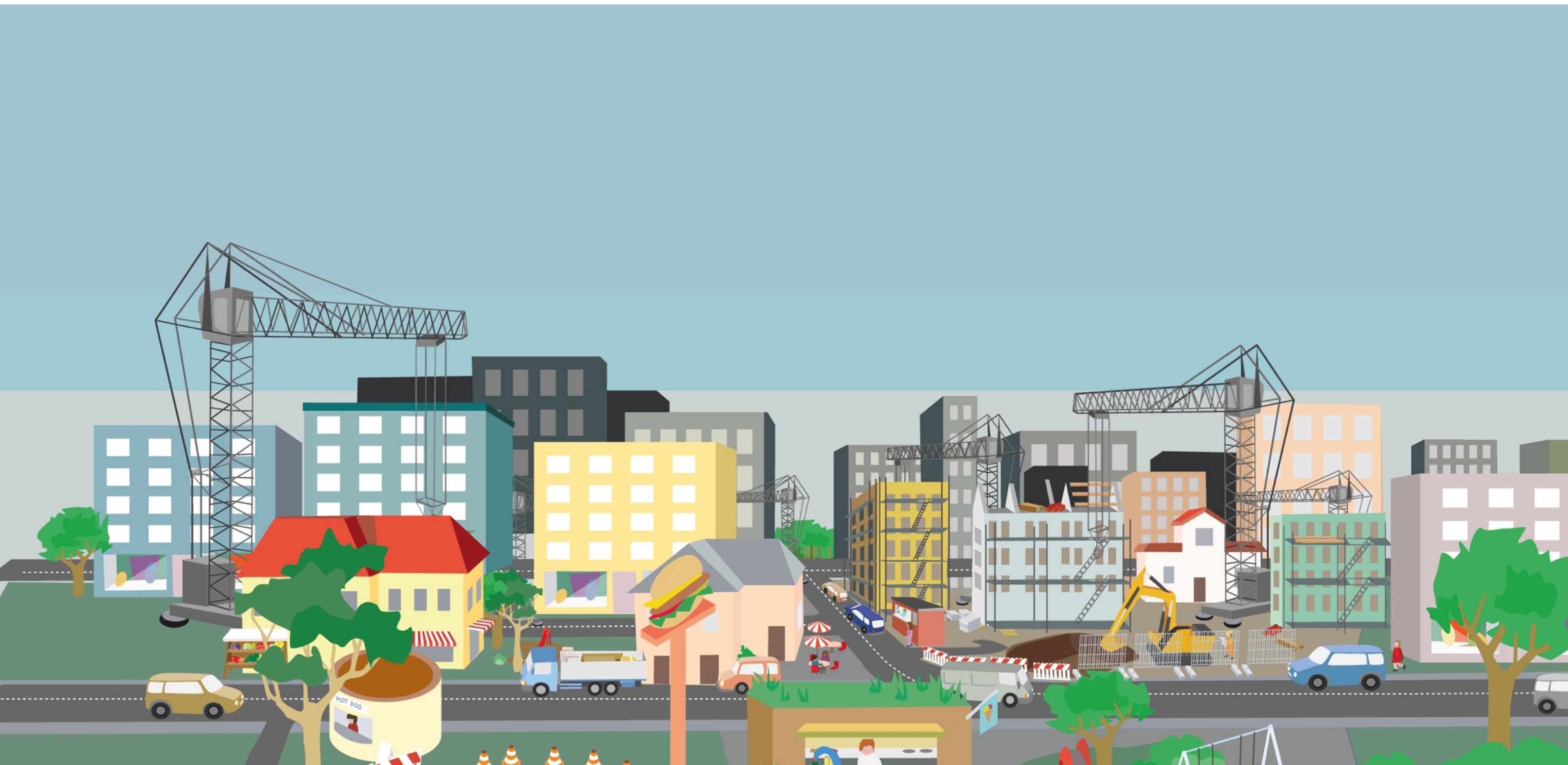
WP2: Impact assessment

Deliverable 2.1: Methodologies for impact assessment of on-site and off-site construction logistics

August 2020



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MIMIC Deliverable 2.1

Methodologies for impact assessment of on-site and off-site construction logistics

Version: 1.0

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Executive summary

Urban construction projects are essential in reducing the housing deficit of the latest urbanization trend (UN, 2015 & 2018). As such, construction projects contribute to more attractive, sustainable and economically viable urban areas once they are finished. However, construction work and construction material flow activities cause severe negative impacts on the surrounding community during the construction process. The MIMIC project focuses on the social, economic and environmental sustainability problems that arise from urban construction, and especially the logistics activities to, from, around and on urban construction sites.

This deliverable is part of Work Package 2 of the MIMIC project (Minimizing impact of construction material flows in cities: Innovative Co-Creation), a JPI Europe funded research project with demonstration cases in Brussels, Vienna, Oslo and Sweden. The objective of WP2 is integration of state-of-the-art impact assessment methods in a practical and easy-to-use framework to assess the sustainability effects of on and off-site construction logistics and assessment of impacts. Based on current knowledge of sustainability impacts of logistics operations, construction management and existing calculation tools, a framework will be set up to monitor and quantify the off-site and on-site economic, social and environmental impact of construction logistics scenarios including major externalities (accidents, air pollution, climate change, infrastructure, congestion and noise) compared to 'business-as-usual'. Deliverable 2.1 introduces the methodologies that will be used to assess the impact of on-site and off-site construction logistics.

In order to cover the impact of both on-site and off-site construction logistics, the assessment framework will combine two distinct methodologies: External Cost Calculations and Life Cycle Assessment. This deliverable presents each methodology in detail, highlighting the scope, the system boundaries, their logistics activities and their data collection plan. Finally, a first building stone will be laid towards expected outcomes, the feedback loop in developing the impact assessment framework, and how both methodologies will be brought together within the framework for the final deliverable by the end of the project.

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1. Introduction

There is an ongoing urbanization trend, making municipalities focus on densifying cities, hence stimulating construction and renovation works in urban areas. Urban construction intrinsically strongly relies on logistics activities, and these in turn are the source of environmental nuisances. These nuisances are referred to as external costs, a cost that "*arises, when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated for, by the first group*" (Bickel et al., 2005: 10).

For transport to and from the construction site (off-site construction logistics), they come in the form of i.a. air pollution, greenhouse gas emissions, noise pollution, congestion, accidents etc. The order of magnitude of external costs of transport in the EU equals approximately 1,000 billion euro per year, which represents about 7% of the EU28's GDP (EC, 2018). The construction sector represents a share of about 20-35% of total freight traffic in urban areas, depending on the cases and calculation methods and variables (Brusselaers et al., 2020). However, to perform accurate external cost calculations, there is a need for accurate data to enable the consideration of significant calculation- variables, like vehicle-type, road type, traffic situation, number of receptors, etc., which are often not considered in construction logistics impact assessments so far (Brusselaers et al., 2020).

For on-site work, the nuisance and vibrations from construction work and waste generation, as well as greenhouse gas emissions and air pollution from construction machinery, are some examples of the considerable negative impact from construction sites. The on-site construction site activities alone, are estimated to represent around 5-10 % of the total GHG emissions from cities (DNV.GL. 2019).

Fossil free and emission free construction activities in Norway are good examples, where the construction industry aims to reduce impact from construction site in order to contribute towards reaching emission reduction targets on the international (e.g. the Paris agreement), national (for example, 50% emission reduction by 2030 and becoming a low-emission society in 2050) and regional level (e.g. 95% direct emission reduction before 2030 in Oslo). The market has developed rapidly since public building owners started to develop requirements for emission free construction sites. In the Norwegian construction industry, the plan is to develop these sites in a stepwise approach to reach the ambition of an emission free construction site (Fufa et al., 2019b). This stepwise approach starts with requirements of a fossil free construction site. Next, ambitions can be raised to an 'on-site emission free' construction site which covers no direct GHG emissions from construction activities taking place on-site (e.g. from internal transport, operation of construction machinery and on-site energy use). The next step involves adding emission free transport to and from the construction site, whilst the final step covers all construction site activities. In addition, there is also a parallel initiative which investigates the 'waste free' construction site. To reach these ambitions, considering all construction activities, the construction logistics itself have to change to become smarter, more efficient and sustainable.

Despite the fact that construction sites have a positive economic impact in the long run, they bear a vast amount of external costs during the site duration. Improved control and coordination of logistics flows to, from and on construction sites can decrease such negative environmental and social impacts. However, The full picture of the environmental impacts from construction sites is not known, and there is an increased need for environmental (and social) evaluations of construction logistics.

For cities, there is a great potential to reduce negative impacts through stronger requirements on construction logistics. However, today there is a lack of knowledge within cities on how to set such demands and how to involve and manage stakeholders in these processes. The purpose of the MIMIC project is therefore to demonstrate how SMART Governance concepts can be used as an aid in the construction and city planning processes to facilitate and support construction logistics.

1.1 About MIMIC

"Minimizing impact of construction material flows in cities: Innovative co-creation" (MIMIC) is a JPI Urban Europe project that aims to demonstrate how SMART Governance concepts can be used as an aid in the construction and city planning processes. The SMART Governance concepts aims to facilitate and support logistics to, from and on urban construction sites to improve mobility and reduce congestion within cities and thereby reduce the negative impact of construction sites on the surrounding community. This is done by:

(1) The analysis and identification of construction logistics scenarios (both on- and off-site) highlighting the relation between projects context and logistics solutions;
(2) Stakeholder involvement and management throughout the different project phases, through identification of stakeholders and stakeholder objectives in a participatory MAMCA and gaming;
(3) The implementation of a sustainability impact assessment framework to evaluate the economic, social and environmental performance of the construction logistics scenarios (which is the main focus of this report);
(4) Enhanced data collection and optimization of construction logistics processes to evaluate and visualize the different construction logistics scenarios, using dynamic data technologies;
(5) Combining 1-4 into a SMART Governance Concept 2.0;
(6) The deployment of the SMART Governance Concept 2.0 to eliminate functional barriers for implementation and;
(7) The transferability and scalability of construction logistics scenarios and the SMART Governance concept 2.0 across European cities.

The activities within the MIMIC project are divided in six work packages (WP). The overall structure of the work packages and the connection between them is presented in Figure 1. This report mainly focusses on the impact assessment framework under WP2.

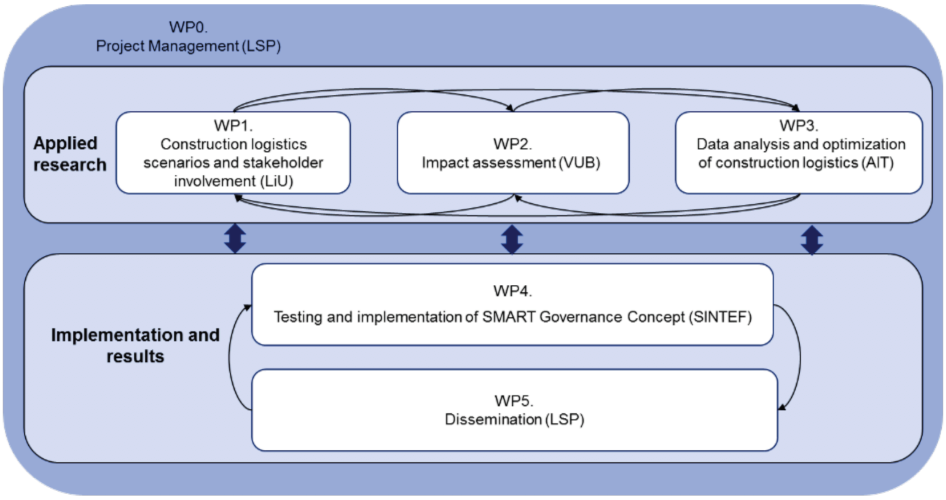


Figure 1. Structure of the different work packages within the MIMIC project

The MIMIC project integrates construction logistics, construction management, city logistics, sustainability and optimization of flows research, with the goal of developing the SMART Governance Concept 2.0. This concept provides the implementation partners (Cities and companies in the construction process and supply chain) with a structure of tools organized into a supportive platform for construction logistics issues in the urban development decision and procurement processes (D4.2 and D4.3). The tools help to increase the knowledge of construction logistics (D1.3), collecting stakeholder needs and criteria of construction logistics scenarios (D1.1, D1.2 and D1.4), and to evaluate the impact of construction logistics solutions on different stakeholders (D2.2, D2.3, D3.1, D3.2 and D3.3).

1.2 The present report

This report is a deliverable (D2.1) under work package 2 *"Impact Assessment"* and is primarily targeted towards the MIMIC consortium partners directly involved in the development of the Impact Assessment framework, and per extension the partners who will provide input data from their respective national demonstration cases in order to test and further develop the framework.

The objective of WP2 is the integration of state-of-the-art impact assessment methods in a practical and easy-to-use framework to assess the sustainability effects of construction logistics and assessment of impacts. Based on current knowledge of sustainability impacts of logistics operations, construction management and existing calculation tools, a framework will be set up to monitor and quantify both the off-site and on-site economic, social and environmental impact of construction logistics scenarios including major externalities (accidents, emissions, congestion and noise) compared to 'business-as-usual'. Although the various data sources highlight its complexity, the goal is to develop a framework flexible enough to cope with specific local constraints, whilst generic enough to allow comparability across the European cases, and ultimately across construction logistics globally.

Deliverable 4.1 specifically introduces the methodologies that will be used for impact assessment of on-site and off-site construction logistics. In order to cover the impact of both on-site and off-site construction logistics, the assessment framework will combine two distinct methodologies:

External Cost Calculations and Life Cycle Assessment. This deliverable presents both in detail, and highlights the scope, the system boundaries, the logistics activities that fall within the latter and their data collection plan for each methodology. Finally, a first building stone will be laid towards expected outcomes, the feedback loop in developing the impact assessment framework, and how both methodologies will be brought together within the framework for the final deliverable by the end of the project.

The structure of this deliverable is as follows:

Chapter 2 provides an overview of construction logistics activities, digging deeper into the External Cost Calculation (ECC) and Life Cycle Assessment (LCA) methodologies.
Chapter 3 and ***Chapter 4*** provide the relevancy of the ECC and LCA within Construction Logistics and how these methodologies can be implemented within the MIMIC project, tailored towards construction logistics.
Chapter 5 presents a first draft of the construction logistics impact assessment framework which will be work in progress until the end of the project.
Chapter 6 summarizes the key highlights of this deliverable, and addresses limitations and the scope for further work on the impact assessment framework.

