Material supply chain for 3D printed construction projects

A case study for Mexico

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Abstract

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Title of the thesis

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Abstract

3D Printing technologies is closely associated with the construction industry. Nowadays more and more start-ups and companies are focusing on 3D printing technology in the construction industry.

This research was conducted in collaboration with his Hyperion Robotics Oy, a Finland-based company, and his LAB University of Applied Sciences.

This paper aims to determine a greener approach to the supply chain and raw material local availability for 3D printing projects in Mexico.

Search methods for effective results include examining a variety of information sources, websites, and articles on the subject, As well as analysis for evaluation and comparability of Energy consumption and Greenhouse gas emissions from transportation between different raw material sources.

Keywords

3D printing technology, Construction industry, Basic materials, Mexico, Green supply chain

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List of terms

BIM	Building Information Modeling
VR	Virtual Reality
3DP	Three-dimensional printing
A.S.T.M	American Society for Testing and Materials
GGBS	Granulated Blast-Furnace Slag
ASR	alkali-silica reaction
VMA	Viscosity modifying agents
GSCM	Green Supply Chain Management
GHG	Greenhouse Gases Emissions
WTW	Well-to-Wheel
WTT	Well-to-Tank
TTW	Tank-to-Wheel

1 Introduction

The construction industry is an important factor in the economic development of the country, and its importance is well known to the public.

Since the industrial revolution of the 16th century, the construction industry has received a major boost through the manufacture and introduction of tools and processes that enable rapid development. (Ringen & Englund, 2006)

Currently, the most relevant building technologies are:

- The implementation of BIM (Building Information Modeling) technology in construction projects makes project planning and all technical preparations easier than ever before.
- Virtual reality is making rapid progress to augment mixed reality, and its application in construction spaces is helping field teams gain better control over the construction process, helping them get ahead of problems before they occur. Detects and resolves on-time so you can avoid significant delays on schedule.
- Modular construction involves off-site prefabrication of individual 3D elements in an enclosed space and later assembly on-site into a single building or structure.
- Additive manufacturing or 3D Printing technology (3DP)

In construction, most of the information needed for this technology to work comes from the design process. Since the construction industry is already experienced with computer-aided manufacturing processes and BIM continues to boom in the construction industry, the integration of 3DP technology is not too complicated. Through a CAD or BIM program, the 3D printer is given information about what needs to be printed, and the machine begins laying down layers of material according to specifications.(Khajavi et al., 2021)

These are just some of the recent technological advances that are revolutionizing the construction industry.

This report focuses on 3D concrete printing technology as it is being developed in different regions of the world and the optimal supply chain has yet to be established. The purpose of the report is to provide a database of 3D concrete printing suppliers and required materials in Mexico and to analyze the energy consumption and CO2 emissions of transporting the materials to the construction site. As a research limit, only the transportation of materials was established, the manufacture and production of 3D printed concrete elements are excluded in this report.

2 3D Printing in the construction industry

Additive manufacturing (AM) was invented in the 1980s as a method for prototyping polymers. AM creates the shape of a part using a layer-by-layer process of adding material. In addition, AM is tool-independent, so the AM process is much faster than traditional manufacturing processes that use tools in the first part of the production process.

The term 3D printing is commonly used to refer to all types of additive manufacturing (AM). Strictly speaking, however, 3D printing only refers to converting a digital CAD (computer-aided design) file into a three-dimensional, physical solid object or part. This object is created by a 3D printer that "translates" a CAD file into a 3D model. This is typically done by depositing the material layer by layer into precise geometries using printheads, nozzles, or other printing techniques. Each layer can be viewed as a thinly sliced cross-section of the final object being built. (Shakor et al., 2019)

3D printing technology has been pushed by large companies, universities, and start-ups around the world, but the gap between the development of 3D technology and its practical application on construction sites remains unmanageable. So compared to other technological advancements in the construction industry such as virtual reality and BIM technology (digitization), 3D printing in the construction industry (automation) has many innovations and pilot project demonstrations around the world (Ituarte, 2016).

3D Concrete printing

3D Concrete printing enables new structures with dimensional accuracy and evaluation of structural morphology. 3D Concrete printing can be used without formwork by using a concrete mix that meets several design and operational constraints.

Currently are a variety of companies specializing in 3D printing concrete, each with a different and unique 3D printing station configuration. In the Figure 1 is shown the 3D printing configuration used by Hyperion Robotics OY based in Finland.

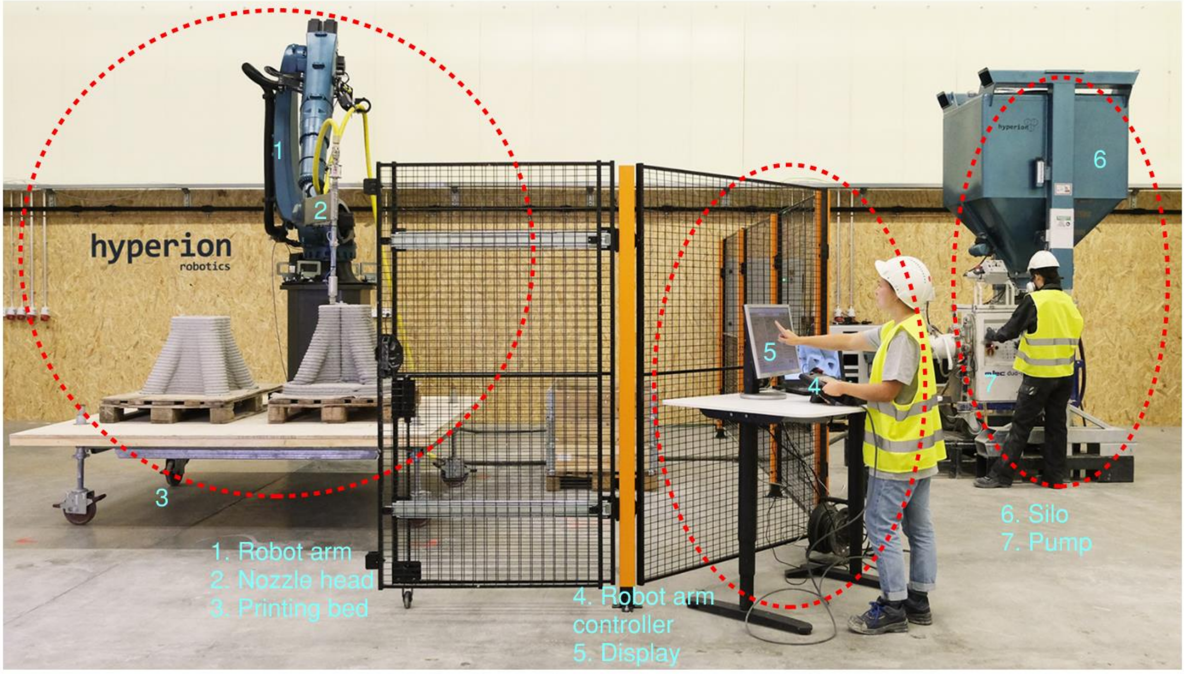

Figure 1. 3D concrete printing station developed by Hyperion Robotics (Hyperion Robotics, 2022)

3D printing of metal structures

The MX3D metal printing process was developed jointly with Acotech and Autodesk in the Netherlands and uses industrial robots and advanced welding equipment. The welder gradually increases the amount of molten metal that cools rapidly. A variety of materials such as bronze, copper, aluminum, and stainless steel can be air printed with graceful skeleton lines. The technique can even print lines with varying levels of quality, from bumpy bars resembling Alberto Giacometti's sculptures to more sophisticated cylinders like smooth rebar.

One Off Robotics is another company that developed a 3D printing process (Meltio). Meltio 3D printing process takes metal additive manufacturing to the next level. This integration enables high-performance, affordable, and easy-to-use metal 3D printing, part repair, cladding, and feature addition. Produce custom metal parts of 99.998% density in a single-step process.

Figure 2. Robotic Metal 3D Printing Integration by One Off Robotics (Oneoffrobotics, 2022)

2.1 Integration of 3D printing technology into the construction industry

In recent years there have been numerous projects that served to demonstrate the adaptability of 3D technology in the construction industry, some of its greatest advantages being the reduction of CO_2 emitted, the automation of the construction process and project execution speed, among others. Some examples are mentioned below.

MX3D Bridge in Amsterdam

In 2018, MX3D, a 3D metal printing base in The Netherlands, completed the 3D printing of a fully functional stainless-steel bridge (2-metre-wide pedestrian bridge) to cross one of the oldest and most famous canals in the center of Amsterdam, and was officially placed in 2021.

The bridge was fabricated from stainless steel rods using a six-axis robotic arm incorporated with a welding gear.

This technology has allowed MX3D to 3D print strong and complex structural elements out of metal.

As result of the showcase of the MX3D Bridge project, the potential applications of the multi-axis 3D printing technology was shown to the industry.

Figure 4. Smart 3d-Printed MX3D Bridge (MX3D, 2021)

3D printed home community in Austin, Texas

In 2021, Austin, Texas-based start-up ICON 3D printed a 60 m^2 home to solve the homeless crisis and affordable housing shortage.

Concrete 3D printing technology was used as a basis for efficient use of space and materials in a quest to reduce the cost of housing. With this project as a precedent, in 2022 ICON announced the building of his 3D printed community of 100 homes co-designed by BIG-Bjarke Ingels Group and developed by Lennar.

Figure 5. 3D-printed home built by Icon. (INSIDER, 2020)

3D Printed Optimized Pad Foundation, Helsinki, Finland

While most companies specializing in 3D-printing concrete focus on printing houses, Hyperion Robotics uses 3D-printed structural elements to design optimized foundations that save up to 75% on materials.

Multiple calculations and mechanical tests have been performed to demonstrate the strength capabilities of the 3D printed foundation.

While most companies specializing in 3D-printing concrete focus on printing houses, Hyperion Robotics, a concrete 3D printing company based in Finland bets on 3D printed structural elements, and in cooperation with IBERDROLA has designed a 3D Concrete printed foundation that reaches up to 75% savings in materials. and could replace the traditional pad foundation.

Calculations and mechanical tests were carried out to demonstrate the strength of the 3D printed foundation.

Hyperion is currently working on implementing an automated placement of steel reinforcement into the 3D printing process.

Figure 6. 3d Printed Optimized Pad Foundation (HyperionRobotics. 2021)

2.2 Development of 3D concrete printing

The last two decades have seen constant research and innovation in concrete 3D printing. This technology enables significant advances in buildings with industrial robots and gantry systems. Previous demonstrations of 3D printing technology for construction have included the fabrication of dwellings, building elements such as columns, structural panels, bridges, civil infrastructure, and artificial reefs.

Among the various techniques currently used in concrete 3D printing, extrusion of concrete sheet material is the most widely used.

Layered Extrusion 3D Concrete printing (Contour Crafting)

Layered extrusion concrete 3D printing includes a controlled nozzle that precisely extrudes cementitious material layer by layer that is be able to support its own weight and the weight of the next layer allowing the 3D printing element to arrive at the final design without deformation. The extrusion nozzle can be equipped with an automatic trowel tool that smoothes the 3D printed layers and covers the inter-layer grooves between layers, resulting in a smooth concrete surface.