2. Methodological background

The current chapter presents the background for impact assessment of construction logistics. Chapter 2.1 introduces the logistics activities related to the construction site. It explains the physical activities that is going to be considered in the impact assessment framework and construction logistics solutions. Then, Chapter 2.2 presents the two methodologies which will be used to develop the impact assessment framework for construction logistics. Chapter 2.2.1 presents the methodology used to calculate transport externalities. The External Cost Calculation (VUB-MOBI, 2020) module will be implemented for the assessment of social and environmental impacts of construction logistics flows, including climate change, air pollution, traffic safety, noise, congestion and transport infrastructure, taking into account the relevant transport and calculation variables. The economic cost calculation module takes into account all relevant total logistics costs from a multi-stakeholder perspective (solutions will only be feasible if viable for all stakeholders). Chapter 2.2.2 is devoted to the second methodology that is used to assess the impact of construction logistics – the Life Cycle Assessment (LCA) methodology. In the current framework, the LCA approach will be used to assess the environmental impact of physical logistic activities, both on the construction site and outside of the construction site fence (like transport of materials etc.). The environmental impact will be assessed in terms of climate change (GHG emissions) and energy use (in MJ). To conclude the background chapter, Chapter 2.3 presents case studies from the four participating countries (Belgium, Norway, Sweden and Austria), that will be used for developing and testing the common impact assessment framework for construction logistics.

2.1 Construction logistics activities

In this work, the construction logistics activities are divided into two main parts:

1. Transport of materials, mass, waste, machineries and workers to and from the construction site (later referred to as *"off-site construction logistic activities"*)
2. Construction site logistics activities such as operation of construction machineries, storage and installation of material, consumption of auxiliary/temporary installations and materials and waste flows (later referred to as *"on-site construction logistics activities"*).

The system boundary for construction logistics activities considered in the impact assessment framework is shown in Figure 2 and includes: transport of materials, mass, waste, machineries and workers to, on and from the construction site; use of construction machinery, temporary works, infrastructure for energy use, waste management. Any demolition work belongs to the previous life cycle of the existing construction site, and any cleaning services or water use during the construction period are not accounted for in the system boundary.

Each of these activities are either covered by the ECC, the LCA, or both. Detailed system boundaries for each methodology are presented in Chapters 3 (ECC) and Chapter 4 (LCA).

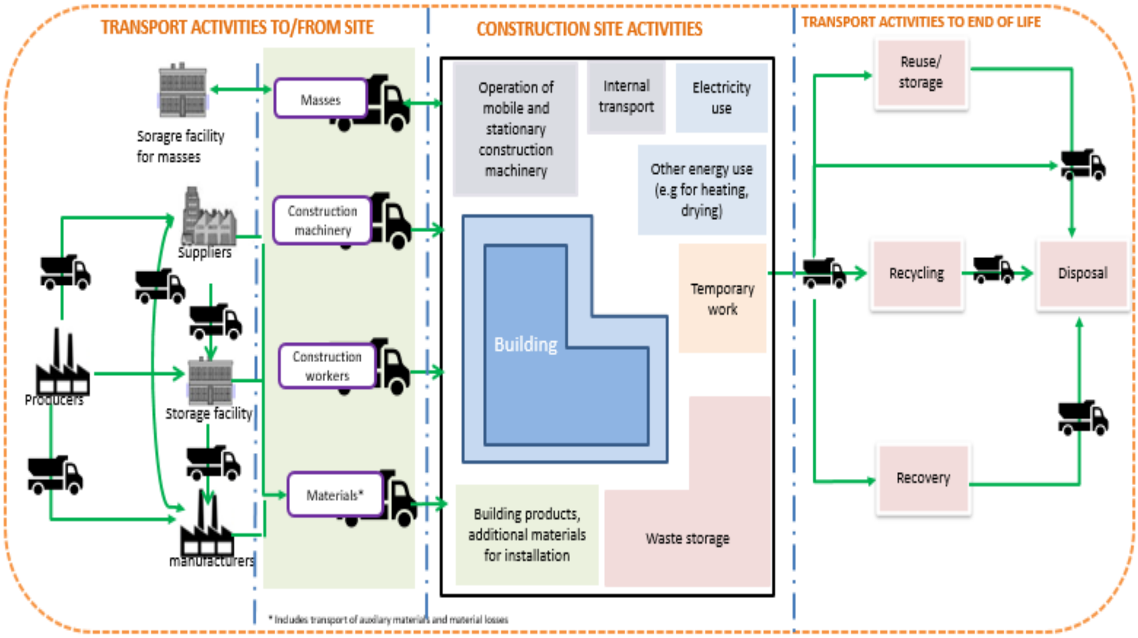


Figure 2. System boundaries for construction logistics physical activities (adopted from Wiik et al., 2018 and Fufa et al., 2019a)

Construction logistics scenarios are used to consider alternative construction logistics solutions which enable to improve the logistics performance of a project. Construction logistics scenarios provide alternative construction logistics solutions for decision making process at strategical (short term, high level planning such as goal and scope definition), tactical (planning possible logistics scenarios that enable to achieve the goals defined at a strategic level) and operative (implementation of selected setups of scenarios) construction logistics planning phases (Fredriksson et al., forthcoming). Fredriksson et al. categorize construction logistics scenarios as contextual scenarios and logistics scenarios.

The construction logistics scenarios considered in this study are developed based on the comprehensive categorization of construction logistics solutions presented by Janné et al. (2019b) (Figure 3).

Infrastructure category	Traffic management
• Checkpoint (For planning on-time or just-in-time deliveries)	• Traffic control and monitor (signs, personnel, speed limits, access restrictions, loading zones)
• Terminal (Consolidation centres, utilising nearby delivery areas, cooperative logistics)	• Traffic routing (on-site and in neighbourhood controlling of traffic flow by routing traffic)
• Vehicle waiting area (avoid queue at gate, congestion in neighbourhood/city)	• Milk-round deliveries (deliveries for several sites on one route, to increase loading rate)
• Safety and security (specific surveillance)	**Regulatory measures**
• Site establishment (On-site infrastructure, storage containers, charging stations)	• Time access restrictions (timeslots for delivery activity)
• On-site material handling (certain installation spot (kitting) managed)	• Load/size access restrictions (capacity, weight/size restrictions for vehicles)
• Machinery (Pooling of machinery between actors, machine park)	• JIT deliveries (small storage on-site)
• Waste management	• Land use restrictions (due to nature or to avoid damage, part of the site cannot be used)
Land use management	• Strict booking rules (deliveries must be booked within a certain point before arrival, JIT)
• Site- layout plans (Map of temporary facilities on-site, on-site routes)	• Follow up on adherence to rules (measures to sanction or reward adherence to rules)
• Gradual site enlargement (stepwise development, possible mass deployment, storage)	• Education of rules
• Dedicated/common unloading zone (Loading/unloading space)	• Environmental restrictions (EURO class and other emission standards, fossil free deliveries, low emission zones, noise regulations etc)
• Integrated logistics plan (avoid conflicts of deliveries between actors, time and space)	• Off-hour deliveries
Technology shift	**Eco-logistics**
• Integrated planning systems	• Modal shift (rail, waterways, airborne, pipeline; emission free vehicles)
• Standardised labelling (Digitalised recognition of deliveries where specific delivery is to be placed/used)	• Anti-idling (reduction of the pollution caused by idling engines)
• Modernising vehicle fleet (EV, hydrogen, drones)	• Eco-driving (training of drivers)
Marked based measures	• Staggered work hours (shift work hours/ night-time deliveries)
• Pricing (penalties like road pricing, congestion charging, parking charge, deposit on packaging)	• Eco-awareness (competence/knowledge development, raising awareness, to follow requirements)
• Tax allowances (tax deductions, e.g. for using electrical technology)	• Certification programs (BREEAM, introduction of new schemes)
• Tradeable permits and mobility credits (E.g. fixed number of deliveries (permits), or credits that can be bought from municipality)	• Common goals (ownership, understanding)
• Incentives and subsidies	• Coordination between project and logistics (raise awareness, follow-up of logistics improvements)

Figure 3. Construction logistics scenarios (Janné et al., 2019b)

The figure illustrates the range of available solutions for seven construction logistic elements:

1. Infrastructure
2. Land use management
3. Traffic management
4. Regulatory measures
5. Technology shift
6. Market-based measures
7. Eco-logistics

Some of the solutions directly affect the physical activities illustrated in Figure 3, and some are organizational/planning activities that indirectly affect the physical activities. According to Fredriksson et al. (forthcoming), a construction logistics setup concerns how the logistics are organized specifically for one or several construction projects, by considering the available logistics solutions together with other project-specific requirements and characteristics. Thus, the logistic setup is a mechanism enabling a flow to, from, and on the construction site. Based on how it is structured and managed, the construction logistics setup will affect the construction and the surrounding society.

Hence, there is a need for an impact framework that can quantify the significance of these different setups.

2.2 Impact assessment methodology

This part gives a general overview of the impact assessment methodology used in this study, built on two methodologies:

1. External cost calculations (ECC) used to assess monetized effects of environmental and social impacts of construction transports and;
2. Life cycle assessment (LCA) used to evaluate the environmental impact of construction logistics activities.

The two impact assessment methods follow a life cycle perspective and cover two aspects of sustainability, namely economic and environmental dimensions. External costs or externalities include the monetarized effects of environmental and social impacts not directly covered by suppliers, producers, consumers or government (SPP Regions 2018, Rebitzer & Hunkeler 2003). Life cycle costing (LCC) is an assessment of all internal costs and revenues associated with the life cycle of a product, whereby the costs of production, use and end of life expenses are covered by any one or more actors in the product life cycle (supplier, producer, consumer or/and end of life actors). The life cycle perspective includes not only the direct impact (for e.g. from the transportation itself), but also the indirect emissions (for e.g. from producing the transportation vehicle and production of the fuel consumed in the vehicle).

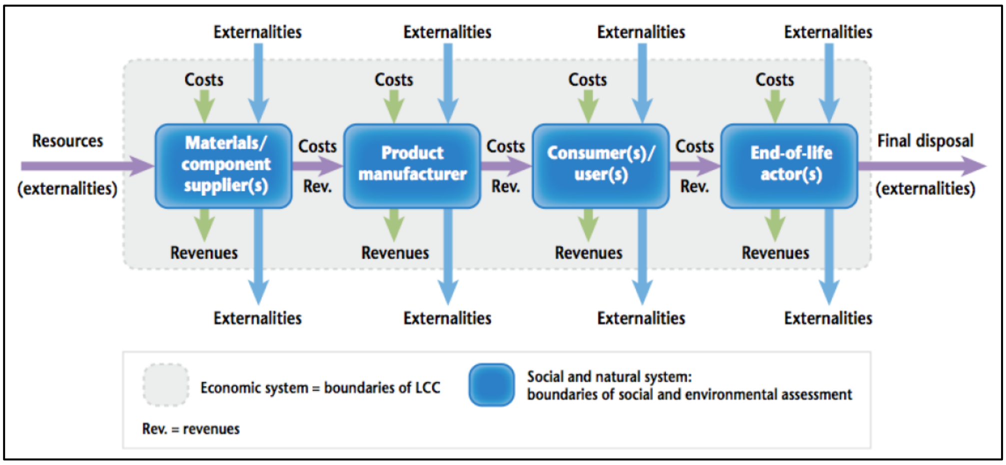


Figure 4. Externalities within life cycle costing (LCC) concept (SPP regions 2018, adapted from Rebitzer and Hunkeler, 2003).

LCC covers all internal costs and revenues within economic system whilst externalities are outside economic system though they are inside the natural and social system.

2.2.1 External Cost Calculations (ECC)

This segment gives a brief overview of transport-related external costs, building the bridge towards the calculation of external effects caused by off-site construction logistics.

Externalities arise when the associated changes in wealth are not included in the market price of activities. In the case of transport, for example the impact air pollution has on human health, is not included in the cost of the vehicle use (Weinreich et al., 2000; Bickel & Friedrich, 2005), although the impact of freight transport-related air pollution on human health has been proven to incur significant negative external effects (Mommens et al., 2019). These externalities, or transaction spillovers, can be either positive (the ability to provide emergency services, an increase in land value, agglomeration benefits etc.) or negative (noise nuisances caused by delivery of construction materials), and can be defined as either a benefit or a cost incurred by a party who did not agree to the action causing the cost or benefit, while at the same time the cost or benefit is not reflected in the market price of the respective product or service (Laffont, 2008, Macharis and van Lier, 2017).

Classic economics goes out of the assumption that, under theoretical conditions, the competitive price mechanism inevitably leads to a Pareto optimal allocation of resources. However, welfare economics has shown the externalities lead to a non- or suboptimal situation, causing an imbalance between the market price and the societal price, hence leading to a market failure (Schmidtchen et al., 2009). These welfare changes can be monetized by means of non-market valuation techniques (van Lier, 2014; Macharis, Brusselaers & Mommens, 2019).

Transport activities lead to a large number of negative externalities. The main ones are climate change and air pollution (consequences of emissions), accidents, noise, soil contamination, interference in the ecological system, damage to infrastructure, visual nuisance, and congestion (van Lier and Macharis, 2017). The European Commission (2018) estimates the total size of external costs for transport in the EU at around 1,000 billion euro annually, or, as a size estimation, approximately 7% of the EU28 GDP (EC, 2018). The European Commission uses the polluter-pays principle (Pigou, 1920), which accounts for the external costs generated by the causer, as he/she is responsible for it and should pay for it. The impact assessment framework will be in line with this principle. For completeness, it should be mentioned that there is an alternative principle, the cheapest cost avoider principle (Coase, 1960; 1988). This principle accounts for external costs as the minimal cost necessary to ‘undo’ or compensate for the externality. Consequently, it should thus equal the polluter-pays principle; however, in some cases it might be cheaper to undo or compensate for the externality by means of an adequate policy or by addressing the victims of the externality. The latter could by done by e.g. moving all citizens away from polluting industry plants instead of imposing the industry plants to pay for their pollution. The cheapest cost avoider principle is economically superior to the polluter-pays principle; however, it is less intuitive and creates a sense of unfairness.

External costs of transport can be addressed in two ways; looking at either (1) average external costs or (2) marginal external costs. Average external costs refer to the total amount of transport-related external costs divided by the number of units (volume/vehicles/etc.). It is used for evaluations of external effects of a wider system, for example on a country or a sector level. Average external costs should thus be used when addressing the entire construction logistics sector. Marginal external costs refer to the additional cost provoked by the transport of one additional unit. It is based on the external effects of a particular element and how it affects its environment. Marginal external costs are used for scenario analysis.

Transport-related externalities are caused by a moving vehicle. The amount of generated external costs is dependent of a significant list of variables. Obviously, the vehicle used – age, size, emission-norm, etc. – is an important variable. Besides the vehicle itself, also its use influences the amount of external costs. One should then also consider loading rate and driving behavior. Next, the surroundings play a crucial role, such as the type of road and its affected speed, vehicle interactions, etc. and consequently congestion, fuel consumption and the associated emissions. The amount of people in proximity of the vehicle, so-called receptors, significantly define the magnitude the impact for air pollution and noise. While the externalities thus depend on a moving vehicle and who, how and where it moves, many traffic data are on point level (traffic counts, surveys and checkpoints (Brusselaers et al., 2020). For correct impact assessments, one ideally needs data on the movements itself – vehicle-kilometres and tonne-kilometres. Those can be for example be gathered via GPS data, simulations and company data (Brusselaers et al., 2020).

Although there is a large lack of accurate data on urban construction logistics flows (Brusselaers et al., 2020), current estimates from European countries assume about 20-35% of all urban freight traffic would be linked to the sector (Brussels Mobility, 2008 & 2016; Dablanc, 2009; TfL & OPDC, 2018). Besides its share in total traffic, the sector would also be responsible for a significant share in terms of external costs, but as indicated by Brusselaers et al. (2020), current studies so far often do not consider vehicle-kilometres or tonne-kilometres that are linked to the significant number of vehicles in the sector, and the available reports seem to be consolidated using educated guesses. As current calculations are thus most often based on the number of vehicles used and on transported volume, these are not adequate to conduct external cost calculations (Brusselaers et al., 2020).

As leader of Work Package 2, VUB-MOBI will investigate the following 2 main Research Gaps as part of the development of the Impact Assessment Framework for Off-Site Construction Logistics:

RG 1 *Providing insight in the share of construction logistics related transport in the total transport flows.*

RG 2 *Calculating the environmental impact of sector in terms of externalities using robust methodologies and state-of-the-art metrics.*

The External Cost Calculation methodology within the MIMIC project and its demonstration cases will be further presented in Chapter 3.

2.3.2 Life cycle assessment (LCA)

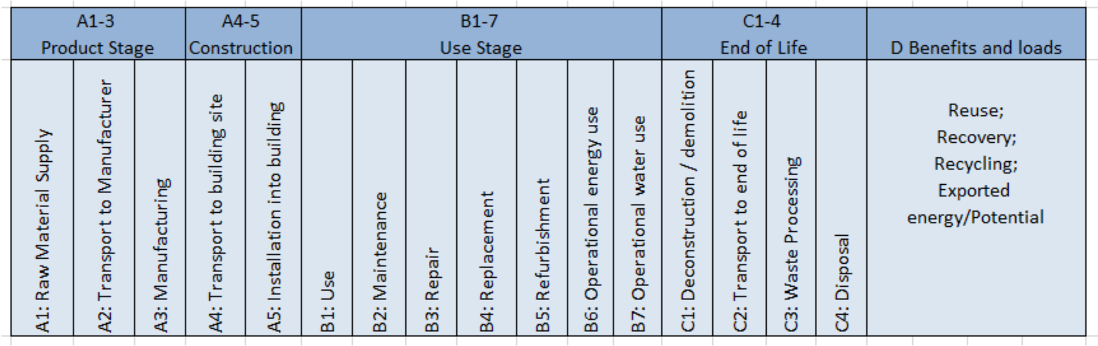
Life cycle assessment (LCA) is a well-used method to evaluate the environmental impact from products, services, systems and entire urban areas. The LCA methodology follows the principles and framework for LCA as defined by ISO 14040/44 (ISO 14040 2006, ISO 14044 2006) and consists of four steps:

1. *Definition of goal and scope* - definition of the functional unit, system boundaries, assumptions and limitation of the study, impact categories and methods used;
2. *Life cycle inventory (LCI)* - identify and quantify inputs and outputs in each stage of the life cycle;
3. *Life cycle impact assessment (LCIA)* - links each LCI result to the corresponding environmental impact categories, each with a category indicator. Impacts may be assessed at the midpoint and endpoint (which links emissions and resource demands with damages to human health, resource depletion and ecosystem quality);
4. *Interpretation of the results* - identification, quantification, evaluation (including sensitivity analysis) of the results from LCI and LCIA and generate conclusions and recommendations. Findings from LCA results are communicated to different end users

through tools such as eco-labels (such as EPDs) and certification schemes (such as BREEAM) as a guide to make informed decisions.

Established international, European and national standards are used to harmonize LCA methodologies in order to conduct transparent assessments and communicating its results. In the building and construction industry, the European standard on assessment of environmental performance of buildings, EN 15978 (EN 15978 2011), and the national Norwegian standard NS3720 (NS 3720 2018) on methods for GHG emission calculation for buildings, have been used to evaluate the environmental impact of the building and construction industry.

EN 15978 presents a modular structure for defining the system boundary to evaluate the cradle-to-grave impacts from four main life cycle stages: product stage (modules A1-A3), construction stage (modules A4-A5), use stage (modules B1-B7) and end-of-life (modules C1-C4). In addition, the optional stage (module D) is defined to account for the potential positive impacts of processing or reuse of materials after end-of-life (Figure 5).



A1-3 Product Stage			A4-5 Construction		B1-7 Use Stage							C1-4 End of Life				D Benefits and loads
A1: Raw Material Supply	A2: Transport to Manufacturer	A3: Manufacturing	A4: Transport to building site	A5: Installation into building	B1: Use	B2: Maintenance	B3: Repair	B4: Replacement	B5: Refurbishment	B6: Operational energy use	B7: Operational water use	C1: Deconstruction / demolition	C2: Transport to end of life	C3: Waste Processing	C4: Disposal	Reuse; Recovery; Recycling; Exported energy/Potential

Figure 5. The life cycle modules of the building according to EN 15978.

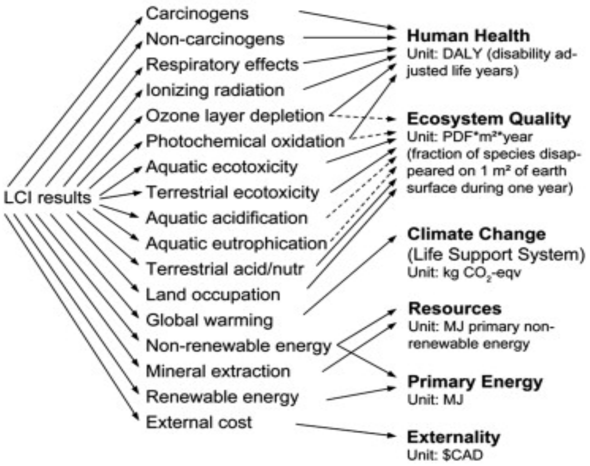


Figure 6. Illustration of the concept of characterization of LCI results into impact categories (from Pa et al., 2013).

Figure 6 shows how the characterization of LCI results first can be assessed in several midpoint impact categories, then further into five suggested endpoint categories. Characterization factors are used to convert an LCI result to the common unit of category indicator, like kg CO2-eq in the global warming category. In the current study the indicators climate change and resource use will be analyzed by the following impact categories: global warming (GHG emissions in kg CO2-equivalent) and primary energy (MJ), non-renewable energy (MJ) and renewable energy (MJ).

The evaluation is based on both specific or general data, and practitioners often use LCA databases (like Ecoinvent (Ecoinvent 2016) or Gabi) to build comprehensive LCA inventories. Within the databases, unit processes or system processes (i.e. life cycle inventories, collection of unit processes) are available for a large range of categories, like energy, transport, metals, industrial processes etc., and includes the impact assessment of these processes. For example, for the transportation of goods, the LCI and LCIA results for the system process of transportation of one ton of goods over one kilometer for a specific vehicle can be provided by the database. Such relevant characterization factor would be given as the amount of the unit of the impact category (e.g. kg CO2-eq. for GHG emissions) per tonne-kilometer. The current study will gather specific data from activities related to construction sites, and background data (inventory) will be from the Ecoinvent database.

The scope of the LCA method applied in the current study is further explained in Chapter 4.

2.3 Description of demonstration pilot

Norway: Omsorgsbygg Oslo KF in collaboration with Arkitema Architects will build the world's first energy-positive nursing home for elderly (Tåsenhjemmet) with low greenhouse gas emissions. The pilot building in massive wood will enable the best indoor environment for the residents and be the new meeting venue in the neighbourhood of Tåsen. A main goal is to use the most simple and passive measures that enables to meet the requirements for low emission energy-plus houses. Another high ambition for the project is to be certified as BREEAM-NOR Outstanding.

Tåsen nursing home project, Oslo (Norway)

Sweden: Two of the large development projects in Sweden are the Stockholm Royal Seaport and Väsjön projects. Together, these projects will amount to approximately 18 500 new residences and some 770 000 m2 of commercial areas.

Stockholm Royal Seaport and Väsjön project (Sweden)

Belgium: A first goal in Brussels is to gain better insight in the share of construction logistics related transport in the total transport flows per type of project, as there is currently a large gap in accurate data on these flows. The data collection on construction logistics related transport movements will be attempted by using i.e. OBU (on-board unit) data of +3,5 T trucks as well as traffic counts for a selection of (larger) construction sites, providing a better understanding on the amount and type of flows generated in practice by construction works. A second goal is to better understand the impact of these flows on urban sustainability. Therefore, VUB-MOBI will contribute to the development of tools to assess and evaluate the sustainability impact of construction logistics solutions on different stakeholders. In association with owner and city development agency CityDev and main building contractor Van Roey Vastgoed, the application of the

City Campus project, Brussels (Belgium) sustainability impact assessment framework will be tested on the City Campus project, a 17.600 m² site bringing together light industrial activities and housing facilities. This will allow to assess the impact on economic, social and environmental sustainability (with specific focus on congestion, emissions and safety) of construction freight flows from origin to destination.

Austria: To enable efficient logistics for urban construction processes, we combine optimization, traffic simulation, and novel data science approaches. Our construction logistics optimization deals with coordinating workers, material delivery, and storage to optimize resource efficiency and reduce road traffic. We develop heuristic solution methods to approach real-world uncertainties and dynamic changes in construction processes. To evaluate the optimized solutions with respect to real-world conditions, we perform a traffic simulation. The simulation assesses the impact of construction traffic in terms of congestion, travel times, etc. based on realistic traffic volumes over times of the day.

Vienna project, Austria

3. External cost calculation (ECC)

3.1 Calculation variables and methods

Extensive literature can be retrieved on valuation techniques, especially in the last decade. Two major concepts are highlighted (Figure 7, Pearce and Howarth, 2000): revealed preference techniques (preferences based on actual, observed, market-based information) and stated preference techniques (a more generic term to include contingent valuation and choice experiments).

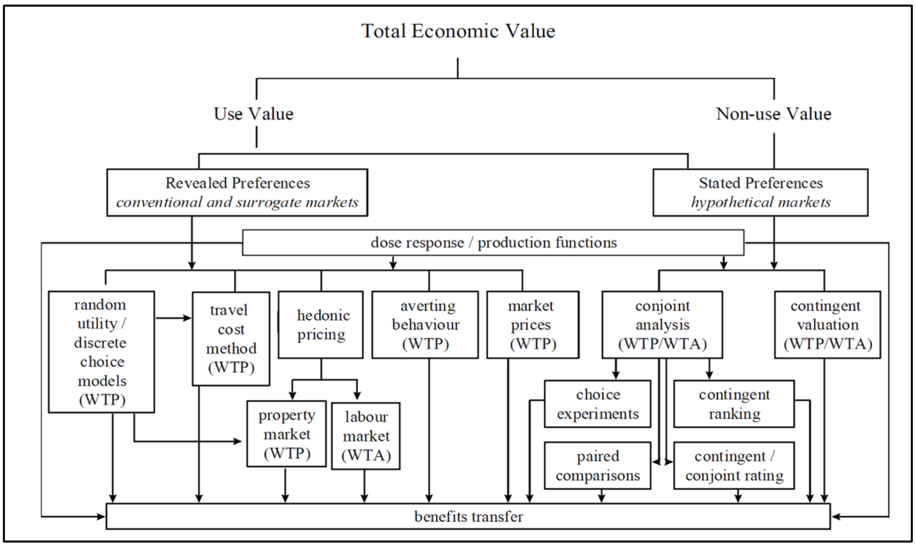


Figure 7. Total Economic Value methods (Pearce and Howarth, 2000).

However, we continuously thrive to improve economic impact assessment models. In the case of climate change, a major aspect is the realistic evaluation of the carbon price (Ricardo-AEA, 2014; van Essen et al., 2019), the social costs of climate change often associated to impacts on health, ecosystems and biodiversity, rising sea levels, energy use and demand, etc. While these are complex to estimate due to numerous factors such as their unpredictable risk patterns, long-term effects and geographical spread (Maibach et al., 2008), both a damage cost approach and a mitigation cost approach are needed (Delhaye et al., 2010; van Lier and Macharis, 2009). Each external cost category is thus dependent on different calculation-variables (such as transport mode and fuel type) in the calculation of the impact of generated emissions.

As presented in Brusselaers et al. (2020), the main methodologies used so far to assess the external costs of construction logistics are traffic counts (Brussels Mobility, 2008 & 2016; TfL, 2018), surveys (TfL, 2017 & 2018; Mommens & Macharis, 2014) and/or data from Construction Logistics Setups (CLS) such as checkpoints (Ekeskär & Rudberg, 2016; Sundquist et al., 2018) or construction consolidation centres (CCCs) (Lundesjö, 2015; Janné, 2019a; TfL, 2013). Further data sources can also serve as validation for traffic flows and freight transport data, such as the Construction Scope Statement and the Bill of Quantities (Brusselaers et al., 2020). Information could also be derived from invoices and consignment notes facilitating data gathering and analyses in the future, especially when stimulating the use of digital waybills (e-CMR) (Brusselaers et al., 2020).