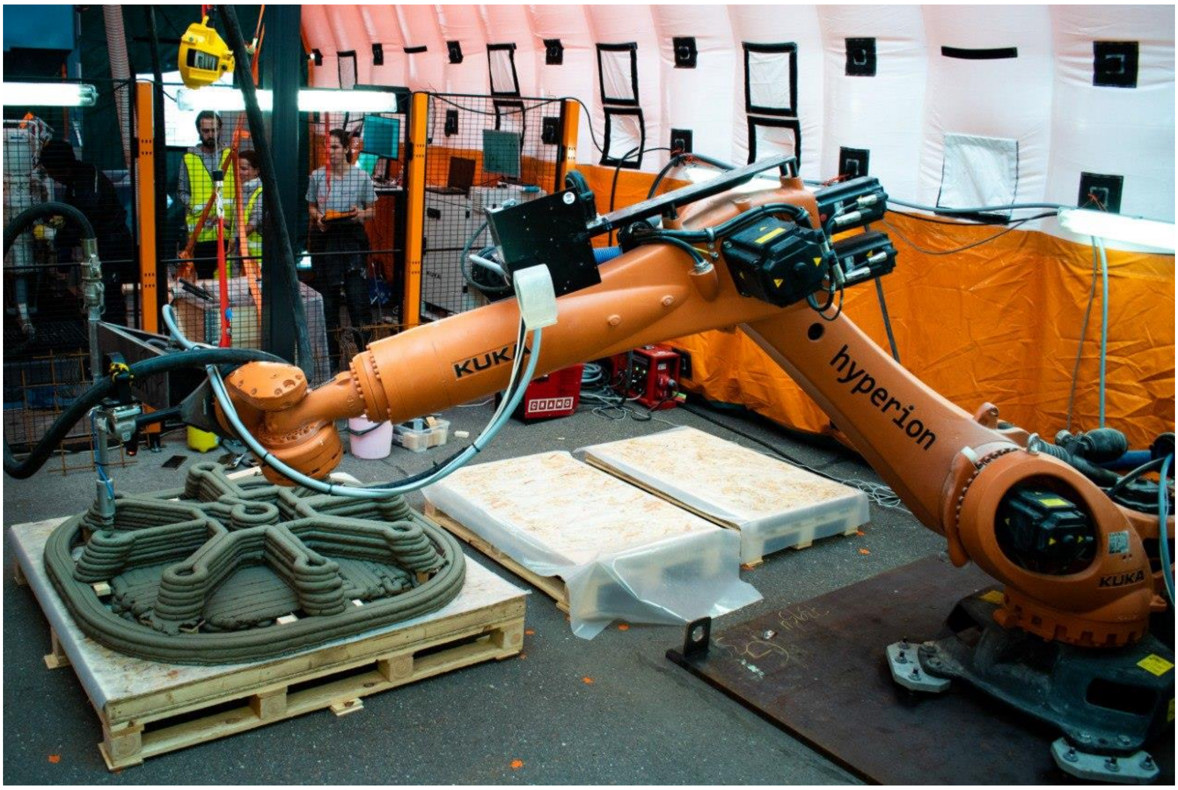

Figure 3. Layered Extrusion 3D Concrete printing example by Hyperion Robotics 3D Concrete Printer (HyperionRobotics, 2022)

2.3 Challenges facing the 3D concrete printing

Material for 3D Concrete Printing

Every new technology has its challenges. Concrete is an unstable material, especially when the resulting product must have good structural properties.

The biggest challenge for 3D concrete printing is the material itself: Concrete is a complex material. Its curing time is affected by many factors such as temperature, humidity, and components. If the concrete mix is not perfect, the structure will not gain the required strength and may fail. (Bos et al., 2022)

When designing the material for 3D Concrete printing, two conditions are considered.

First, the cohesive force between layers decreases with increasing time interval between layers.

Second, the material must be sufficiently hardened to withstand the weight of the next layers to be applied without deformation.

Comparing these two limits leads to a print speed optimization paradox. The amount of time between two sedimentary layers should be sufficiently long to provide the required strength, but short enough to ensure a strong bond between the layers. The ability of a sedimentary layer to support its own weight is directly related to its yield strength. If the wall is built up in layers, the first applied layer will receive the greatest load. The yield point must be sufficient to withstand this load to ensure wall stability during this process (Slavcheva et al., 2019).

Meanwhile, the mixture must be sufficiently fluid for extrusion. To build the structure, care should be taken to ensure sufficient fluidity and stability during extrusion after application of the layers. The yield strength of cementitious materials increases with rest time.

Early stage of standardization

An important obstacle to the widespread implementation of 3D concrete printing technology is the lack of a regulatory framework for concrete 3D printing in general and the lack of quality control over materials, construction process, technology, equipment, and properties for the application of concrete 3D printed elements from concrete.

Although the movement toward standardization is progressing, it is difficult to reach a consensus because each company and research institute participates in material experiments and works with different formulations. And building consensus on 3DP standardization in the construction industry has proven to be a challenge (Romdhane, 2020).

Some items may be standardized by general standardization or assigned national standardization. But there will always be a line between standardization and flexibility (similarity and individualization) because standardization in construction the regularity, repetition, and widespread use of components, parts, procedures, or processes that have predictability with successful practice, and this can lead to impotence of design of new products and slow down the innovation in the industry. (Pasquire C., Gibb A. 2002.)

3 Basic materials used in the 3D printing technology

As mentioned earlier, concrete mixes for 3D printing have specific performance requirements and to achieve them different materials are used with admixtures that act as modifiers of the required parameters. Its features are described in detail below.

3.1 Aggregates

Aggregate is a very important quantity in the production of concrete and is a determining factor in the economics, durability, and stability of construction projects. For example, the aggregate volume in standard concrete is 65% to 85%, and about 60% in 3D printed mixtures. Therefore, studying its physical and mechanical properties is critical for its proper and efficient use.

Aggregate can be defined as a composite of geological materials such as stone, sand and gravel used in almost all forms of construction. It is used in its natural state or broken into smaller pieces depending on the mixture requirements.

Fine aggregates mostly consist of natural sand or crushed stone, most of whose particles are less than 5 mm^2 and must comply with certain rules to give optimum technical application. The particles are durable, clean, strong and free of inorganic impurities that can affect the mechanical properties of concrete in the hardened state

The aggregates constitute a determining factor in the economy, durability, and stability of constructions projects since they occupy a very important volume in the concrete production. For example, the volume of aggregates in standard concrete is 65% to 85%, and in 3D printing mixes about 60%. Therefore, due to its physical and mechanical properties is of vital importance to cementitious mixtures for its adequate and efficient use.

Aggregates can be defined as composites of geological materials such as stone, sand, and gravel that are used in virtually all forms of construction. They can be used in their natural state or crushed into smaller pieces.

Fine aggregates commonly consist of natural sand or crushed stone with most of its particles being less than $5mm^2$ and must comply with certain rules to give them optimal engineering use: The particles must be durable, clean, resistant, and free of inorganic impurities, since they could affect the mechanical properties of concrete in its hardened state

The aggregate particle size used is highly dependent on the pump and its ability to pump the material. (Kosmatka, 2004)

3.2 Binders

A binder is a material that can join fragments of one or more materials into a compact whole, the bonding occurs through chemical transformations. They are different binders, according to the way they perform the integration. Examples: gypsum, lime, cement.

3.2.1 Cement

Cement is a hydraulic binder, that is, it is an inorganic or mineral material that, after being finely pulverized and then mixed with water, forms a paste that, through reactions and hydration processes, sets and hardens, maintaining, even under water, its resistance and stability.

The American Society for Testing and Materials (ASTM)

The American Society for Testing and Materials (ASTM) recognizes five types of Portland cement (C150/C150M Standard Specification for Portland Cement 1.). All basic materials are the same but using different mixtures of these materials alters their properties.

- Type I - Ordinary cement used for general construction.
- Type II - An improved cement that in compassion with type I cement has a lower heat of hydration and can withstand sulphate attack.
- Type III – This cement gains strength at earlier stage than the above mentioned and produces concrete approximately twice as strong as Type I cement in the first 2 hours. This cement has a much higher heat of hydration.
- Type IV – A low heat cement that produces concrete that develops heat very slowly. Used for very large concrete structures.
- Type V - Cement used in concrete exposed to high sulphate concentrations.

European cement standards

In the other hand, the European Union classifies cement in accordance with the UNE-EN-197-1:200031 standard. The difference between the different types of cement is marked by the percentage and class of additives contained in each of them. Depending on the proportion of additions, they are classified into subtypes A, B and C, with those in class A corresponding to those with the lowest percentage of addition and those with the highest percentage to class C.

- CEM – Portland Cement consist of around 92 % of Portland Cement Clinker as main constituents.
- CEM II – Portland Pozzolana Cement consists of Portland Cement Clinker with 35 % Fly Ash or Slag or Natural Pozzolana or Lime Stone as main constituents.
- CEM III – Blast Furnace Cement consist of Portland Cement Clinker with 65 % or 80 % or 95 % Granulated Blast furnace slag as main constituents.
- CEM IV – Pozzolanic Cement is consist of a minimum of 45 % Portland Cement Clinker with Natural Pozzolana or Lime Stone as main constituents.
- CEM V – Composite Cement is an composition of Portland Cement Clinker with Blast Furnace Slag, Natural Pozzolana & Fly Ash.

These types and classifications of cement have to be studied depending on where each project will be carried out, this is to avoid misunderstandings and therefore inconveniences to the realization of the project.

For the project in Mexico, the classification provided by ASTM is taken as a reference, because the ASTM International standards are recognized by the World Trade Organization (WTO) Agreement on Technical Barriers to Trade (TBT), which created rules for standardization measures that Mexico, as a member of the WTO, must comply with in order to avoid unnecessary barriers to international trade.(Iliana R., 2014)

3.2.2 Supplementary cementitious materials and wastes

Alternative cements are materials that can partially replace cement and improve mechanical properties. The use of cement substitutes has great environmental benefits derived from diversion from waste streams, the reduction in energy required for recycling in comparison to the manufacture of cement, silica, alumina, and iron oxides.

Alternative Cementitious Materials are divided materials that replace or complement the use of cement. The use of alternative cementitious materials reduces costs and improves the mechanical properties of concrete. These materials include fly ash, crushed blast furnace slag, condensed silica fume, limestone, cement kiln dust (CKD) and many others.

Fly ash

Fly ash is obtained by electrostatic or mechanical precipitation of powdery particles entrained by gaseous flows from furnaces fed with pulverized coal. Siliceous fly ash is a fine powder of spherical particles that has pozzolanic properties

Fly ash is characterized by a fine particle size distribution (80 – 90% < 45um) and high content of aluminium and silicon and in reactive phases.

The addition of fly ash has a beneficial effect on physical characteristics (absorption, suction, and moisture content), exterior appearance, and texture of the concrete mixture. (Peña Rodríguez et al., n.d.).

Granulated blast-furnace slag - GGBS

Slag is a metallurgical residue that sometimes acquires the category of by-product, since it can be used as a construction material, blocks or as an insulator against humidity and in the manufacture of cement and glass.