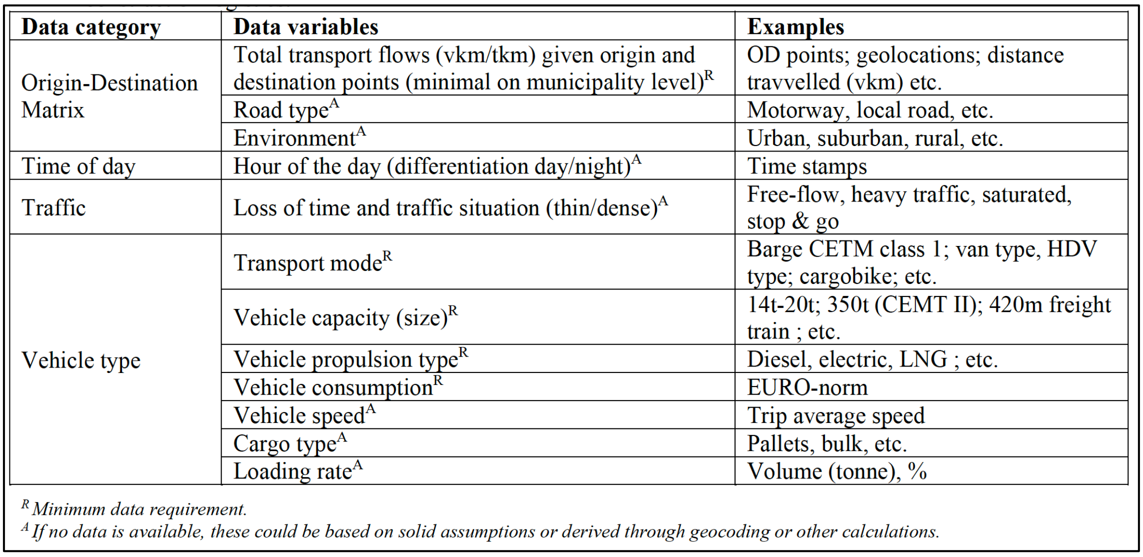
While these methods and their data collection each have advantages and disadvantages, the main concern is the robustness of current construction logistics data and its impact assessments. Four transport performance indicators can be distinguished: (1) number of vehicles used, (2) transported volume, (3) vehicle-kilometres and (4) tonne-kilometres, for which the two last ones (vkm and tkm) are the most relevant in the calculation of external costs of transport (Brusselaers et al., 2020). However, current impact assessments often rely on the number of vehicles used and/or on transported volume, which are not adequate in external cost calculations (ECC).

Within MIMIC, the overall goal is to reduce the negative impact of construction sites by improving the governance of construction logistics. Based on current knowledge of sustainability impacts of logistics operations, construction management and existing calculation tools, a framework will be set up to monitor and quantify the off-site economic, social and environmental impact of construction logistics scenarios including major externalities compared to 'business-as-usual'. The External Cost Calculation (VUB-MOBI, 2020) module, based on the most up-to-date methods and metrics, will be used for the assessment of impacts of construction logistics flows, including climate change, air pollution, congestion, accident costs and traffic safety, noise pollution and transport infrastructure damage, thereby taking into account the relevant variables as mentioned above, such as receptor density, time of day, traffic flow, network type and vehicles used in off-site construction logistics.

Several factors make the feeding of this framework with relevant data complex: *“(1) the large gap in accurate and available data on urban construction logistics flows; (2) the source of the available logistics data that is typically scattered amongst different actors within the construction chain and (3) The nature of the (unstandardized) data formats, typically distilled from various sources within the sector*” (Brusselaers et al., 2020). Although the various data sources highlight its complexity, the goal is to develop a framework flexible enough to cope with specific local constraints, whilst generic enough to allow comparability across the European cases, and ultimately across construction logistics globally. More information on the data availability issue in the development of this framework can be retrieved in Brusselaers et al., 2020.

3.1.1 Calculation-variables and transport indicators

The figure below was taken from Brusselaers et al. (2020) and highlights the different calculation-variables needed in the assessment of the main transport-related externalities.



Data category	Data variables	Examples
Origin-Destination Matrix	Total transport flows (vkm/tkm) given origin and destination points (minimal on municipality level)^{R}	OD points; geolocations; distance travvelled (vkm) etc.
	Road type^{A}	Motorway, local road, etc.
	Environment^{A}	Urban, suburban, rural, etc.
Time of day	Hour of the day (differentiation day/night)^{A}	Time stamps
Traffic	Loss of time and traffic situation (thin/dense)^{A}	Free-flow, heavy traffic, saturated, stop & go
Vehicle type	Transport mode^{R}	Barge CETM class 1; van type, HDV type; cargobike; etc.
	Vehicle capacity (size)^{R}	14t-20t; 350t (CEMT II); 420m freight train ; etc.
	Vehicle propulsion type^{R}	Diesel, electric, LNG ; etc.
	Vehicle consumption^{R}	EURO-norm
	Vehicle speed^{A}	Trip average speed
	Cargo type^{A}	Pallets, bulk, etc.
	Loading rate^{A}	Volume (tonne), %

^{R} *Minimum data requirement.*

^{A} *If no data is available, these could be based on solid assumptions or derived through geocoding or other calculations.*

Table 1. Data requirements to conduct an economic and environmental impact assessment for off-site construction logistics (Brusselaers et al., 2020).

As presented in Table 1 some data are minimally required in order to calculate the external costs from the transport flows, such as origin-destinations encompassing vehicle-kilometres or tonne-kilometres, vehicle type and propulsion type (marked with ^{R}). Other data types can further enrich the analyses, such as road type, loading rate etc. (marked with ^{A}).

The considered transport indicators that are calculated using the above-mentioned variables are:

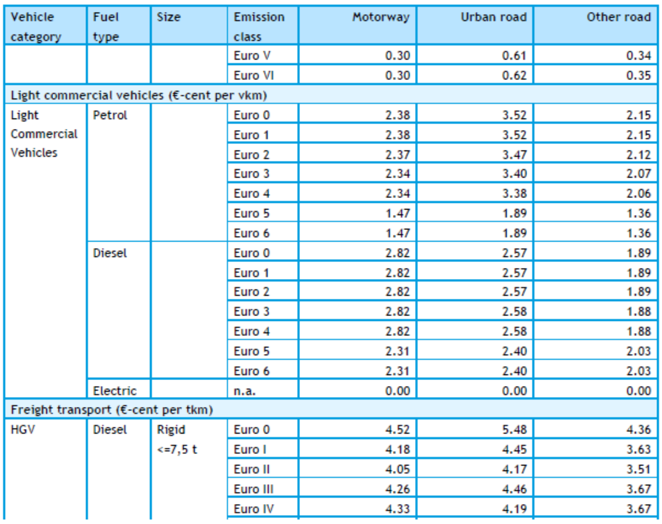
- Air pollution costs;
- Climate change costs;
- Congestion costs;
- Accident costs;
- Infrastructure costs and;
- Noise.

Derived from these, we can also calculate the ratio of overall travelled vs. avoided transport-kilometres.

3.1.2 Calculation methods

We can distinguish three methods for the calculation of external costs of transport: (1) using output values, (2) using input values and, (3) calculating case-specific input values.

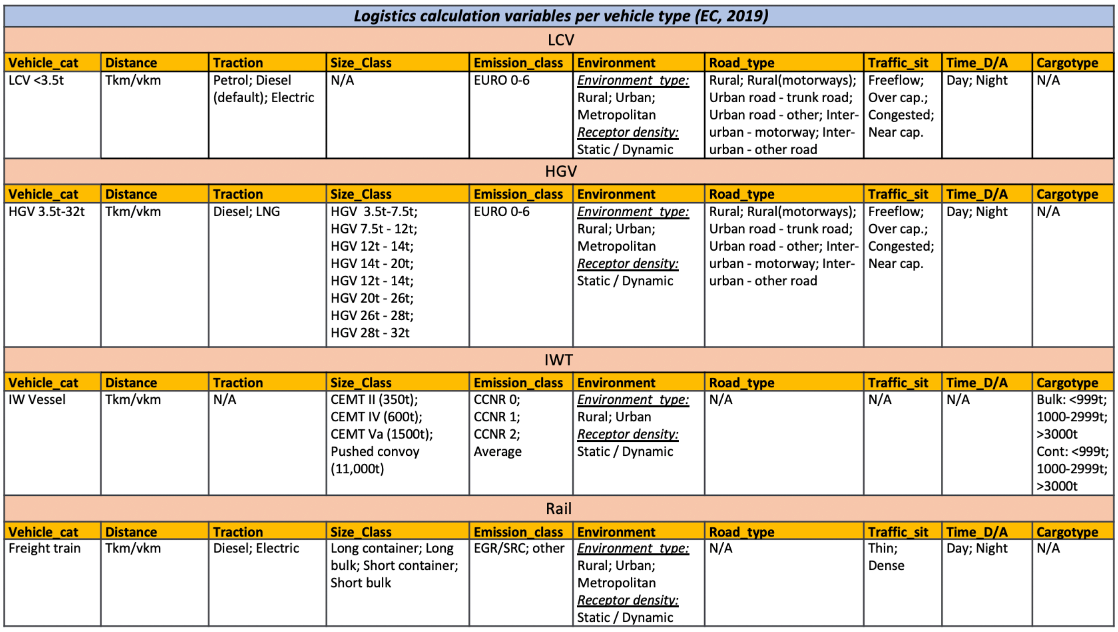
The first and most straightforward calculation is done by using external cost output values. These are monetary values per vehicle- or tonne-kilometre. These can, for example, be retrieved in the Handbook on the External Costs of Transport: Version 2019 (van Essen et al., 2019), part of the STICITE study. These studies consider at best – like the mentioned study – a large variety of influencing parameters (see Table 2). Yet, at the same time they use average values for those variables, generally at a high level of aggregation. Table 2 illustrates the marginal external costs for climate change for different freight vehicles. The study considers vehicle-type (propulsion, size, emission norm) and type of road (motorway, urban road, other). To this end, it assumes one single traffic situation (congestion, free flow), one loading rate, etc. Climate change is caused by greenhouse gas (GHG) emissions, of which CO_2 is the most important one. CO_2 emissions are linearly related to diesel consumption, and therefore to loading rate and traffic conditions. This accentuates the weakness of the output value method. Nevertheless, this method is heavily used and appropriate when data access is limited.



Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
			Euro V	0.30	0.61	0.34
			Euro VI	0.30	0.62	0.35
Light commercial vehicles (€-cent per vkm)						
Light Commercial Vehicles	Petrol		Euro 0	2.38	3.52	2.15
			Euro 1	2.38	3.52	2.15
			Euro 2	2.37	3.47	2.12
			Euro 3	2.34	3.40	2.07
			Euro 4	2.34	3.38	2.06
			Euro 5	1.47	1.89	1.36
			Euro 6	1.47	1.89	1.36
	Diesel		Euro 0	2.82	2.57	1.89
			Euro 1	2.82	2.57	1.89
			Euro 2	2.82	2.57	1.89
			Euro 3	2.82	2.58	1.88
			Euro 4	2.82	2.58	1.88
			Euro 5	2.31	2.40	2.03
			Euro 6	2.31	2.40	2.03
	Electric		n.a.	0.00	0.00	0.00
Freight transport (€-cent per tkm)						
HGV	Diesel	Rigid <=7,5 t	Euro 0	4.52	5.48	4.36
			Euro I	4.18	4.45	3.63
			Euro II	4.05	4.17	3.51
			Euro III	4.26	4.46	3.67
			Euro IV	4.33	4.19	3.67

Table 2. Marginal Climate change costs for freight transport vehicles (sample of Table 28, van Essen et al., 2019).

Table 3 presents the calculation-variables per vehicle type needed to take into consideration the external cost factors. It also highlights the data categories that are differentiated throughout the van Essen et al. (2019) study.



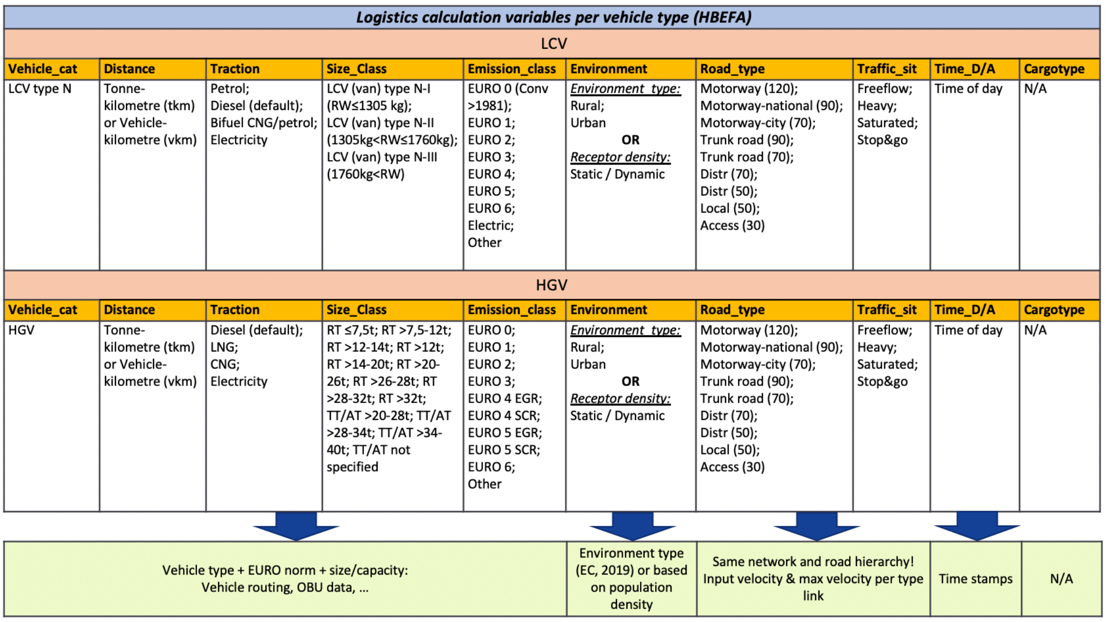
Logistics calculation variables per vehicle type (EC, 2019)

Vehicle_cat	Distance	Traction	Size_Class	Emission_class	Environment	Road_type	Traffic_sit	Time_D/A	Cargotype
LCV									
LCV <3.5t	Tkm/vkm	Petrol; Diesel (default); Electric	N/A	EURO 0-6	*Environment_type:* Rural; Urban; Metropolitan *Receptor density:* Static / Dynamic	Rural; Rural(motorways); Urban road - trunk road; Urban road - other; Inter-urban - motorway; Inter-urban - other road	Freeflow; Over cap.; Congested; Near cap.	Day; Night	N/A
HGV									
Vehicle_cat	**Distance**	**Traction**	**Size_Class**	**Emission_class**	**Environment**	**Road_type**	**Traffic_sit**	**Time_D/A**	**Cargotype**
HGV 3.5t-32t	Tkm/vkm	Diesel; LNG	HGV 3.5t-7.5t; HGV 7.5t - 12t; HGV 12t - 14t; HGV 14t - 20t; HGV 12t - 14t; HGV 20t - 26t; HGV 26t - 28t; HGV 28t - 32t	EURO 0-6	*Environment_type:* Rural; Urban; Metropolitan *Receptor density:* Static / Dynamic	Rural; Rural(motorways); Urban road - trunk road; Urban road - other; Inter-urban - motorway; Inter-urban - other road	Freeflow; Over cap.; Congested; Near cap.	Day; Night	N/A
IWT									
Vehicle_cat	**Distance**	**Traction**	**Size_Class**	**Emission_class**	**Environment**	**Road_type**	**Traffic_sit**	**Time_D/A**	**Cargotype**
IW Vessel	Tkm/vkm	N/A	CEMT II (350t); CEMT IV (600t); CEMT Va (1500t); Pushed convoy (11,000t)	CCNR 0; CCNR 1; CCNR 2; Average	*Environment_type:* Rural; Urban *Receptor density:* Static / Dynamic	N/A	N/A	N/A	Bulk: <999t; 1000-2999t; >3000t Cont: <999t; 1000-2999t; >3000t
Rail									
Vehicle_cat	**Distance**	**Traction**	**Size_Class**	**Emission_class**	**Environment**	**Road_type**	**Traffic_sit**	**Time_D/A**	**Cargotype**
Freight train	Tkm/vkm	Diesel; Electric	Long container; Long bulk; Short container; Short bulk	EGR/SRC; other	*Environment_type:* Rural; Urban; Metropolitan *Receptor density:* Static / Dynamic	N/A	Thin; Dense	Day; Night	N/A

Table 3. Logistics calculation-variables per vehicle type used in the Handbook on the External Costs of Transport. Developed by VUB-MOBI (2020) based on main output data categories from STICITE (van Essen et al., 2019).

As elaborated, in the case of climate change costs, the estimation of the unit cost for different transport modes envelops different steps, combining (1) the quantification of GHG emission factors for a range of vehicle types (in tonnes CO2-equivalent per vkm) and (2) the valuation of climate change (per ton of CO2-equivalent) to finally calculate (3) the marginal climate change costs for a range of different types of vehicles and fuels. In this process, the cost valuation of e.g. climate change is thus important. The valuation of external costs also varies from study to study and evolves over time (Maibach et al., 2008; Macharis, Brusselaers & Mommens, 2019).

The second method focuses on the above-mentioned step 1 – quantification of nuisance level. For emissions, this method calculates the emitted pollutants in grams per vehicle- or tonne-kilometre given a series of calculation-variables. For noise, it is measuring noise levels, etc. This makes it for example possible to calculate nuisance along the pathway of the vehicle (known as the Impact-Pathway Approach), hence enabling the external cost calculation which overcomes the (over)use of averages. The next step is then to link the nuisance level (grams of pollutant / GHG), noise level, number of accidents, etc. to the monetary value they represent. Input values for emitted pollutants can i.a. be retrieved in the Handbook of Emission Factors for Road Transport (HBEFA, 2019), which gives emission levels per road type, gradient, vehicle type, heat of the engine, propulsion type, weather, loading rate and traffic situation. Table 4 presents the main logistics calculation-variables and data categories per vehicle type needed to compute emitted pollutants from transport using input values from HBEFA (2019).



Logistics calculation variables per vehicle type (HBEFA)									
LCV									
Vehicle_cat	**Distance**	**Traction**	**Size_Class**	**Emission_class**	**Environment**	**Road_type**	**Traffic_sit**	**Time_D/A**	**Cargotype**
LCV type N	Tonne-kilometre (tkm) or Vehicle-kilometre (vkm)	Petrol; Diesel (default); Bifuel CNG/petrol; Electricity	LCV (van) type N-I (RW≤1305 kg); LCV (van) type N-II (1305kg<RW≤1760kg); LCV (van) type N-III (1760kg<RW)	EURO 0 (Conv >1981); EURO 1; EURO 2; EURO 3; EURO 4; EURO 5; EURO 6; Electric; Other	*Environment type:* Rural; Urban **OR** *Receptor density:* Static / Dynamic	Motorway (120); Motorway-national (90); Motorway-city (70); Trunk road (90); Trunk road (70); Distr (70); Distr (50); Local (50); Access (30)	Freeflow; Heavy; Saturated; Stop&go	Time of day	N/A
HGV									
Vehicle_cat	**Distance**	**Traction**	**Size_Class**	**Emission_class**	**Environment**	**Road_type**	**Traffic_sit**	**Time_D/A**	**Cargotype**
HGV	Tonne-kilometre (tkm) or Vehicle-kilometre (vkm)	Diesel (default); LNG; CNG; Electricity	RT ≤7,5t; RT >7,5-12t; RT >12-14t; RT >12t; RT >14-20t; RT >20-26t; RT >26-28t; RT >28-32t; RT >32t; TT/AT >20-28t; TT/AT >28-34t; TT/AT >34-40t; TT/AT not specified	EURO 0; EURO 1; EURO 2; EURO 3; EURO 4 EGR; EURO 4 SCR; EURO 5 EGR; EURO 5 SCR; EURO 6; Other	*Environment type:* Rural; Urban **OR** *Receptor density:* Static / Dynamic	Motorway (120); Motorway-national (90); Motorway-city (70); Trunk road (90); Trunk road (70); Distr (70); Distr (50); Local (50); Access (30)	Freeflow; Heavy; Saturated; Stop&go	Time of day	N/A
Vehicle type + EURO norm + size/capacity: Vehicle routing, OBU data, …					Environment type (EC, 2019) or based on population density	Same network and road hierarchy! Input velocity & max velocity per type link		Time stamps	N/A

Table 4. Logistics calculation-variables per vehicle type retrieved in the Handbook of Emission Factors for Road Transport (HBEFA). Developed by VUB-MOBI (2020) based on main data categories from HBEFA (2019).

In order to develop the framework within MIMIC, mainly input values will be used and where needed complemented with output values.

The third and most precise method to assess the external costs is to both calculate the nuisance level and to calculate the case-specific monetary value through its entire impact pathway (IPA), as is presented in Mommens et al. (2019). Modelling dynamic emission sources (moving freight vehicles), dynamic receptor densities (exposed people) and pollutant dispersions, the impact on human health can be calculated using dose-response functions and then translated to monetary values. Although this last method renders the most accurate results, this would go beyond the scope of building a framework flexible enough to cope with specific local constraints, whilst generic enough to allow comparability across the European cases, and ultimately across construction logistics globally.

3.2 System boundaries and logistics activities

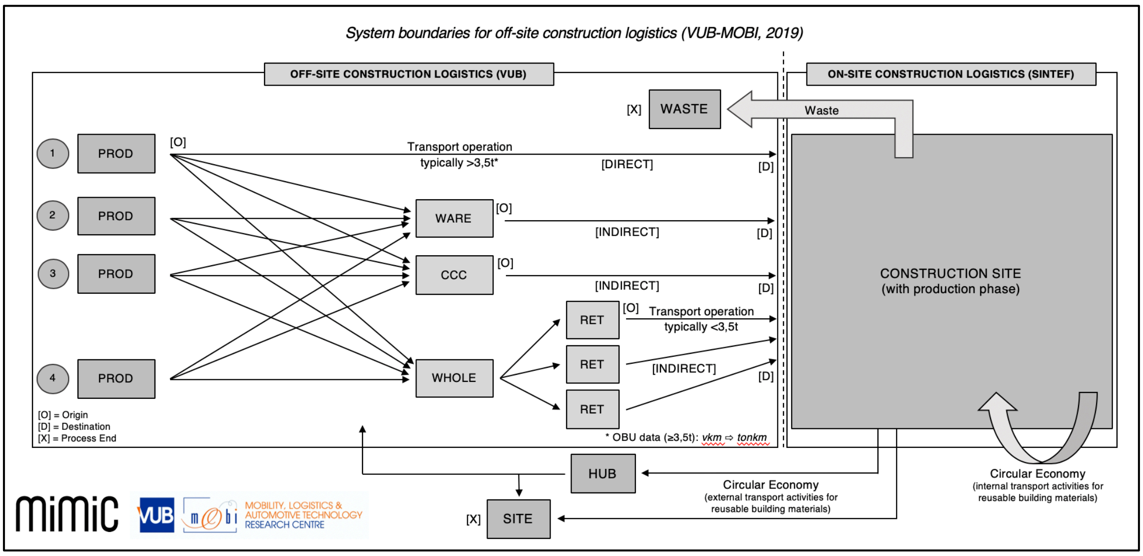


Figure 8. System boundaries for off-site construction logistics (VUB-MOBI, 2019).

Figure 8 presents the system boundaries for the calculation of transport externalities. These are defined by the off-site transport flows, from the origin ('O') to the destination point ('D') of the freight transport trip.

In case of a direct incoming transport operation, the origin of the transport flow is the address of the manufacturer or producer of the construction materials (indicated as 'PROD'). However, most materials are transported indirectly to the construction site through intermediary parties, such as a warehouse ('WARE'), Construction Consolidation Centre ('CCC'), a wholesaler ('WHOLE'), and/or a retailer ('RET'). In case of lack of logistics data, one should consider the origin to be the furthest available data point, hence taking into account as many (multimodal) transport-kilometres leading back to the original manufacturer. For the above-mentioned material flows, the destination point is the entrance of the construction site.

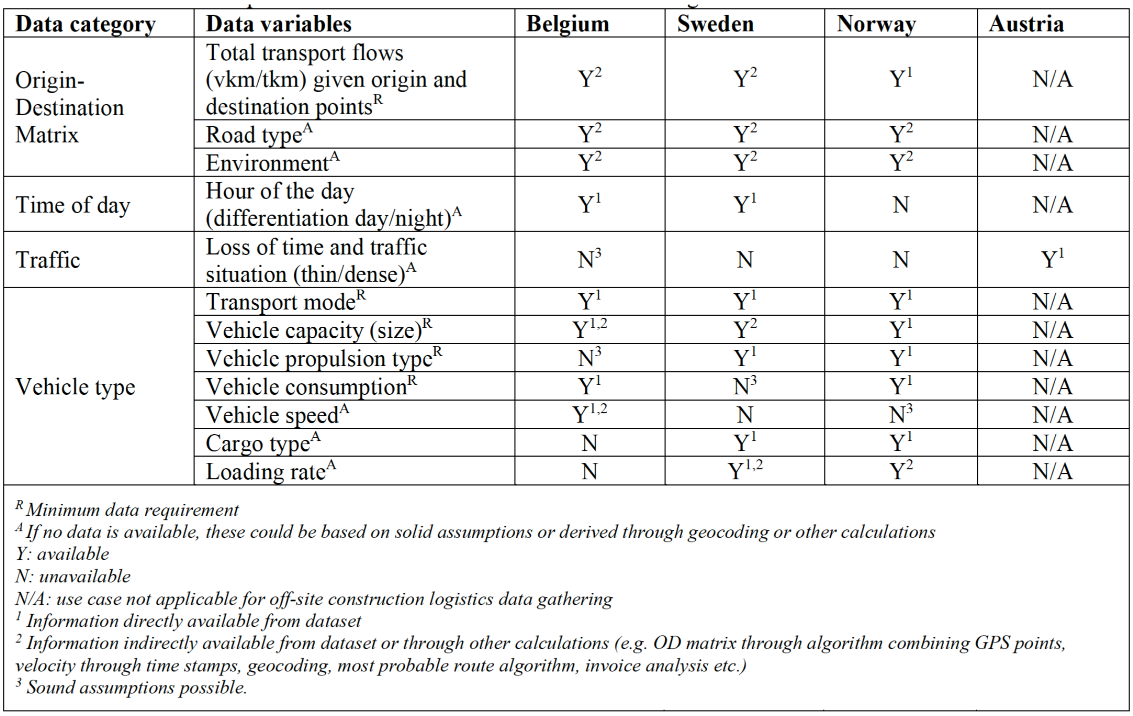
In case of reverse logistics, the origin is the construction site, and the destination the address of delivery, such as a waste collection or incineration point, recycling firm or transshipment zone, where the logistics process ends. Indirect reverse transport flows, such as trips through a hub back into the system, or via a material audit firm to another construction site for reutilization, will be considered if the necessary data is available.

The presented methodology thus includes both hinterland and urban (or last mile) freight transport flows. Results can thus be obtained on both an (inter)national and regional/local geographical level. The scope is clearly defined on the transport operation or vehicle usage part. Manufacturing and end-of-life – which are addressed in a Life-Cycle Analysis (LCA) – are not considered.

The considered logistics activities include the transport of materials to and from the construction site, the transport of machinery to and from the site and the transport of waste.

3.3 Data collection

Taken from Brusselaers et al. (2020), Table 4 harmonizes the available off-site logistics data categories in the four demonstration countries within MIMIC (Belgium, Sweden, Norway and Austria), with the data needs in order to develop the economic, social and environmental impact assessment framework for construction logistics. The detailed explanation of data collection points per demonstration country is explained hereafter.



Data category	Data variables	Belgium	Sweden	Norway	Austria
Origin-Destination Matrix	Total transport flows (vkm/tkm) given origin and destination points[R]	Y[2]	Y[2]	Y[1]	N/A
	Road type[A]	Y[2]	Y[2]	Y[2]	N/A
	Environment[A]	Y[2]	Y[2]	Y[2]	N/A
Time of day	Hour of the day (differentiation day/night)[A]	Y[1]	Y[1]	N	N/A
Traffic	Loss of time and traffic situation (thin/dense)[A]	N[3]	N	N	Y[1]
Vehicle type	Transport mode[R]	Y[1]	Y[1]	Y[1]	N/A
	Vehicle capacity (size)[R]	Y[1,2]	Y[2]	Y[1]	N/A
	Vehicle propulsion type[R]	N[3]	Y[1]	Y[1]	N/A
	Vehicle consumption[R]	Y[1]	N[3]	Y[1]	N/A
	Vehicle speed[A]	Y[1,2]	N	N[3]	N/A
	Cargo type[A]	N	Y[1]	Y[1]	N/A
	Loading rate[A]	N	Y[1,2]	Y[2]	N/A

[R] Minimum data requirement
[A] If no data is available, these could be based on solid assumptions or derived through geocoding or other calculations
Y: available
N: unavailable
N/A: use case not applicable for off-site construction logistics data gathering
[1] Information directly available from dataset
[2] Information indirectly available from dataset or through other calculations (e.g. OD matrix through algorithm combining GPS points, velocity through time stamps, geocoding, most probable route algorithm, invoice analysis etc.)
[3] Sound assumptions possible.