Granulated blast-furnace slag is obtained by quenching (the rapid cooling of a metal to adjust the mechanical properties of its original state by submerging the metal element in water) a molten slag of suitable composition, obtained by smelting iron ore in a blast furnace. (FICHA TÉCNICA ESCORIA GRANULADA, 2011)

One of the most widespread applications of granulated slag is the manufacture of cement. According to the UNE-EN 197-1 standard - Cement - Part 1: Composition, specifications, and conformity criteria for common cements (EN-197-1, 2000.), blast furnace slag must meet the following conditions: It must be composed, at least in two thirds of their mass, by CaO, MaO and Sio_2. The rest must be formed by aluminium oxide compounds Al_2O_3 and small amounts of other oxides; It must be constituted, at least in two thirds of their mass, by vitreous phase; And the ratio of (CaO% + MgO%)/SiO_2% must be greater than 1

The addition of blast furnace slag improves the mechanical resistance of the mixtures in the first phases of curing and protects the mortars against attacks caused by external aggressive agents and media (sulphates, chlorides, carbonation, etc.)

Metakaolin

Metakaolin is a supplementary cementitious material, since it is a thermally activated aluminosilicate, which is produced by calcining kaolin at temperatures around 500ºC and 600ºC; At this temperature, a transformation of its crystalline structure takes place by breaking the Van der Waals bonds (OH) that join the silica tetrahedrons, SiO_2, and the alumina octahedrons, Al_2O_3, that is, by losing the combined water due to thermal action. the crystal structure of kaolin is destroyed.

Fundamentally, its applicability has focused on taking advantage of its chemical composition and reactivity to use it as an artificial pozzolan in the production of mortar and concrete, since its important contribution to mechanical resistance, reduction of permeability and increase in durability is recognized.

The pozzolanic activity of metakaolin is evidenced when a material with a series of advantages over Portland cements without additions, such as:

- Increased mechanical properties especially at early ages
- Increased resistance to sulphate attack
- Increased resistance to alkali-silica reaction (ASR)
- Increased pore refinement
- Decrease in permeability
- Reinforcement corrosion decrease
- Decrease in the evolution of the heat of hydration

Silica fume

Silica fume is formed by the carbon reduction of high-purity quartz in electric arc furnaces used to produce silicon and ferrosilicon alloys and consists of very fine spherical particles. The fact that

Silica Fume is an essential ingredient in the production of very high strength concrete means that this additive is widely recognized as a concrete quality-enhancing ingredient in formulations.

In any event, this general consideration should be used with caution, as the beneficial effects of silica fume on concrete strength and durability are accompanied by undesirable side effects such as: B. The impact on concrete consistency that is important to know is to control and minimize.

The great success of Silica fume lies in its remarkable chemical potency when compared to fly ash.

This effectiveness he derives the high content of chemically active compounds (mainly amorphous silica), which usually constitute about 90% of the total composition and its great fineness, which makes it very reactive.

For both reasons, this additive significantly improves the strength and durability of concrete when used in very small proportions of 5 to 15% by weight of cement (Pilar A, 1999).

3.3 Admixtures

Unlike cement, aggregates, and water, admixtures are not essential ingredients in traditional concrete mixes, but they are very important in 3D concrete printing.

Admixtures play an important role when comes to 3D concrete printing, as they are key to controlling the properties a material needs to print. The effectiveness of admixtures depends on factors such as cementitious material type, brand, quantity, moisture content, aggregate shape, particle size, proportion, mixing time and concrete temperature. They are important and need to modify the properties of concrete appropriately, so the mixture can meet the parameters that 3D concrete printing requires.

Superplasticizer

Superplasticizers transform hard, stable concrete into flowable, pourable and workable concrete. And help improve the workability, strength, material savings (cement), and reduce thermal cracking and shrinkage.

Superplasticizer are used in three ways: First, to make the mixture more flowable, and produce self-leveling concrete with no necessity of increasing the water content, reducing cement, or losing strength. Second, to make the mixture more workable, and produce high-strength concrete by using less water and lowering the water-to-cement ratio. And third, to save cement by reducing both water and cement content while maintaining the same water-cement ratio and workability. Each of these applications has a different impact on the 3D printing mixture, so their dosage should be treated with particular care.

Setting retardant

Setting retardant acts in the concrete as a setting agent understood in a controlled manner. It is dosed to achieve an extended setting, up to 30 hours.

Setting accelerator

Setting accelerator acts through a chemical reaction with the cement, accelerating the setting time and the resistance to axial compression at an early age. These additives are compatible with air-entraining agents, certain superplasticizer additives, and certain conventional water-reducing additives. These accelerators are based on different formulations such as calcium Formate, C-S-H seeds, amorphous calcium Aluminate and so on.

Viscosity modifying agents (VMA)

The addition of VMA to the mixture improves the performance of cementitious materials. Their applications include mortar and concrete design for 3D printing applications. Using VMA can improve dynamic stability. This means the resistance of concrete to component separation during transport, placement and pouring (Bessaies-Bey et al., 2022). It also lead provides with higher static stability to the 3D printed element to ensure even distribution of the material until hardening begins. The usefulness of VMA in improving the stability of cementitious materials translates into the performance of hardened systems such as impermeability and bonding to embedded rebar.

Anti-shrinkage agents

A grand percentage of Anti-shrinkage agents are based on ethylene glycol derivatives. These organic liquids fundamentally differ from most other water-based admixtures.

After casting, compaction, finishing and curing, an air/water interface is created within the capillaries or pores of the cement paste of the concrete because the extra water in the 3D printed element begins to evaporate from the concrete surface.

4 Green supply chain management for 3D printing in the construction industry

Recently, the terms green, sustainability and circular construction have become relevant. Because these are important concepts that every company should consider when planning their business model.

Green Supply Chain Management (GSCM) practices have significant environmental benefits. On the one hand, the pursuit of supply chain sustainability reduces energy consumption, thereby reducing emissions of carbon dioxide (CO_2) and other air pollutants. CO_2 is produced by a wide range of activities, including industrial work and vehicle operation. CO_2 is one of the main greenhouse gases responsible for global warming, an issue that is already impacting industries that rely on natural resources, from commercial fishing to forestry.

By moving to more sustainable practices, companies can do much to slow or stop global warming and ensure a brighter future for the planet. Practice reduces waste and conserves non-renewable resources. For example, companies can reduce their dependence on petroleum-based products while keeping waste away from landfills and fragile ecosystems. Loading trucks more efficiently and introducing stricter driving speed and idle guidelines will use less fuel (Scrădeanu et al., 2021).

Implementing GSCM practices is not only important to the health of the environment. This is essential for sustaining industries and communities well into the future.

4.1 EU Sustainable Development Strategy

The concept of sustainable development is very important in European Union. The construction industry accounts for approximately 50% of polluting emissions in the world.

In line with the EU Sustainable Development Strategy, over the past decade the European Union has set general targets and concrete actions for its key priorities: Sustainable Consumption and Production, or Conservation and Management of Natural Resources *(European Comission. 2010)*

Considering the main sources of pollution from the transportation, production and management of natural resources, businesses should be aware of their commitment to the environment and reduce the emission of pollutants. should try to reduce throughout the business process. The supply chain of raw material used to generate the 3D printable concrete, is at a very early stage and not yet well established

4.2 Green supply chain management GSCM

The modern Green supply chain concept was born out of the concept of a hybrid approach, adding to meet environmental requirements throughout the product life cycle of each product and its design.

Sustainable development and green supply chain initiatives are growing rapidly for many businesses and corporations as they seek to reduce supply chain costs while reducing their carbon footprint and better managing natural resources, is becoming a higher priority. (Badkoobehi, 2011).

Logistics refers to supply chain management practices and strategies that reduce the environmental and energy footprint of goods transportation. Emphasis is on materials handling, waste management, packaging, and transportation. Green logistics can encompass several aspects related to production planning, material management and logistics, opening the door to possible applications of green strategies in the supply chain.

The different strategies used by stakeholders to reduce the Energy consumption and Greenhouse gases emissions are called green logistics. (Carolina M,. Davim J.,2017))

For a greener supply chain, it is essential to prioritize the energy consumption and Greenhouse Gases Emissions (GHG) during all stages and processes involved in the production of 3DP elements.

Due to the very complex composition of printable material and the uncertain availability of the raw material necessary for its production, Hyperion Robotics proposes a new strategy for research and execution of projects.

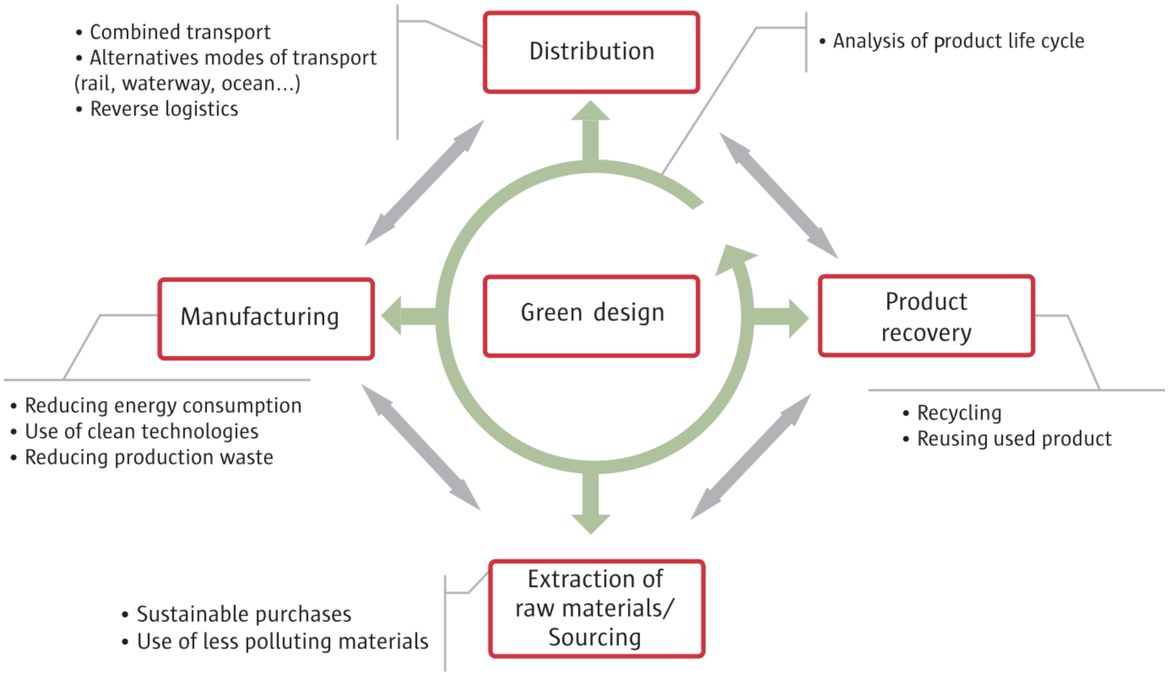

Figure 7. Delimitation diagram of the Green Supply Chain (Insight, 2008)

The delimitation of a green supply chain is shown in the Figure x and it covers all stages of life cycle of the product, from the extraction of raw materials through the design, manufacturing, distribution stages, use of the product by the consumer, and with special emphasis on the disposal of a product at the end of its life cycle (Beamon, 1999).

From this green supply chain perspective, the entire product life cycle should be considered. Thus, the traditional linear model of supply chains is replaced by a circular model, which involves all parties including subcontractors, suppliers, traders, and consumers.

4.3 Hyperion Robotics Green Material research and development.

3D printing companies are now doing their own research and mixed printing advances, but depending on where they are based, they have access to a wide variety of basic materials, and the quality and specifications of aggregates, binders, and additives are determined by their suppliers. And the materials will have different, specifications, brands, and others.