Table 5. Available data in the respective demonstration countries, in relation to the data needs in order to develop the economic, social and environmental impact assessment framework for construction logistics (Brusselaers et al., 2020).

3.3.1 Belgium

The first project demonstration case will be held in Brussels, on which the application of the impact assessment framework will first be tested. In close collaboration with Brussels Mobility, the Brussels Regional Development Agency (CityDev) and building contractor Van Roey Vastgoed, the framework will be tested on the City Campus project, a 17.600m² construction site in the municipality of Anderlecht. The construction-related transport data will be retrieved from On-Board Units ('OBU'). These GPS-based devices were introduced in 2016 in the implementation of the kilometer charge mandatory for i.a. trucks above 3,5t on motorways and certain regional axes in Belgium. This kilometre charge scheme covers all roads in the Brussels Metropolitan Region. The associated data collection includes specific vehicle characteristics, as the kilometre tax is differentiated based on, amongst others, the distance travelled and how environmentally friendly the vehicle is. This OBU dataset is thus a strong dataset in order to collect the vehicle's geometry by means of a unique identifier, the vehicle mode and capacity, the EURO norm, the time of day accurate on a 30 seconds interval basis, and the velocity of the vehicle. Given these data points, further information can be derived: to this end, VUB-MOBI developed an algorithm to map the vehicle's trajectory (Origin-Destination-matrix), which allows for very precise derivation of travelled vehicle-kilometres (vkm) as well as the duration and speed of the trip. Furthermore, these can be overlaid to match the network, environment and road types, hence further enriching the analyses by means of geocoding, linking its response to the hierarchical classification of roads on the network by means of geographical information systems (GIS). Furthermore, additional data will be collected to cover transport means not equipped with an OBU, such as road vehicles below 3,5t (vans), inland waterway transport and rail, as well as their vehicle type and class. The loading rate, volumes and receptor densities are data points that are currently not included but could be added if access to those sources is gained. Otherwise, assumptions will be used. More information can be retrieved in Brusselaers et al. (2020).

3.3.2 Norway

The demonstration in Oslo will enable the collection of direct off-site transport data based on the number of trips. The latter are defined as transport flow to or from a construction site or reverse flows (cf. Figure 8). The datasets will also encompass the origin and destination of each trip, its date, the number of traveled kilometres, the vehicle type and its capacity, its propulsion type and consumption (EURO), the type of goods transported with information on the manufacturer and the transported item), and the item's weight expressed in gross kg. The aforementioned datapoints enables the derivation of additional variables such as environment and road types by means of geocoding and Geographical Information Systems (GIS). Bar milk-runs, the source data could also provide the theoretical loading rate. Based on the available data, it will not be possible to derive the average velocity of the vehicle, nor time lost in traffic, as the logistics data only has a temporal resolution of one day. However, these two variables could be based on sound assumptions, simulating the preferential transport trajectory using geocoding and GIS.

3.3.3 Sweden

The available datasets in the use cases in Sweden will include relevant transport data on (1) project data (BTA, project size (SEK), time plans, type of project and location); (2) the number of transports arriving at and leaving from the construction site (with time stamps) including the type of vehicle and its propulsion type, the transported product type and potential damages, fill rates ((un)loadings per truck in kg, ton, pallets, containers etc.), turn-around time, the vehicle's routing, deliveries in accordance to the planning etc.; (3) distribution between vehicles in relation to the total number of transports; (4) potential incidents with third parties; and others. The vehicle type, its propulsion type, its loading rate, the transported product type and time of day could thus be collected upon arrival at the construction site. Certain hauliers could also provide information on the origin and destination points, as well as information on transported volume and the value and number of packages, which can then consequently be linked to the construction planning. The preferential route, along with environment and road type can be assumed using geocoding. The available variables as fill rates and loadings per truck could be used to approximate the vehicle's capacity and size. While the vehicle's consumption is not directly available, it could be based on sound assumptions given the vehicle's propulsion type, for example using national, regional or local statistics or averages. No data is available on the traffic situation, the vehicle's speed, and receptor densities.

3.3.4 Austria

In Vienna, the focus will be on the impact of construction logistics on the city's mobility. To this end, mobile phone-based movement data will be investigated to monitor the impact of urban construction works on city traffic. Direct results from simulations using Mobile Service Provider (MSP) data will render the density of the traffic, while the most probable mobility mode (walking, public transport, car, etc.) and most probable trajectory can be derived through the development of algorithms. Direct data will thus render information on the traffic situation, which can then be overlaid on off-site logistics data. These MSP data thus form an indirect link with the framework and not a direct data source for construction logistics specifically.

3.4 Scenario evaluation

The collected data will be used to conduct a scenario-based evaluation of the environmental logistics impact.

First, a business-as-usual (BAU) scenario is defined, which will be used as a baseline for the evaluation. This baseline scenario assumes all logistics activities under current working methods. Within the construction sector, this baseline scenario thus often assumes none or fragmented coordination amongst actors, the main contractors being responsible for the logistics activities and induced costs, diesel trucks as the main mode of transport, and for example a high reliance on last minute deliveries using vans.

This BAU baseline scenario can then be compared to different logistics setups and solutions, given a different fleet composition, alternative modes of transport, improved planning schemes, etc. as to assess the performance difference between different logistics implementations. An example could be the introduction of Construction Consolidation Centre as the main bundling hub, while incentivizing the modal shift from road to inland waterways. An illustrative list of possible alternatives is presented in Table 6. It is important to define each logistics setup and solution as clear as possible to allow clear scenario boundaries.

List and description of illustrative alternatives		
BAU	Business As Usual	Baseline scenario. • None or fragmented coordination • Main contractors manage logistics and induced costs • Diesel trucks as main mode of transport
Solution A	Controlling city	Construction consolidation centre as main bundling hub and incentives to stimulate the modal shift from road to inland waterways. • Construction Consolidation Center (CCC) in collaboration with port • Imposed delivery address: consolidation of goods and delivered by waterway transport near the construction site • Bundling of construction material on common delivery tours • Costs divided between city and contractors • Expected impact: higher load factor, improved air quality, potential benefits for contractors and transport operators

Solution B	Planning city	Construction consolidation centre and strong incentives for electric vehicles. • Toll scheme at construction area entrance for non-EV • Maximum number of transports & designated time slots (bundling) • Supporting services are available • Costs carried by contractors
Solution C	Night-time deliveries	Night-time delivery of materials on-site. • BAU scenario with higher temporal dispersion of material deliveries • Goods are delivered with trucks at night (before morning peak hours) • Expected impact: less congestion, higher average speed, lower emission levels but significantly higher noise levels during night time
…	…	…

Table 6. Illustrative list of alternatives to evaluate.

Ultimately, the different external cost performance indicators, i.e. Air pollution, Climate change, Congestion, Accidents, Infrastructure and Noise costs, will be evaluated and compared for each defined scenario.

3.4.1 Link with the Multi-Actor Multi-Criteria Analysis

Figure 9 presents the link between the developed external cost calculation framework for off-site construction logistics (WP2) and the Multi-Actor-Multi Criteria Analysis (MAMCA) (WP1), connected by its logistics scenarios. More information can be retrieved in Deliverable 1.4 of the MIMIC project.

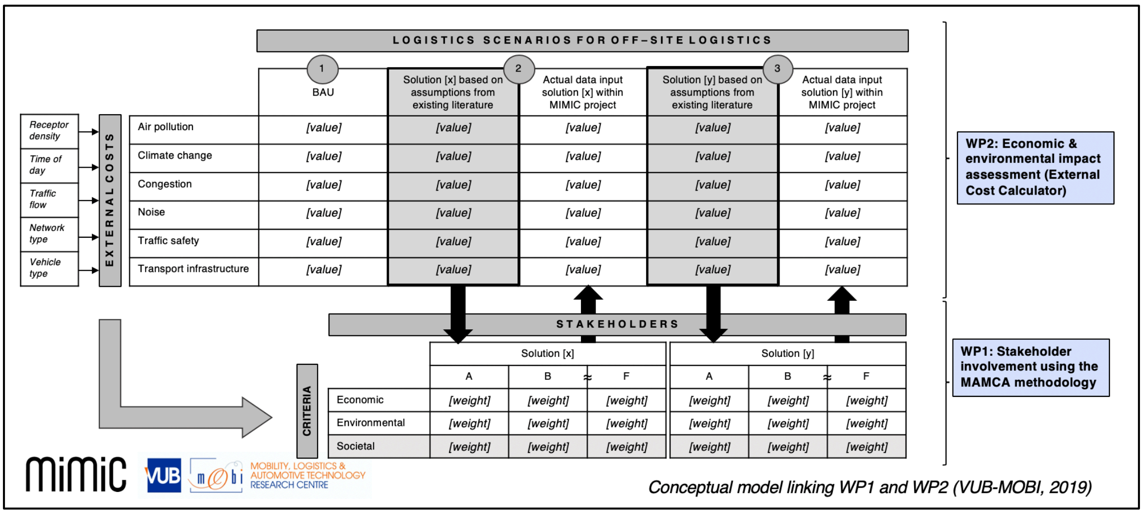


Figure 9. Conceptual model linking WP1 'Stakeholder involvement' and WP2 'Impact Assessment' (VUB-MOBI, 2019)

4. Life Cycle Assessment (LCA)

This part gives an overview of LCA calculation methodologies following the guideline provided in well-known LCA standards.

4.1 Goal and scope

The goal of the LCA study is to evaluate the environmental impact of construction logistic activities shown in Figure 5. Physical activities considered in the LCA calculation include transport of materials, mass, waste, machineries and workers to, on and from the construction site; use of construction machinery, temporary works, infrastructure for energy use, waste management. Any demolition works belong to the previous life cycle of the existing building, and any cleaning services or water use during the construction period are not accounted for in both phases.

The LCA system boundary is defined according to the modular life cycle system as defined in EN 15978 (Figure 5). In this study, the LCA system boundary focus on the construction phase, modules A4-A5. Lifecycle module A4 covers transport from the manufacturing site to the construction site, whilst lifecycle module A5 covers installation into the building.

The environmental impact indicators which are considered in the LCA study are: Climate change (in greenhouse gas emissions in kg CO2-eq.) and resource use (in renewable and non-renewable energy use and primary energy use in MJ).

4.2 Inventory and data sources

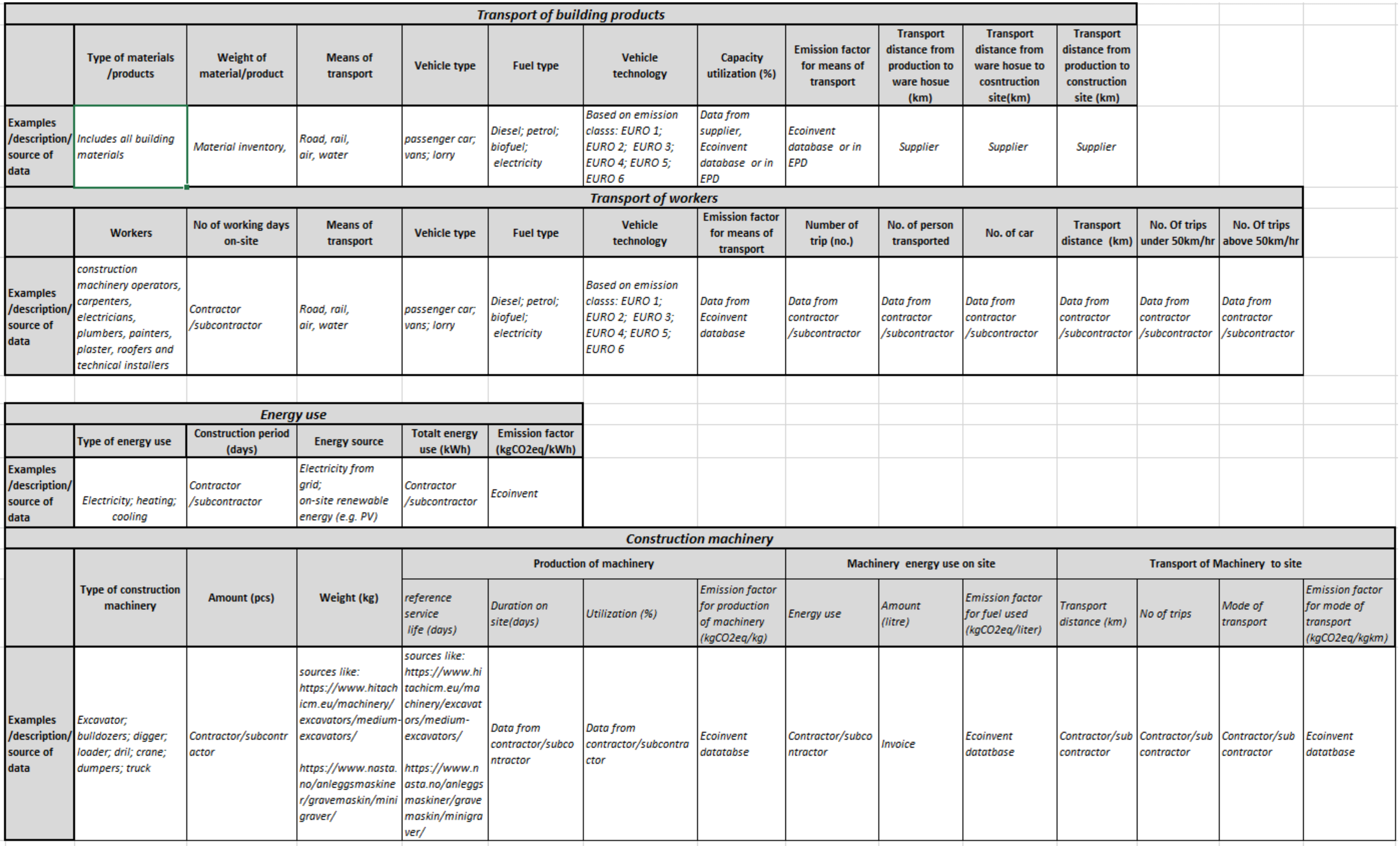
The inventory can be based on estimated data, in the early project phase where there is lack of actual data. Throughout the construction process more actual data will be collected (from construction sites) through for e.g. building information modelling (BIM), the bill of quantities, invoices, building site reports, construction drawings, product data sheets and through transport logs and a waste reports.