Therefore, carrying out a project outside of an established raw material supply chain presents new challenges. Hyperion Robotics OY is about to deploy a project in Mexico.

Still the mixtures used by Hyperion have been tested and meet customer expectations. The ingredients and the batch mixing plant are sourced from Finland and shipping mixed materials from Finland has not only a financial impact, but also an environmental impact due to its carbon footprint and associated energy consumption.

4.4 Logistics of basic materials and its relationship with the green supply chain

Transport contributes to the deterioration of the environment and human health through toxic pollutants and greenhouse gas emissions, waste and noise pollution, and territorial fragmentation.

The environmental impact of the raw material transportation process is a significant contributor to atmospheric CO_2 emissions, suspended dust particulates, noise, vibration, liquid emissions into water, waste, and excessive energy consumption.

Seeking optimized procurement processes, reduced environmental impact, and a green supply chain approach, the purpose of this study was to analyze and compare the impacts of using local basic materials required for manufacturing mixture for 3D Concrete Printing and importing the basic materials from largest production and external supply locations.

By choosing the shortest and most cost-effective routes for sourcing basic materials and delivering goods, businesses can reduce transportation time and fuel costs. Route optimization software can analyze critical logistical issues such as vehicle availability, traffic conditions, and labor for loading and unloading. Automated route planning allows logistics companies to optimize and streamline routes and reduce CO_2 emissions.

5 Research and Analysis.

5.1 Scope of the research and analysis

As an object of investigation, a large-medium scale project in which Hyperion Robotics will be a participant is considered, said project will be carried out in Mexico-Veracruz in June 2023.

Due to the scale and importance of the project, a evaluation of the availability of basic materials for 3D printing, a creation of a database of suppliers of the materials required in Mexico, and a Well-to-Wheel analysis in case of importing materials from 6 different sources and delivery times were carried out.

5.2 Database of basic materials for 3D printing for a project in Mexico.

The planning and management of basic materials in construction becomes relevant during the whole execution time, in which the greatest flow of supplies occurs, especially during the execution of the work itself, since there are materials that due to their nature do not withstand the passage of time in unfavourable storage conditions.

3D printing construction companies must focus their efforts and resources on guaranteeing adequate planning and management of basic materials so that the works are carried out in a timely manner, so that the clients and those involved in the project are satisfied with the results.

To start a construction project, it is vital to have a vast database of suppliers and to have established contact with them, especially if they are materials that are not as abundant as in the case of materials for 3D printing.

After an arduous process of searching and contacting suppliers of basic materials for 3D printing, the following database was obtained.

Company	Material	Country	Delivery time	Min. order
INTERNATIONAL MATERIALS	GGBS	Global	28 days	100 ton
Ternium	GGBS	ARGENTINA	14 days	100 ton
Grupo Comosa	GGBS	MEXICO	14 days	100 ton
EdificaMex	Sand	MEXICO	-	100 ton
Sika Peru	Silica Fume	PERU	14 days	25 kg
Construrama	Cement TYPE 1	MEXICO	14 days	25 kg
Lanxess	Accelerator, Calcium Formate	GERMANY	28 days	100 ton
Herschi Trading	Retardant, Calcium sulphate	MEXICO	20 days	-
IMPERQUIMIA	Anti-Shrinking	MEXICO	14 days	-
CEMEX	Anti-Shrinking, GGBS, Concrete	MEXICO	14 days	-
POCHTECA MATERIAS PRIMAS	Accelerator, Calcium Formate	MEXICO	14 days	-
Quimicret	Anti-Shrinking, Accelerator, Retardant	MEXICO	14 days	-
Fermentando	Retardant, Calcium Sulphate	MEXICO	20 days	-
Termoplastocs de caribe	Anti-cracking fibber	MEXICO	20 days	-
Denka Infrastructure tecnologies	Anti-cracking, Accelerator, Retardant	Global	14 days	-
Cemento cruz azul	Cement TYPE 1	MEXICO	14 days	100 ton

Table 1. Supplier database for the Mexico project

Having analysed the availability of the materials and found mostly local suppliers, the project manager can proceed to establish a supply chain for the project in Mexico.

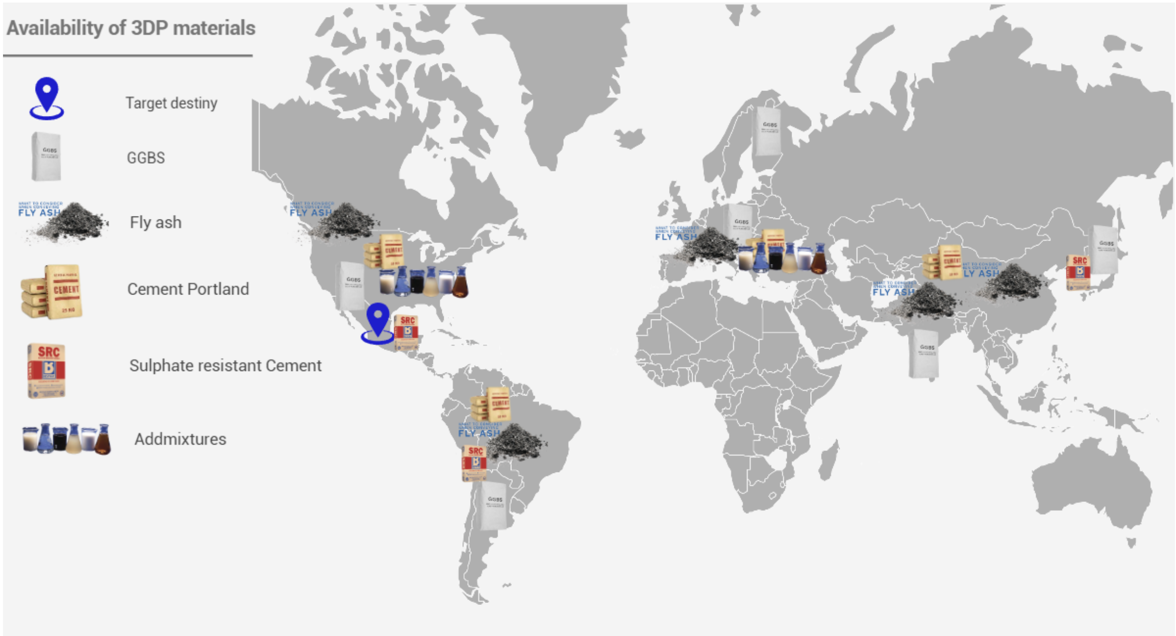

Figure 8. Availability map of 3DP Materials

5.3 Well to wheel analysis

Companies can make a difference in basic things and continue to develop more environmentally friendly services and products.

In case of Hyperion Robotics, the goal is to create a low carbon footprint product, by utilizing tailing mining and other waste (binders produced from large industries) materials for the concrete mixture to be 3D printed. An important factor of making a low carbon footprint product is the logistics and transportation.

To carry out this analysis, the following 3 elements were first defined: Purpose of analysis, Method of analysis and Context of analysis

5.3.1 Purpose of analysis

The purpose of this analysis was to determine the ecological impact that the use of local materials in Mexico would have for the preparation of a mixture for 3D printing of concrete and its corresponding project execution.

5.3.2 Method of analysis

The analysis carried out was a well-to-wheels analysis by JEC, which pursue the objectives of estimating: greenhouse gas emissions, energy efficiency and industrial costs.

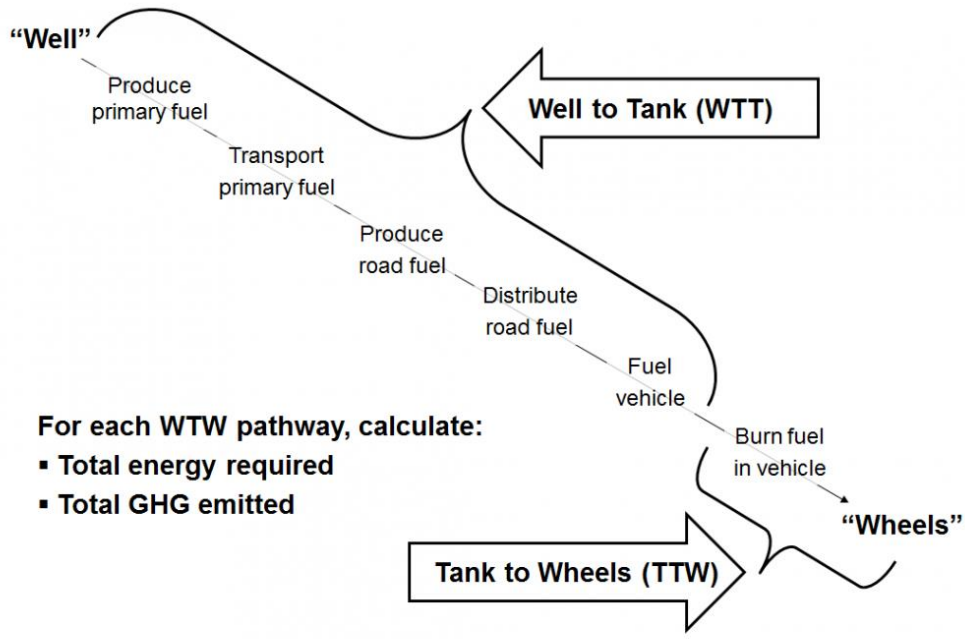

Figure 9. Graphic representation of the well-to-wheels analysis (EU, 2016)

The two components of a Well-to-wheels analysis are Well-to-tank, which assets the fuel production phases (WTT) and Tank-to-wheels (TTW), which assets the use of fuel.

The energy demand in the tank is expressed in kilowatt-hours (kWh), to make the evaluation and compare different drivetrains more intuitive. WTT evaluation takes into account the energy and associated emissions in the steps required to supply the finished fuel (derived from the raw material) to the tank of the vehicle. While in TTW evaluation the greenhouse gases emissions are considered and expressed as tones of CO2 (tonnes). The integration of these two evaluations gives the overall WTW energy consumption and emissions (JEC Well-To-Wheels Report V5, 2020).

The chosen analysis tool for calculating environmental impact and efficiency of transport systems was Ecological Transport Information Tool for Worldwide Transports (EcoTransITWorld)

5.3.3 Context of analysis

As a context for the analysis, a volume of 300 m^3 of raw material was defined to be delivered to Mexico City, Mexico.

With the help of the database created in this project, 6 possible places of origin of the material were considered:

- Italy

- Finland
- India
- Japan
- Argentina
- and Mexico (local).

5.4 Results

The result of the materials availability investigation is the database shown in table 1 (materials availability map).

The analysis has shown the Greenhouse gases emissions (CO2 tonnes) produced and Energy consumption (Killowatt/hours) used for every 300 m^3 of the 3DP concrete mixture if it had to be delivered from 6 different sources.

The WTW analysis found that using local materials for the development of 3DP materials in construction can reduce polluting gas emissions by up to 75% and energy consumption by up to 70%.

Source of material	Greenhouse gases GHG (Tonnes)	Energy Consumption (Kilowatt/hours)
Mexico	6.7	24383
Argentina	26.1	93701
Italy	22	78793
Finland	23	83220
India	49.9	179883
Japan	34.8	124521

Table 2. Energy consumption and Greenhouse gases emissions

The WTW analysis reports can be found in appendix 1.