The environmental impact from the construction logistics activities described in Figure 2 are calculated for the following 7 activities, which belongs to Module A4 and A5 building life cycle stages:

- *Transport of building products;*
- *Transport of masses;*
- *Transport of workers;*
- *Construction machinery;*
- *Energy use;*
- *Temporary work;*
- *Transport of waste.*

Table 7 shows an example of type of data and some default values (that can be used in lack of data) for the environmental impact assessment of the main construction site activities (Fufa et al 2019a, Wiik et al 2017).

Table 7. Examples of type and source of data needed for LCA.



Transport of building products

	Type of materials /products	Weight of material/product	Means of transport	Vehicle type	Fuel type	Vehicle technology	Capacity utilization (%)	Emission factor for means of transport	Transport distance from production to ware hosue (km)	Transport distance from ware hosue to cosntruction site(km)	Transport distance from production to construction site (km)
Examples /description/ source of data	Includes all building materials	Material inventory,	Road, rail, air, water	passenger car; vans; lorry	Diesel; petrol; biofuel; electricity	Based on emission classs: EURO 1; EURO 2; EURO 3; EURO 4; EURO 5; EURO 6	Data from supplier, Ecoinvent database or in EPD	Ecoinvent database or in EPD	Supplier	Supplier	Supplier

Transport of workers

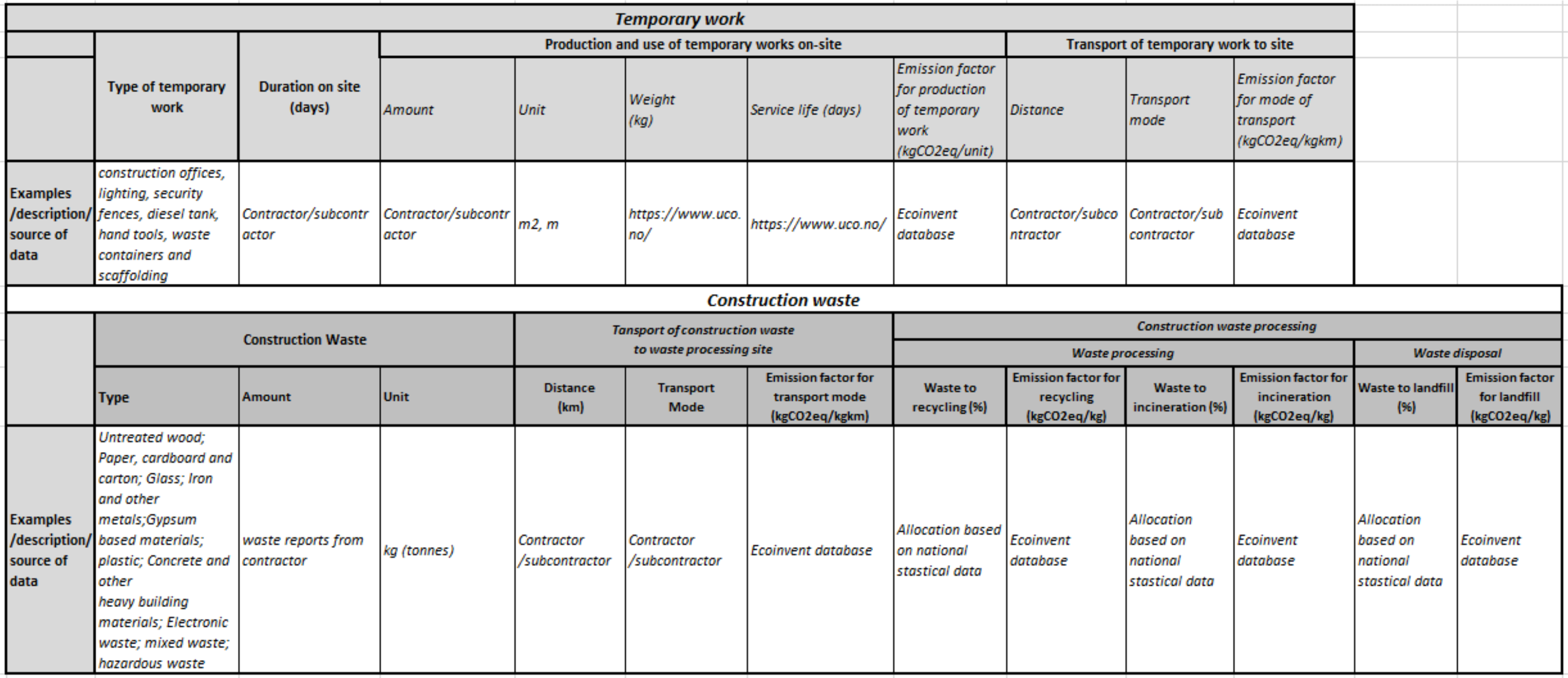
	Workers	No of working days on-site	Means of transport	Vehicle type	Fuel type	Vehicle technology	Emission factor for means of transport	Number of trip (no.)	No. of person transported	No. of car	Transport distance (km)	No. Of trips under 50km/hr	No. Of trips above 50km/hr
Examples /description/ source of data	construction machinery operators, carpenters, electricians, plumbers, painters, plaster, roofers and technical installers	Contractor /subcontractor	Road, rail, air, water	passenger car; vans; lorry	Diesel; petrol; biofuel; electricity	Based on emission classs: EURO 1; EURO 2; EURO 3; EURO 4; EURO 5; EURO 6	Data from Ecoinvent database	Data from contractor /subcontractor	Data from contractor /subcontractor	Data from contractor /subcontractor	Data from contractor /subcontractor	Data from contractor /subcontractor	Data from contractor /subcontractor

Energy use

	Type of energy use	Construction period (days)	Energy source	Totalt energy use (kWh)	Emission factor (kgCO2eq/kWh)
Examples /description/ source of data	Electricity; heating; cooling	Contractor /subcontractor	Electricity from grid; on-site renewable energy (e.g. PV)	Contractor /subcontractor	Ecoinvent

Construction machinery

	Type of construction machinery	Amount (pcs)	Weight (kg)	Production of machinery				Machinery energy use on site			Transport of Machinery to site			
				reference service life (days)	Duration on site(days)	Utilization (%)	Emission factor for production of machinery (kgCO2eq/kg)	Energy use	Amount (litre)	Emission factor for fuel used (kgCO2eq/liter)	Transport distance (km)	No of trips	Mode of transport	Emission factor for mode of transport (kgCO2eq/kgkm)
Examples /description/ source of data	Excavator; bulldozers; digger; loader; dril; crane; dumpers; truck	Contractor/subcontractor	sources like: https://www.hitachicm.eu/machinery/excavators/medium-excavators/ https://www.nasta.no/anleggsmaskiner/gravemaskin/minigraver/	sources like: https://www.hitachicm.eu/machinery/excavators/medium-excavators/ https://www.nasta.no/anleggsmaskiner/gravemaskin/minigraver/	Data from contractor/subcontractor	Data from contractor/subcontractor	Ecoinvent datatabse	Contractor/subcontractor	Invoice	Ecoinvent datatbase	Contractor/subcontractor	Contractor/subcontractor	Contractor/subcontractor	Ecoinvent datatbase



	Temporary work									
			Production and use of temporary works on-site					**Transport of temporary work to site**		
	Type of temporary work	**Duration on site (days)**	*Amount*	*Unit*	*Weight (kg)*	*Service life (days)*	*Emission factor for production of temporary work (kgCO2eq/unit)*	*Distance*	*Transport mode*	*Emission factor for mode of transport (kgCO2eq/kgkm)*
Examples /description/ source of data	*construction offices, lighting, security fences, diesel tank, hand tools, waste containers and scaffolding*	*Contractor/subcontractor*	*Contractor/subcontractor*	*m2, m*	*https://www.uco.no/*	*https://www.uco.no/*	*Ecoinvent database*	*Contractor/subcontractor*	*Contractor/subcontractor*	*Ecoinvent database*

	Construction waste											
	Construction Waste			***Tansport of construction waste to waste processing site***			***Construction waste processing***					
							Waste processing				***Waste disposal***	
	Type	**Amount**	**Unit**	**Distance (km)**	**Transport Mode**	**Emission factor for transport mode (kgCO2eq/kgkm)**	**Waste to recycling (%)**	**Emission factor for recycling (kgCO2eq/kg)**	**Waste to incineration (%)**	**Emission factor for incineration (kgCO2eq/kg)**	**Waste to landfill (%)**	**Emission factor for landfill (kgCO2eq/kg)**
Examples /description/ source of data	*Untreated wood; Paper, cardboard and carton; Glass; Iron and other metals;Gypsum based materials; plastic; Concrete and other heavy building materials; Electronic waste; mixed waste; hazardous waste*	*waste reports from contractor*	*kg (tonnes)*	*Contractor /subcontractor*	*Contractor /subcontractor*	*Ecoinvent database*	*Allocation based on national stastical data*	*Ecoinvent database*	*Allocation based on national stastical data*	*Ecoinvent database*	*Allocation based on national stastical data*	*Ecoinvent database*

A more detailed description of the type of data and calculation methods for these activities are given below. The descriptions use the type and source of data used to evaluate the GWP (measured in GHG emissions, CO2-eq.) impact indicator for measuring the environmental impact. The information can be adapted to other indicators in order to fit the data type available, in line with the practice of LCA.

Transport of building products (module A4)

Includes the amount of each building products transport to the construction site. The GHG emissions associated with the transportation of building materials from the factory to the construction site are calculated as follows:

> *Emissions from transport of building materials (kgCO2eq) = weight of the material being transported (kg) x transport distance (km) x emission factor for the transportation mode (kgCO2eq/kgkm)*

The transport distance travelled by the construction product considers the location of the manufacturing site, intermediate storage facilities (if any) and the location of the construction site. The emission factor for the transportation mode can be obtained from generic databases, such as Ecoinvent. In lack of data, the following assumptions can be used: (1) >32t EURO 5 if mode of transport is not available; (2) An assumption of the transport of auxiliary materials together with building products.

Transport of masses

Includes the amount of masses transport to/from construction site. The transport distance travelled by the masses considers the location of the storage site and construction site. Operation of machineries such as excavators in the groundwork belongs to the category *"construction machinery"* (see below).

Transport of workers

Includes one-way transport of construction workers, such as construction machinery operators, carpenters, electricians, plumbers, painters, plaster, roofers and technical installers. GHG emissions associated with workers transport can be calculated as follows:

> *GHG emissions from person transport (kgCO2eq) = number of trips (no) x number of people per trip (no) x transport distance (km) x percentage of driving speed under and/or over 50km/h (%) x GHG emission factor for the transportation mode under and/or over 50km/h (kgCO2eq/kgkm).*

Data on the number of trips, number of people per trip, and distance travelled can be obtained from contractors and subcontractors. In lack of data, the following assumptions can be used: (1) Workers transport based on diesel fuel; (2) Two people per trip; (3) An emission factor of 0.24 kgCO2eq/person.km for the percentage of journey that takes place under 50km/hour; (4) An emission factor of 0.16 kgCO2eq/person.km is used for the percentage of journey that takes place over 50km/hour (Selvig et al., 2017).

Note that EN 15978 and NS 3720 excludes the transport of workers from the life cycle stage A4. It will however be included in the possible scope of the LCA studies in the MIMIC project.

Construction machinery

Includes both mobile and stationary machinery used on-site (from excavators, diggers and cranes to bores and drill). The LCA calculation includes the *production of machinery, transport of machinery to the construction* site, and *fuel use during operation*.

Production of machinery: GHG emissions from the production of construction machinery can be calculated as follows:

> *GHG emissions from production of machinery (kgCO2eq) = amount of machinery (pc) x weight of machinery (kg/pc) x (duration onsite (days)/ service life (days)) x GHG emission factors (kgCO2eq/kg)*

The weight of the construction machinery can be obtained from technical specifications. The onsite duration, service hours and fuel consumption of construction machinery can be obtained from contactor and sub-contractors. In lack of data, the following assumptions can be considered: (1) An estimated service life of 5 years; (2) An emission factor of 2.26 kgCO2eq/kg, from generic database, Ecoinvent, for the process "Industrial machinery, heavy, unspecified, at plant RER /kg".

Transport of machinery to the construction site: GHG emissions from the transportation of construction machinery to site can be calculated as follows:

> *GHG emissions from transport of construction machinery (kgCO2eq) = weight of the construction machinery (kg) x transport distance (km) x GHG emission factor for the transportation mode (kgCO2eq/kgkm)*

The weight of construction machinery can be obtained from technical data sheets, whilst the average round transport distance can be considered. In lack of data, an assumed transportation mode of >32t EURO 5 class truck can be used.

Fuel use during operation: GHG emissions from the fuel use during operation of construction machinery can be calculated as follows:

> *GHG emissions from operation of construction machinery (kgCO2eq) = amount of fuel consumed by the construction machinery (l) x GHG emission factor for fuel consumed by the construction machinery (kgCO2eq/l)*

The amount of fuel consumption can be obtained from contractor and sub-contractor. The well-to-wheel emission factors for diesel (3.24 kgCO2eq/litre), and petrol (2.88 kgCO2eq/litre) can be used (NS 3720 2018). For operation of electrical machinery, the data is often only available on an aggregated level together with all electrical equipment/devices, please see next paragraph.

Energy use

Includes on-site energy use for lightning, heating, drying, cooling and ventilation during the construction period. GHG emissions from electricity consumption can be calculated as:

> *GHG emissions from energy use (kgCO2eq) = amount of onsite energy used (kWh) x GHG emission factor for source of energy used (kgCO2eq/kWh)*

Normally, the responsible contractor or building owner can provide the data on electricity consumption (based on the electricity bill). Data in energy consumption from heating by district heating can be obtained similarly. Further, for obtaining data for energy consumption by heating by (temporary) fossil heating units is similar as given for *"GHG emissions from operation of construction machinery"* above. The energy source varies between countries, where both the availability of energy and regional construction practice is important. The energy consumption is dependent on climate (as well as seasonal variations).

Temporary works

Provide support, protection and services to construction workers. Temporary works includes construction offices, lighting, security fences, diesel tank, hand tools, waste containers and scaffolding. It Is difficult to cover all temporary works (at least at the current state), and the calculation approach must be adapted to data available.

GHG emission calculations associated with the temporary works include the *production* and *transportation of temporary works* to the construction site.

Production of temporary work: GHG emissions from the production of temporary works can be calculated as:

> *GHG emissions from production of temporary work (kgCO2eq) = amount of temporary work (pc) x weight of temporary work (kg/pc) x (duration onsite (days)/ service life (days)) x GHG emission factor (kgCO2eq/kg).*

The amount of the temporary work can be obtained from construction site activities. The weight and service life data of temporary can be obtained from technical specifications.

Transportation of temporary works: GHG emissions from the transportation of temporary works can be calculated as:

> *GHG emissions from transport of temporary work (kgCO2eq) = weight of the temporary work (kg) x transport distance (km) x GHG emission factor for the transportation mode (kgCO2eq/kgkm*)

Construction waste

Includes material losses during the construction processes, packaging waste, transport of waste to waste treatment facilities, waste processing (recycling or incineration) and waste disposal. The impact from the production and transportation of installed building products to the site is accounted to the modules A1-A3 and A4 respectively. However, these emissions for building products that become a production loss (waste products/material) during installation on-site (from cutting/fitting etc.) need to be accounted for in the module A5. Losses during transportation (due to damages) should be allocated to the module A4 (transport of materials). It is important to exclude emissions from production losses during installation from the production phase (A1-A3) and the transport of materials (A4), in order to avoid double counting of the impact.

GHG emissions from the transport of construction waste from the construction site to the waste treatment facilities can be calculated as:

> *GHG emissions from transport of construction waste (kgCO2eq) = amount of waste (kg) x percentage of waste to recycling and/or incineration and/or landfill (%) x transport distance to waste processing and/or disposal (km) x GHG emission factor for the transportation mode (kgCO2eq/kgkm)*

The amount of waste generated on the construction site can be obtained from waste reports. The percentage of waste to the various treatment processes (recycling or incineration) and final disposal can be obtained from national statistics on waste treatment. If there is a lack of data, the following assumptions can be used: (1) 100 km from the building site to the nearest recycling and incineration facility; (2) 50 km to the nearest landfill; (3) 16-32 metric ton, EURO5 means of transport and emission factor from generic database, Ecoinvent, for the mode of transport. All construction waste is sorted onsite.

4.3 Scenario evaluation

Scenario evaluations are regularly used in LCA to allow for comparison of environmental impact results. Pesonen et al (2000) concludes that: *"Scenarios are in one way or another an integral part of any LCA."* In their work, they further define an LCA scenario as *"a description of a possible future situation relevant for specific LCA applications, based on specific assumptions about the future"*. Scenarios in LCA can investigate the environmental impact of two possible alternatives on a shorter or longer term, with the short-term "what if"-scenarios as the most relevant for application in evaluating construction logistics scenarios. In line with section 3.4, scenario evaluation can be important for comparing a Business-as-Usual (baseline) scenario with scenarios involving new and/or innovative logistic solutions. Table 8 shows some example of possible alternatives to include in the scenarios.

List and description of illustrative alternatives	
Fuel use in machineries	Diesel construction machinery vs. electric machinery
Construction methods	Prefabricated vs on-site construction (e.g. for bathroom or inner walls)
Material selection	Local sourcing of materials vs international orders
Material storage	Storage by consolidation center (controlling city) vs storage on-site

Table 8. List and description of illustrative alternatives.

As defined in section 2.1, the decision on the specific construction logistic setup for a construction project involves choosing between many possible solutions, and decision-support should be provided through a scenario evaluation of determined alternative setups by using LCA and ECC. Table 9 exemplifies interesting LCA scenarios possibilities for construction logistics.

Construction logistics scenario	Business as usual	- Diesel vehicles as main mode of transport - Use materials obtained from abroad (with longer transport distances) - Use of diesel machineries on-site - Use on-site construction method - Storage on site
Contextual logistic scenarios	Solution A – Use of vehicles driven with fossil free or emission freee fuels and modal shift	- Biodiesel and/or electricity vehicles as main mode of transport - Use of biodiesel and/or electricity machineries on-site
	Solution B – Use construction consolidation centre	- Storage by consolidation centre - Bundling of construction materials on common delivery tour by collaboration with other construction site
	Solution C – Selection of construction methods	- Use prefab elements - Use off-site construction - Use locally available materials (to reduce impact related to transport)

Table 9. Examples of possible scenarios for construction logistics impact assessments.

5. Construction logistics impact assessment framework

The impact assessment framework will cover both off-site and on-site construction logistics activities, for which two methodologies are used: External Cost Calculations (ECC) and Life Cycle Assessment (LCA). The common and overlapping elements of both approaches will be combined into a single impact assessment framework.

5.1 Comparison of the ECC and LCA methodologies for construction logistics

This section mainly focuses on the comparison of the two methodological approaches, ECC and LCA, for the evaluation of the environmental impacts of construction logistics. While both approaches have a different scope, they also have some overlapping ground and data requirements. Table 10 shows indicators, system boundaries and inventory data used to perform the impact assessment of construction logistics using each methodology.

	External Costs (VUB-MOBI)	**Life Cycle Assessment (SINTEF)**
Damage costs or impact categories	All major transport-related externalities: • Air pollution (all regulated and important non-regulated air pollutants in g/pollutant and monetary values) • Climate change (in g/pollutant and monetary values) • Congestion (monetary) • Infrastructure costs (monetary) • Noise pollution (monetary) • Accidents (monetary)	Impact categories for LCA: • Climate change (GHG emissions in kg CO2-equivalent) • Resource use o Primary energy use (MJ) o Non-Renewable energy use (MJ) o Renewable energy use (MJ)
Logistics activities (scope / physical system boundaries)	Transport activities (all transport modes off-site: cargobike, road, IWT, rail, maritime, air): • Transport of materials to and from the construction site; • Transport of machinery to and from the site; • Transport of waste.	On-site and off-site logistics activities (road): • Transport on-site and off-site of building materials; • Transport of construction machinery; • Transport of waste (incl. packaging); • Transport of construction workers; • Temporary work (production and transport)
Life cycle stages for logistics activities and geographical representativeness	Off-site construction logistics across all transport modes (cargobike, road, IWT, rail, maritime, air): • Hinterland & urban (or last mile) freight transport flows; • (Inter)national and regional/local geographical level The scope is clearly defined on the transport operation or vehicle usage part. Manufacturing and end-of-life are not considered.	Entire life cycle of on-site and off-site logistics activities, including: • Production of machinery, vehicles, temporary installations etc.; • Operation of these (mainly energy use); • End-of life of these Geographical representativeness: International and regional/local geographical level.
Granularity and differentiation of calculation-variables (life cycle inventory)	Calculation-variables: • Origin-Destination (vkm/tkm): OD / route (GPS), road type, environment type (or receptor densities); • Time of the day; • Traffic situation; • Vehicle characteristics: transport mode, vehicle capacity, vehicle propulsion type, vehicle consumption (emission class), vehicle speed (link/segment), cargo type, loading rate.	Type of data for life cycle inventory: • Vehicle and machinery type; • Number of trips /distance; • Transport distance; • Amount of fuel (or energy consumption); • Duration of on-site (e.g. vehicle, electricity); • Amount and type of products, temporary work/equipment (e.g.: kg of fence, # of barracks); • Type and amount of waste.

Table 10. Comparison of the ECC and LCA methodologies.

The External Cost Calculation (ECC) methodology analyzes the environmental damage costs, and the scope is clearly defined on the transport operation or vehicle usage part, from an economic sustainability assessment point of view, taking into account all major transport externalities, such as air pollution, climate change, congestion, infrastructure, noise and accidents costs. The considered logistics activities include the transport of materials to and from the construction site, the transport of machinery to and from the site and the transport of waste, for all available transport modes (road, IWT, etc.). More details about the methodology and data availability within the MIMIC project can be retrieved in Chapter 3.

The aim of LCA is to evaluate the environmental performance of construction logistics activities and different logistic scenarios from an environmental sustainability assessment point of view, taking the whole life cycle into consideration, focusing on GHG emissions (CO2-eq.) from road transport. The scope of the Life Cycle Assessment includes all logistic activities and is specified for each case based on data availability and contextual factors. In LCA, there is a practice of using estimations (proxy data or extrapolations) to cover the desired scope of the study in question, as long as limitations are clearly communicated. More details about the methodology can be retrieved in Chapter 4.

For transport of materials, machinery and waste both methods utilize the transport distance (like Origin-Destination in vkm/tkm) and vehicle characteristics, so there are possibilities of using the same data for calculations of the impact of transports. A detailed list of calculation-variables and their availability within the project demonstration cases can be found in Chapters 3 and 4.

5.2 Scenario analysis

In both LCA and ECC methodologies, scenarios are useful to evaluate the impact of construction logistics. The methods can be applied separately or in combination to make comparative assessments of construction logistic scenarios.

Examples of relevant construction logistics scenarios are given in section 3.4 and 4.3. Both methods are relevant for assessing the impact of transports and other on-site logistics activities by choosing construction logistics solutions compared to a business-as-usual-scenario. The ECC can give more interesting results when assessing transport scenarios affecting traffic, like scenarios with night deliveries, as the method includes the effects of traffic and times of delivery. The LCA can give interesting discussions such as the environmental benefits of technology shifts for transport and ("on-site") construction machinery (e.g. shift from fossil to electric), construction methods (e.g. off-site vs. on-site construction) is going to be assessed, as the method includes the activities on the construction site. Further, when considering construction methods like prefabricated wall elements compared to a business-as-usual with on-site construction, both methods are useful for evaluating the effect this has on transport (volume etc.). For this scenario, the LCA can also include the evaluation of how pre-fabrication affects waste generation or consumption of auxiliary materials compared to on-site construction.

5.3 Implementation of the impact assessment framework in the SMART Governance Concept

Identifying and constructing relevant construction logistics scenarios and evaluation of their performance using an integrated impact assessment framework in the planning of a construction site is an integral part of the SMART Governance concept that is currently being developed within the MIMIC project (Task WP 4) (Figure 10). The evaluation will first focus on the considered future state logistics scenarios, which will reflect estimated values of the impact assessment by means of the Multi-Actor Multi-Criteria Analysis, as part of Work Package 1, which can be further linked to the developed optimization models in Work Package 3. Next, concrete logistics solutions will be evaluated, rendering measured results by means of the developed Impact Assessment Framework of Work Package 2. Feedback loops will further enrich the analyses and will serve to enhance the different logistics modules (e.g. logistics planning). The draft illustration of the implementation of the assessment framework within the SMART Governance concept is shown in Figure 10, and further work will reveal the full potential of impact assessment to improve planning and evaluation of construction logistics.

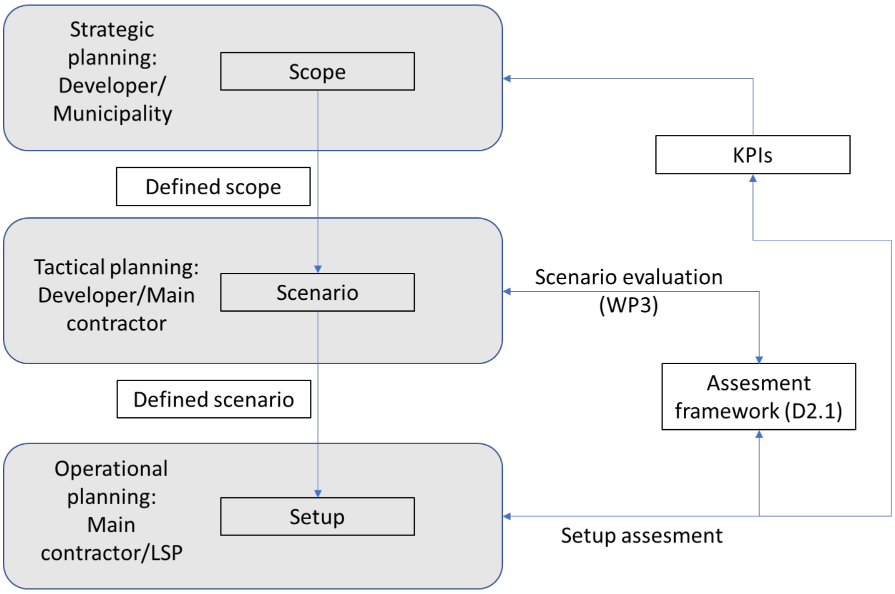


Figure 10. Implementation of impact assessment framework in Smart Governance Concept (Fredriksson et al., forthcoming).

The relationship between the assessment framework D2.1 and the construction logistics scenario and setups defined in deliverable D1.1 (Fredriksson et al., forthcoming). These deliverable then make the link with deliverable D4.1 on the development of the Smart Governance Concept. Together, these three deliverables show the importance of scenario evaluation and setup assessment in the Smart Governance Concept.

6. Limitations and further work

This report is a first version of impact assessment framework for construction logistics. The report provides background information on the importance of conducting impact assessments and presents a detailed description of quantitative evaluation methodologies used for assessing new and existing construction logistic solutions and setups. Both the External Cost Calculation (ECC) and Life Cycle Assessment (LCA) methodologies prove to be important in establishing robust and relevant construction logistics scenarios.

The following limitations will be incorporated in future editions of the MIMIC impact assessment framework report:

- ***Data collection and documentation***: EEC and LCA methods utilize some common data for transport activities, with more detailed data to be collected for the ECC and for LCA assessment for off- and on-site construction logistic activities. Upcoming national case studies will further enable to investigate to what degree a common data collection can be performed.
- ***Testing and evaluation of ECC and LCA methodologies in demonstration pilots***: test and evaluate the performance of the demonstration pilots using ECC and LCA methodologies.
- ***Construction logistics impact assessment framework***: the project consists of developing a common framework that enhance the evaluation of construction logistic scenarios, providing decision support to relevant stakeholders. In each case, the scope and goal of the investigated scenario decides the significance of each method in the specific evaluation. Combined, the two methods give the possibility to investigate a broad range of different construction logistics scenarios. This will be investigated further in the development of the common framework, that will be the content of Deliverable 2.2 of the project.
- ***Implementation of the impact assessment framework:*** Develop a guideline on how the impact assessment framework will be implemented and tested in the SMART Governance Concept.

The list below gives an overview of further advanced reading:

- Bickel, P., Friendrich, R., Droste-Franke, B., Bachmann, T. M., Greßmann, A., Rabl, A., Tidblad, J., 2005. ExternE-Externalities of Energy - Methodology 2005 Update, Publication Office of the European Union, Luxembourg.
- Brusselaers, N., Mommens, K., Janné, M., Fredriksson, A., Venås, C., Flyen, C., Fufa, S.M., Macharis, C. (2020). Economic, social and environmental impact assessment for off-site construction logistics: the data availability issue. World Sustainable Built Environment (WSBE) – Beyond 2020 Conference, Göteborg, Sweden, November 2020. *Earth and Environmental Science Journal* [Accepted/In press].
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