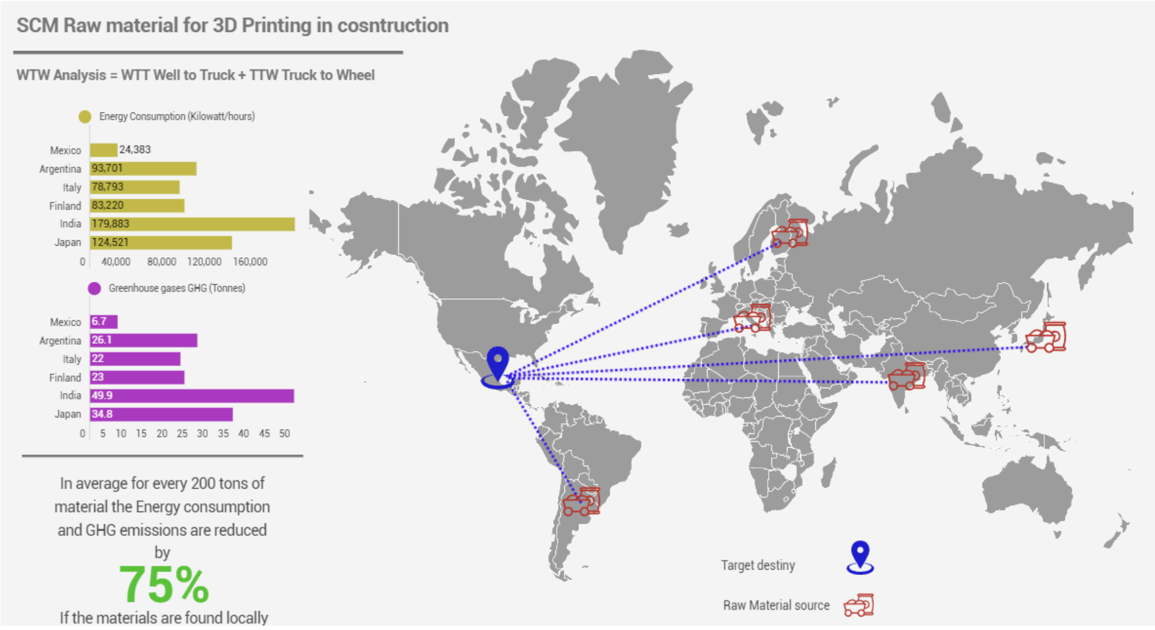

Figure 10. Energy consumption and Greenhouse gases emission

6 Conclusions

In conclusion, at the end of this research study, the proposed objectives have been met. First, according to the current composition of the concrete mixture that Hyperion Robotics works with, the availability of the basic materials needed for its elaboration and possible distribution in Mexico was evaluated. As a result, an illustrative map of the possible sources and major suppliers of the required materials was drawn up (Fig 8), some materials such as Metakaolin showed little presence in the Latin American market.

Second, together with Hyperion Robotics, a database of material suppliers (Table 1) required in Mexico was created in order to develop a sustainable supply chain for a construction project in Mexico using 3D concrete printing technology.

The research consisted of contacting suppliers of the required materials via email, phone calls and contact through their website.

During this research, it was noted that one of the difficulties in establishing a supplier database and consequently a supply chain is the lack of presence in the Mexican territories and the language barrier, as many suppliers required a Mexican business registration to deliver a materials quotation.

Third, the analysis of energy consumption and gas emissions shows that using a local supplier (Mexico) reduces Greenhouse Gas emissions and energy consumption by 75% compared with using suppliers from other countries (Argentina, Italy, India, Finland, Japan). This reduction is very significant and should be considered to improve the sustainability of the final product.

This means that local suppliers can be used, but due to the different technical specifications of the materials, additional validation should be performed by the materials research team at Hyperion Robotics before proceeding to apply the mixture for 3D concrete printing.

This topic applies to the subsequent creation of a green supply chain, expansion of supplier database and use of local materials depending on the construction site.

As with the Mexico project, more projects need to take a sustainable approach and start to reduce the impact on the environment as much as possible.

For future research, it is proposed to analyse the Energy consumption and Greenhouse gases emissions of the manufacturing process of 3D printed concrete elements to better understand the sustainability and eco-friendly approach of concrete 3D printing technology.

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Appendices

Appendix 1. Well-To-Wheel Analysis

EcoTransIT World

EcoTransIT World (Ecological Transport Information Tool for Worldwide Transports) calculates the environmental impacts for any freight transport service. EcoTransIT World provides energy consumption and GHG Emissions for trucks, trains, ships and airplanes in accordance with the European standard EN 16258:2012. Additionally carbon dioxide (CO2) and the most important air pollutants (nitrogen oxide, non-methane hydrocarbons, sulfur dioxide and particulates) can be calculated with EcoTransIT World. Below you will find all information about your transport service selected and data sources used as well as the results of your calculation.

General Information

Creation Date: 01.11.2022
Origin: [City district] [ar] Buenos Aires
Destination: [City district] [mx] Ciudad de México
Cargo weight: 200 ton (t/TEU: 10)

Detailed description of the calculated transport services

Transport service TS 1 - 12,158.46 km

Origin: [City district] [ar] Buenos Aires
Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 8.91 km
Via: [ar] Buenos Aires (UN/LOCODE: ARBUE)
Sea ship (BC Other global trade (35-120k dwt) General,LF: 55.0%,SR: 21%,Scac: null#) - 11,758.24 km
Via: [mx] Veracruz (UN/LOCODE: MXVER)
Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 391.3 km
Destination: [City district] [mx] Ciudad de México

Energy consumption and greenhouse gases (GHG) in accordance with EN 16258

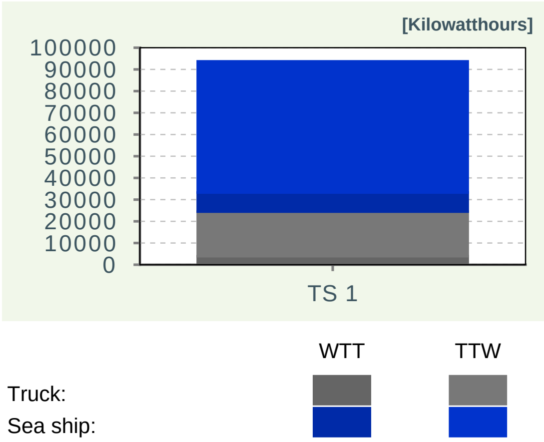
Energy consumption

WTW [Kilowatthours]

	TS 1
Truck	24,467
Sea ship	69,235
Sum	93,701

TTW [Kilowatthours]

	TS 1
Truck	20,554
Sea ship	60,432
Sum	80,986



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

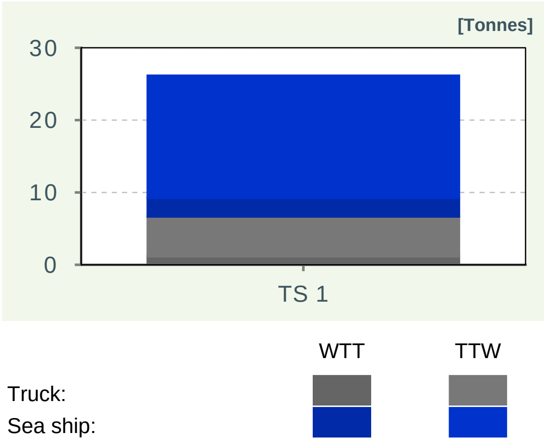
GHG emissions (calculated as CO2 equivalents)

WTW [Tonnes]

	TS 1
Truck	7
Sea ship	19
Sum	26

TTW [Tonnes]

	TS 1
Truck	6
Sea ship	17
Sum	22



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

These four results (TTW and WTW energy consumption and TTW and WTW GHG emissions) have been established according to the standard EN 16258:2012. Please consult this standard to get further information about processes not taken into account, guidelines and general principles. If you wish to make comparisons between these results and other results calculated in accordance with this standard, please take particular care to review the detailed methods used, especially allocation methods and data sources.

Your selected parameters for the calculation of energy consumption and greenhouse gas emissions (GHG emissions) in EcoTransIT World are displayed above in the detailed description of the transport services. The energy and GHG conversion factors (e.g. MJ or kg CO2 equivalent per litre diesel) for the EcoTransIT World calculation are taken from the appendix A of the standard EN 16258 without changes. For European trucks a biofuel share of 5 % is considered for diesel. For train transports the European standard does not contains specific energy and GHG conversion factors. Therefore EcoTransIT World uses own country specific conversion factors which are documented within the methodology report [http://www.ecotransit.org/basis.en.html].

For the allocation of energy consumption and GHG emissions to the individual transport services the parameter tonne-kilometre (tkm) is used. But the European standard allows also other allocation parameters if this is common for the transport mode considered. EcoTransIT World uses deviant allocation parameters for container ships (TEU-km) and ferries (number of decks and vehicle length). All data sources used for the calculation are documented at the appendix of this document. A comprehensive documentation of all data sources and default values aew used for EcoTransIT World as well a detailed description of the methodology can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html].

Carbon emissions and air pollutants

The European standard EN 16258 does not contain methodological guidelines for the calculation of CO_2 and air pollutants. For comparability with the results for energy consumption and GHG emissions the calculation of CO_2 and air pollutants is based on the same methodology as the European standard. Further information about the calculation approach used by EcoTransIT World for CO_2 and air pollutants can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html].

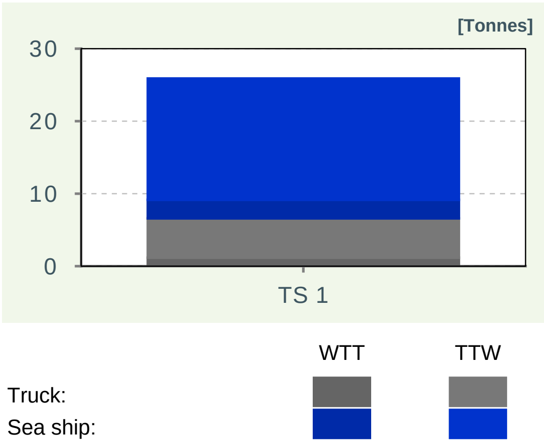
Carbon dioxide (CO2)

WTW [Tonnes]

	TS 1
Truck	7
Sea ship	19
Sum	26

TTW [Tonnes]

	TS 1
Truck	5
Sea ship	17
Sum	22



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

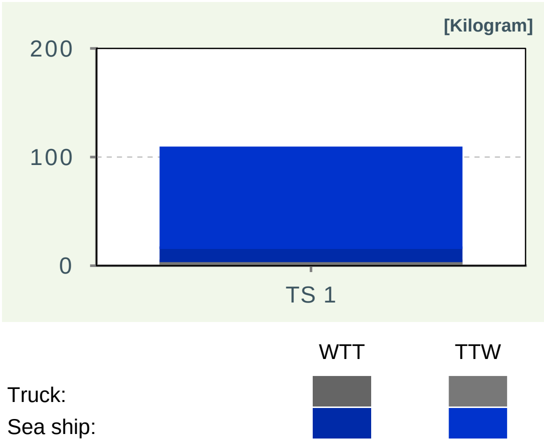
Sulfur dioxide (SO_2)

WTW [Kilogram]

	TS 1
Truck	4
Sea ship	104
Sum	108

TTW [Kilogram]

	TS 1
Truck	2
Sea ship	92
Sum	94



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

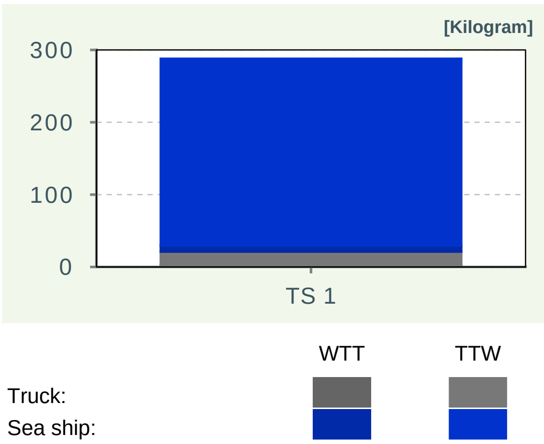
Nitrogen oxides (NOx)

WTW [Kilogram]

	TS 1
Truck	21
Sea ship	266
Sum	288

TTW [Kilogram]

	TS 1
Truck	18
Sea ship	258
Sum	276



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

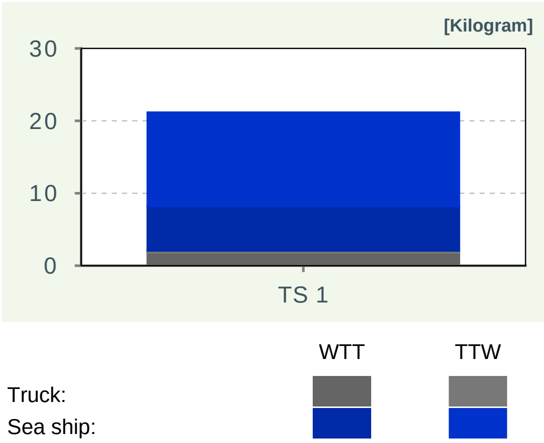
Non-methane hydrocarbon (NMHC)

WTW [Kilogram]

	TS 1
Truck	2
Sea ship	19
Sum	21

TTW [Kilogram]

	TS 1
Truck	0.3
Sea ship	12.9
Sum	13.2



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

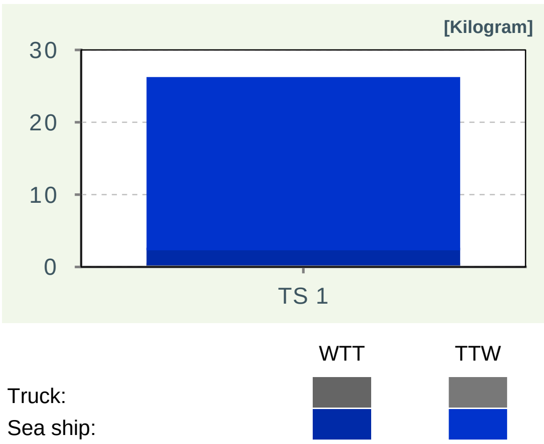
Particulate matter (PM10)

WTW [Kilogram]

	TS 1
Truck	0.4
Sea ship	25.7
Sum	26.1

TTW [Kilogram]

	TS 1
Truck	0.3
Sea ship	23.6
Sum	23.9



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

EcoTransIT World entries

Input mode:	Extended
Ferry routing:	Normal
Version ETW:	Unknown (Unknown)
Version data base:	etw_db_2022r6v1 (2022-10-31 22:10:17.000)

Appendix: Documentation of the data sources used (in accordance with EN 16258)

The following table summarizes in accordance with the standard EN 16258 the data categories (individual measured values, specific value of the shipper, fleet values of the shipper, default values) and data sources of default values used. A detailed description of the methodology, the data sources and the default values can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html]. If the user changed the default values of EcoTransIT World, it will be shown at the following table as Customer specific values.

	Truck	Train	Barge	Sea ship	Ferry	Airplane
General information						
Freight details: Weight, Unit, Amount TEU, t/TEU	Customer specific values	Customer specific values	Customer specific values	Customer specific values	Customer specific values	Customer specific values
Transport distance	Calculated with EcoTransIT (consideration of street type and topography)	Calculated with EcoTransIT (consideration of traction type, topography and line type)	Calculated with EcoTransIT (port-to-port distance, consideration of inland waterway classes)	Calculated with EcoTransIT (port-to-port distance, consideration of canal sizes)	Calculated with EcoTransIT (port-to-port distance)	Calculated with EcoTransIT (airport-to-airport distance)
Transport mode specific data						
Emission standards	Country specific emission standards based on analyses of ETW	No differentiation on emission standards (at diesel traction)	No differentiation on emission standards	No differentiation on emission standards	No differentiation on emission standards	Emission standard depends indirectly from the plane type
Load factor	Assumptions based on statistical data	Based on data from European railway companies	Assumptions based on statistical data	Based on data from UNCTAD Maritime Reviews	Assumptions based on statistical data	Data based on International Civil Aviation Organisation, DEFRA und aviation companies
Empty trip factor	Based on statistical data	Based on data frin European railway companies	Empty trips are considered within the load factor	No empty trips	No empty trips	No empty trips
Maximum payload	Europe: Handbook Emission Factors for Road Transport (HBEFA 3.2); USA: Department of Transport; Other countries: Application of HBEFA values	Results directly from the train type, based on the data of European railway companies	Vessel type depends on the river type and is automatically selected by ETW	Ship type depends on trade lane and is automatically selected by ETW	Data from Network for Transportation and Environment (NTM)	Based on specifications from IATA
Miscellaneous		Traction type: Electrified (Calculated by ETW according to the selected route)		Speed reduction: Analyses based on data from searate.com		Mix Bellyfreight/ freigter based on data from IATA

	Truck	Train	Barge	Sea ship	Ferry	Airplane
Fuel consumption						
Specific energy consumption (Diesel, Heavy fuel oil, Kerosene, Electricity)	Europe: Handbook Emission Factors for Road Transport (HBEFA 3.2), USA: Motor Vehicle Emission Simulator (MOVES), Other countries: Application of HBEFA values	Europe: Based on data of European railway companies; train types outside Europe: literature review	Based on own ETW calculation (compare methodology report)	Based on own ETW calculation (compare methodology report)	Average of the applied ferry type	Data from Small Emitters Tool of Eurocontrol
Share of biofuel	Europe: 5% biofuel content in conventional diesel; outside of Europe: biofuels aren't considered	no biofuel	no biofuel	no biofuel	no biofuel	no biofuel
Energy and GHG emission factors	EN 16258	Diesel: EN 16258 Electricity: ETW calculated based on Ecoinvent	EN 16258	EN 16258	EN 16258	EN 16258

EcoTransIT World

EcoTransIT World (Ecological Transport Information Tool for Worldwide Transports) calculates the environmental impacts for any freight transport service. EcoTransIT World provides energy consumption and GHG Emissions for trucks, trains, ships and airplanes in accordance with the European standard EN 16258:2012. Additionally carbon dioxide (CO2) and the most important air pollutants (nitrogen oxide, non-methane hydrocarbons, sulfur dioxide and particulates) can be calculated with EcoTransIT World. Below you will find all information about your transport service selected and data sources used as well as the results of your calculation.

General Information

Creation Date: 01.11.2022
Origin: [City district] [fi] Helsinki
Destination: [City district] [mx] Ciudad de México
Cargo weight: 200 ton (t/TEU: 10)

Detailed description of the calculated transport services

Transport service TS 1 - 11,335.13 km

Origin: [City district] [fi] Helsinki
Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 24.85 km
Via: [fi] Helsinki (UN/LOCODE: FIHEL)
Sea ship (BC Transatlantic trade (35-80k dwt) General,LF: 55.0%,SR: 21%,Scac: null#) - 10,918.96 km
Via: [mx] Veracruz (UN/LOCODE: MXVER)
Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 391.32 km
Destination: [City district] [mx] Ciudad de México

Energy consumption and greenhouse gases (GHG) in accordance with EN 16258

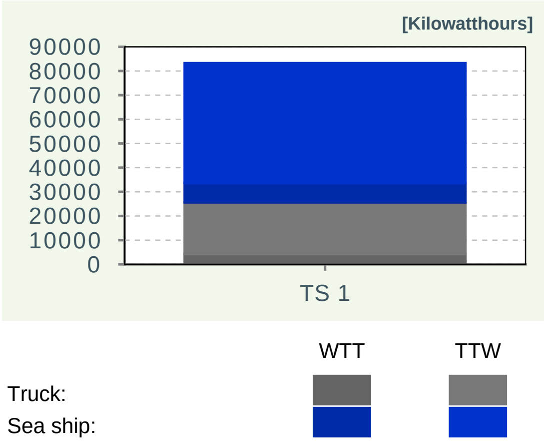
Energy consumption

WTW [Kilowatthours]

	TS 1
Truck	25,626
Sea ship	57,594
Sum	83,220

TTW [Kilowatthours]

	TS 1
Truck	21,379
Sea ship	49,629
Sum	71,008



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

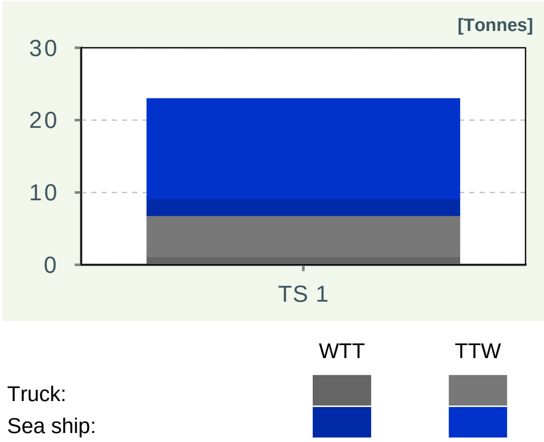
GHG emissions (calculated as CO2 equivalents)

WTW [Tonnes]

	TS 1
Truck	7
Sea ship	16
Sum	23

TTW [Tonnes]

	TS 1
Truck	6
Sea ship	14
Sum	19



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

These four results (TTW and WTW energy consumption and TTW and WTW GHG emissions) have been established according to the standard EN 16258:2012. Please consult this standard to get further information about processes not taken into account, guidelines and general principles. If you wish to make comparisons between these results and other results calculated in accordance with this standard, please take particular care to review the detailed methods used, especially allocation methods and data sources.

Your selected parameters for the calculation of energy consumption and greenhouse gas emissions (GHG emissions) in EcoTransIT World are displayed above in the detailed description of the transport services. The energy and GHG conversion factors (e.g. MJ or kg CO2 equivalent per litre diesel) for the EcoTransIT World calculation are taken from the appendix A of the standard EN 16258 without changes. For European trucks a biofuel share of 5 % is considered for diesel. For train transports the European standard does not contains specific energy and GHG conversion factors. Therefore EcoTransIT World uses own country specific conversion factors which are documented within the methodology report [http://www.ecotransit.org/basis.en.html].

For the allocation of energy consumption and GHG emissions to the individual transport services the parameter tonne-kilometre (tkm) is used. But the European standard allows also other allocation parameters if this is common for the transport mode considered. EcoTransIT World uses deviant allocation parameters for container ships (TEU-km) and ferries (number of decks and vehicle length). All data sources used for the calculation are documented at the appendix of this document. A comprehensive documentation of all data sources and default values aew used for EcoTransIT World as well a detailed description of the methodology can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html].

Carbon emissions and air pollutants

The European standard EN 16258 does not contain methodological guidelines for the calculation of CO2 and air pollutants. For comparability with the results for energy consumption and GHG emissions the calculation of CO2 and air pollutants is based on the same methodology as the European standard. Further information about the calculation approach used by EcoTransIT World for CO2 and air pollutants can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html].

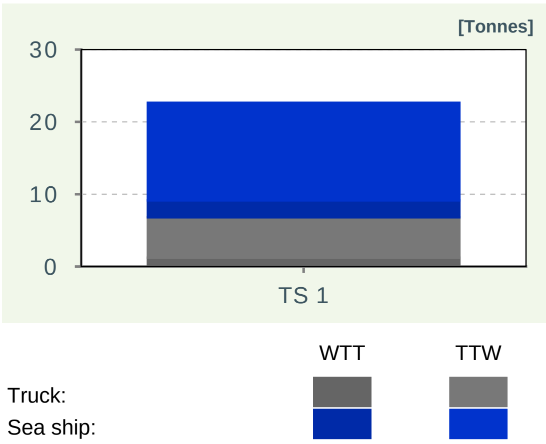
Carbon dioxide (CO2)

WTW [Tonnes]

	TS 1
Truck	7
Sea ship	16
Sum	23

TTW [Tonnes]

	TS 1
Truck	6
Sea ship	13
Sum	19



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

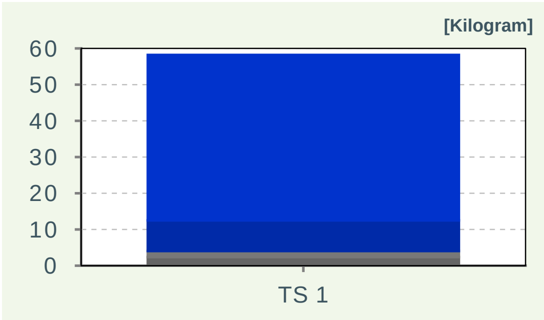
Sulfur dioxide (SO2)

WTW [Kilogram]

	TS 1
Truck	4
Sea ship	54
Sum	58

TTW [Kilogram]

	TS 1
Truck	2
Sea ship	46
Sum	47



WTT TTW
Truck:
Sea ship:

Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

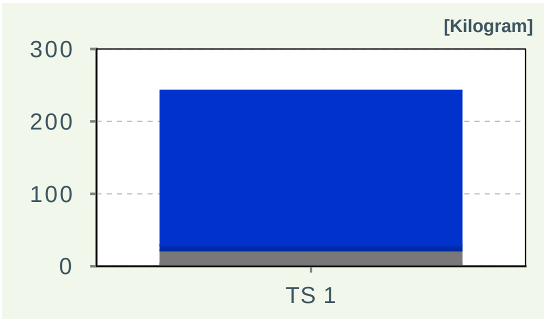
Nitrogen oxides (NOx)

WTW [Kilogram]

	TS 1
Truck	22
Sea ship	220
Sum	242

TTW [Kilogram]

	TS 1
Truck	19
Sea ship	213
Sum	232



WTT TTW
Truck:
Sea ship:

Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

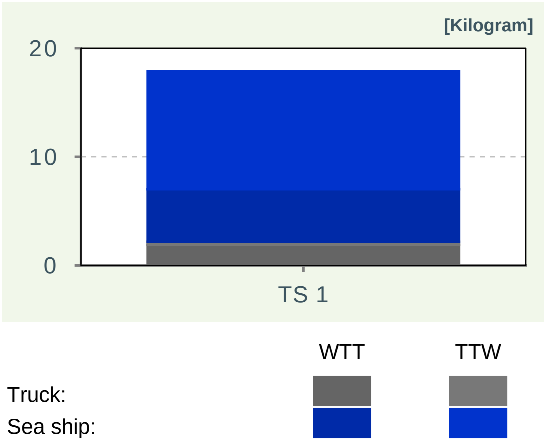
Non-methane hydrocarbon (NMHC)

WTW [Kilogram]

	TS 1
Truck	2
Sea ship	16
Sum	18

TTW [Kilogram]

	TS 1
Truck	0.3
Sea ship	10.9
Sum	11.1



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

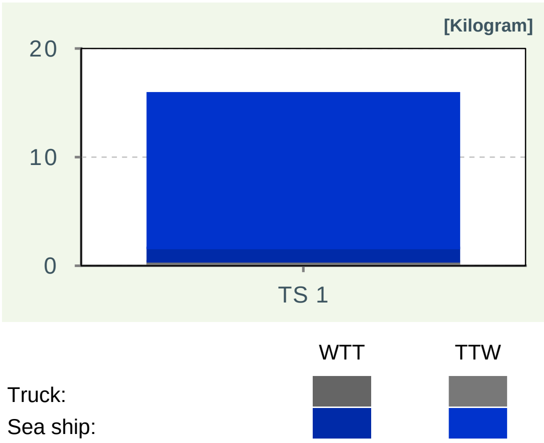
Particulate matter (PM10)

WTW [Kilogram]

	TS 1
Truck	0.4
Sea ship	15.5
Sum	15.9

TTW [Kilogram]

	TS 1
Truck	0.3
Sea ship	14.2
Sum	14.5



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

EcoTransIT World entries

Input mode:	Extended
Ferry routing:	Normal
Version ETW:	Unknown (Unknown)
Version data base:	etw_db_2022r6v1 (2022-10-31 22:10:17.000)

Appendix: Documentation of the data sources used (in accordance with EN 16258)

The following table summarizes in accordance with the standard EN 16258 the data categories (individual measured values, specific value of the shipper, fleet values of the shipper, default values) and data sources of default values used. A detailed description of the methodology, the data sources and the default values can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html]. If the user changed the default values of EcoTransIT World, it will be shown at the following table as Customer specific values.

	Truck	Train	Barge	Sea ship	Ferry	Airplane
General information						
Freight details: Weight, Unit, Amount TEU, t/TEU	Customer specific values	Customer specific values	Customer specific values	Customer specific values	Customer specific values	Customer specific values
Transport distance	Calculated with EcoTransIT (consideration of street type and topography)	Calculated with EcoTransIT (consideration of traction type, topography and line type)	Calculated with EcoTransIT (port-to-port distance, consideration of inland waterway classes)	Calculated with EcoTransIT (port-to-port distance, consideration of canal sizes)	Calculated with EcoTransIT (port-to-port distance)	Calculated with EcoTransIT (airport-to-airport distance)
Transport mode specific data						
Emission standards	Country specific emission standards based on analyses of ETW	No differentiation on emission standards (at diesel traction)	No differentiation on emission standards	No differentiation on emission standards	No differentiation on emission standards	Emission standard depends indirectly from the plane type
Load factor	Assumptions based on statistical data	Based on data from European railway companies	Assumptions based on statistical data	Based on data from UNCTAD Maritime Reviews	Assumptions based on statistical data	Data based on International Civil Aviation Organisation, DEFRA und aviation companies
Empty trip factor	Based on statistical data	Based on data frin European railway companies	Empty trips are considered within the load factor	No empty trips	No empty trips	No empty trips
Maximum payload	Europe: Handbook Emission Factors for Road Transport (HBEFA 3.2); USA: Department of Transport; Other countries: Application of HBEFA values	Results directly from the train type, based on the data of European railway companies	Vessel type depends on the river type and is automatically selected by ETW	Ship type depends on trade lane and is automatically selected by ETW	Data from Network for Transportation and Environment (NTM)	Based on specifications from IATA
Miscellaneous		Traction type: Electrified (Calculated by ETW according to the selected route)		Speed reduction: Analyses based on data from searate.com		Mix Bellyfreight/ freigter based on data from IATA

	Truck	Train	Barge	Sea ship	Ferry	Airplane
Fuel consumption						
Specific energy consumption (Diesel, Heavy fuel oil, Kerosene, Electricity)	Europe: Handbook Emission Factors for Road Transport (HBEFA 3.2), USA: Motor Vehicle Emission Simulator (MOVES), Other countries: Application of HBEFA values	Europe: Based on data of European railway companies; train types outside Europe: literature review	Based on own ETW calculation (compare methodology report)	Based on own ETW calculation (compare methodology report)	Average of the applied ferry type	Data from Small Emitters Tool of Eurocontrol
Share of biofuel	Europe: 5% biofuel content in conventional diesel; outside of Europe: biofuels aren't considered	no biofuel	no biofuel	no biofuel	no biofuel	no biofuel
Energy and GHG emission factors	EN 16258	Diesel: EN 16258 Electricity: ETW calculated based on Ecoinvent	EN 16258	EN 16258	EN 16258	EN 16258

EcoTransIT World

EcoTransIT World (Ecological Transport Information Tool for Worldwide Transports) calculates the environmental impacts for any freight transport service. EcoTransIT World provides energy consumption and GHG Emissions for trucks, trains, ships and airplanes in accordance with the European standard EN 16258:2012. Additionally carbon dioxide (CO2) and the most important air pollutants (nitrogen oxide, non-methane hydrocarbons, sulfur dioxide and particulates) can be calculated with EcoTransIT World. Below you will find all information about your transport service selected and data sources used as well as the results of your calculation.

General Information

Creation Date: 01.11.2022
Origin: [City district] [in] Jawaharnagar
Destination: [City district] [mx] Ciudad de México
Cargo weight: 200 ton (t/TEU: 10)

Detailed description of the calculated transport services

Transport service TS 1 - 19,373.66 km

Origin: [City district] [in] Jawaharnagar
Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 830.36 km
Via: [in] Hazira (UN/LOCODE: INHZR)
Sea ship (BC Other global trade (35-120k dwt) General,LF: 55.0%,SR: 21%,Scac: null#) - 18,152 km
Via: [mx] Veracruz (UN/LOCODE: MXVER)
Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 391.3 km
Destination: [City district] [mx] Ciudad de México

Energy consumption and greenhouse gases (GHG) in accordance with EN 16258

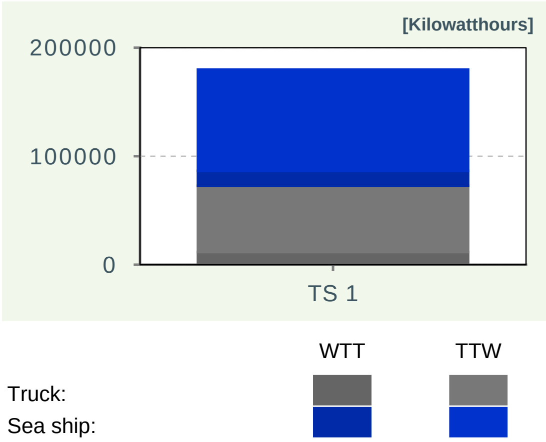
Energy consumption

WTW [Kilowatthours]

	TS 1
Truck	72,878
Sea ship	107,005
Sum	179,883

TTW [Kilowatthours]

	TS 1
Truck	61,223
Sea ship	93,352
Sum	154,575



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

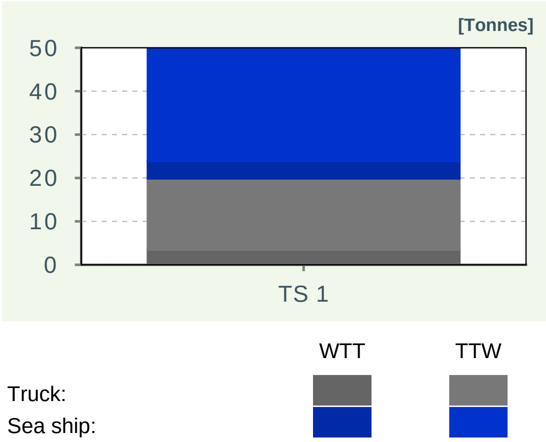
GHG emissions (calculated as CO2 equivalents)

WTW [Tonnes]

	TS 1
Truck	20
Sea ship	30
Sum	50

TTW [Tonnes]

	TS 1
Truck	16
Sea ship	26
Sum	42



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

These four results (TTW and WTW energy consumption and TTW and WTW GHG emissions) have been established according to the standard EN 16258:2012. Please consult this standard to get further information about processes not taken into account, guidelines and general principles. If you wish to make comparisons between these results and other results calculated in accordance with this standard, please take particular care to review the detailed methods used, especially allocation methods and data sources.

Your selected parameters for the calculation of energy consumption and greenhouse gas emissions (GHG emissions) in EcoTransIT World are displayed above in the detailed description of the transport services. The energy and GHG conversion factors (e.g. MJ or kg CO2 equivalent per litre diesel) for the EcoTransIT World calculation are taken from the appendix A of the standard EN 16258 without changes. For European trucks a biofuel share of 5 % is considered for diesel. For train transports the European standard does not contains specific energy and GHG conversion factors. Therefore EcoTransIT World uses own country specific conversion factors which are documented within the methodology report [http://www.ecotransit.org/basis.en.html].

For the allocation of energy consumption and GHG emissions to the individual transport services the parameter tonne-kilometre (tkm) is used. But the European standard allows also other allocation parameters if this is common for the transport mode considered. EcoTransIT World uses deviant allocation parameters for container ships (TEU-km) and ferries (number of decks and vehicle length). All data sources used for the calculation are documented at the appendix of this document. A comprehensive documentation of all data sources and default values aew used for EcoTransIT World as well a detailed description of the methodology can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html].

Carbon emissions and air pollutants

The European standard EN 16258 does not contain methodological guidelines for the calculation of CO_2 and air pollutants. For comparability with the results for energy consumption and GHG emissions the calculation of CO_2 and air pollutants is based on the same methodology as the European standard. Further information about the calculation approach used by EcoTransIT World for CO_2 and air pollutants can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html].

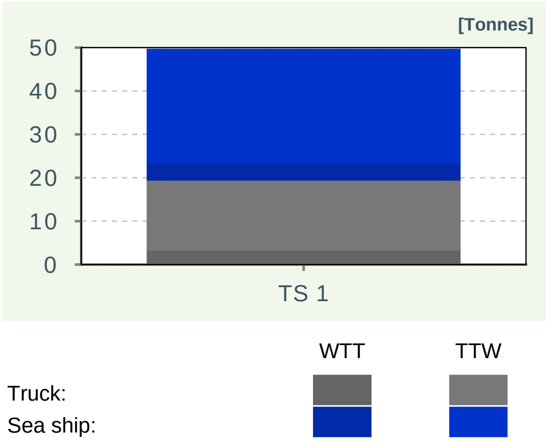
Carbon dioxide (CO_2)

WTW [Tonnes]

	TS 1
Truck	20
Sea ship	30
Sum	49

TTW [Tonnes]

	TS 1
Truck	16
Sea ship	26
Sum	42



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

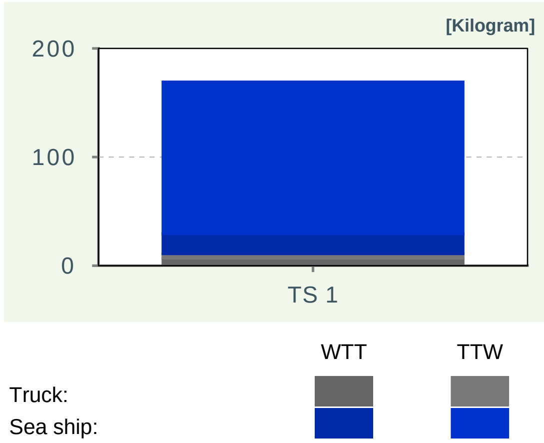
Sulfur dioxide (SO2)

WTW [Kilogram]

	TS 1
Truck	11
Sea ship	158
Sum	169

TTW [Kilogram]

	TS 1
Truck	4
Sea ship	140
Sum	144



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

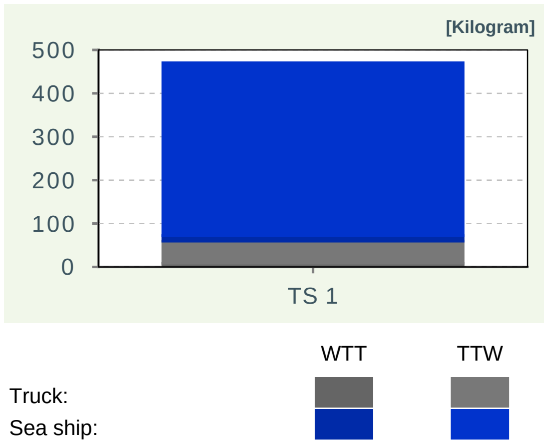
Nitrogen oxides (NOx)

WTW [Kilogram]

	TS 1
Truck	59
Sea ship	411
Sum	471

TTW [Kilogram]

	TS 1
Truck	51
Sea ship	398
Sum	449



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

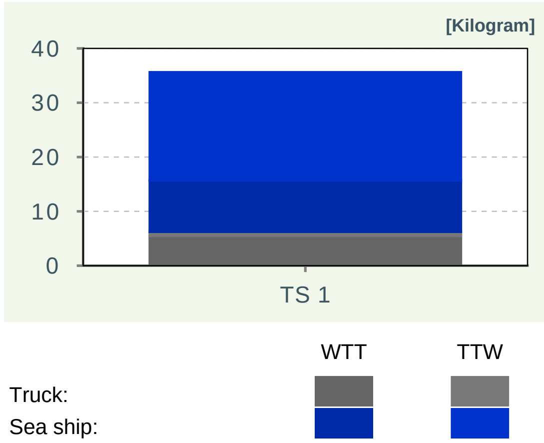
Non-methane hydrocarbon (NMHC)

WTW [Kilogram]

	TS 1
Truck	6
Sea ship	29
Sum	36

TTW [Kilogram]

	TS 1
Truck	0.8
Sea ship	19.9
Sum	20.7



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

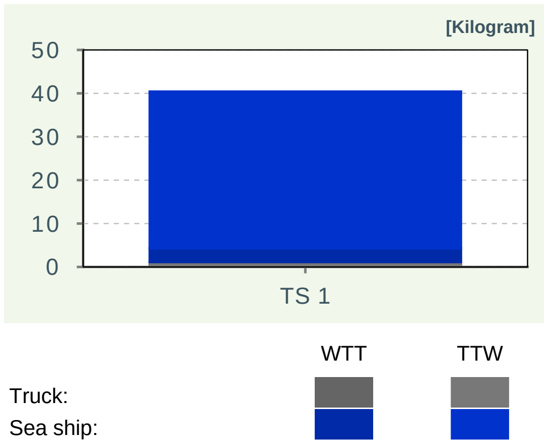
Particulate matter (PM10)

WTW [Kilogram]

	TS 1
Truck	1
Sea ship	39
Sum	40

TTW [Kilogram]

	TS 1
Truck	0.8
Sea ship	36.1
Sum	36.9



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

EcoTransIT World entries

Input mode:	Extended
Ferry routing:	Normal
Version ETW:	Unknown (Unknown)
Version data base:	etw_db_2022r6v1 (2022-10-31 22:10:17.000)

Appendix: Documentation of the data sources used (in accordance with EN 16258)

The following table summarizes in accordance with the standard EN 16258 the data categories (individual measured values, specific value of the shipper, fleet values of the shipper, default values) and data sources of default values used. A detailed description of the methodology, the data sources and the default values can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html]. If the user changed the default values of EcoTransIT World, it will be shown at the following table as Customer specific values.

	Truck	Train	Barge	Sea ship	Ferry	Airplane
General information						
Freight details: Weight, Unit, Amount TEU, t/TEU	Customer specific values	Customer specific values	Customer specific values	Customer specific values	Customer specific values	Customer specific values
Transport distance	Calculated with EcoTransIT (consideration of street type and topography)	Calculated with EcoTransIT (consideration of traction type, topography and line type)	Calculated with EcoTransIT (port-to-port distance, consideration of inland waterway classes)	Calculated with EcoTransIT (port-to-port distance, consideration of canal sizes)	Calculated with EcoTransIT (port-to-port distance)	Calculated with EcoTransIT (airport-to-airport distance)
Transport mode specific data						
Emission standards	Country specific emission standards based on analyses of ETW	No differentiation on emission standards (at diesel traction)	No differentiation on emission standards	No differentiation on emission standards	No differentiation on emission standards	Emission standard depends indirectly from the plane type
Load factor	Assumptions based on statistical data	Based on data from European railway companies	Assumptions based on statistical data	Based on data from UNCTAD Maritime Reviews	Assumptions based on statistical data	Data based on International Civil Aviation Organisation, DEFRA und aviation companies
Empty trip factor	Based on statistical data	Based on data frin European railway companies	Empty trips are considered within the load factor	No empty trips	No empty trips	No empty trips
Maximum payload	Europe: Handbook Emission Factors for Road Transport (HBEFA 3.2); USA: Department of Transport; Other countries: Application of HBEFA values	Results directly from the train type, based on the data of European railway companies	Vessel type depends on the river type and is automatically selected by ETW	Ship type depends on trade lane and is automatically selected by ETW	Data from Network for Transportation and Environment (NTM)	Based on specifications from IATA
Miscellaneous		Traction type: Electrified (Calculated by ETW according to the selected route)		Speed reduction: Analyses based on data from searate.com		Mix Bellyfreight/ freigter based on data from IATA

	Truck	Train	Barge	Sea ship	Ferry	Airplane
Fuel consumption						
Specific energy consumption (Diesel, Heavy fuel oil, Kerosene, Electricity)	Europe: Handbook Emission Factors for Road Transport (HBEFA 3.2), USA: Motor Vehicle Emission Simulator (MOVES), Other countries: Application of HBEFA values	Europe: Based on data of European railway companies; train types outside Europe: literature review	Based on own ETW calculation (compare methodology report)	Based on own ETW calculation (compare methodology report)	Average of the applied ferry type	Data from Small Emitters Tool of Eurocontrol
Share of biofuel	Europe: 5% biofuel content in conventional diesel; outside of Europe: biofuels aren't considered	no biofuel	no biofuel	no biofuel	no biofuel	no biofuel
Energy and GHG emission factors	EN 16258	Diesel: EN 16258 Electricity: ETW calculated based on Ecoinvent	EN 16258	EN 16258	EN 16258	EN 16258

EcoTransIT World

EcoTransIT World (Ecological Transport Information Tool for Worldwide Transports) calculates the environmental impacts for any freight transport service. EcoTransIT World provides energy consumption and GHG Emissions for trucks, trains, ships and airplanes in accordance with the European standard EN 16258:2012. Additionally carbon dioxide (CO2) and the most important air pollutants (nitrogen oxide, non-methane hydrocarbons, sulfur dioxide and particulates) can be calculated with EcoTransIT World. Below you will find all information about your transport service selected and data sources used as well as the results of your calculation.

General Information

Creation Date: 01.11.2022
Origin: [City district] [jp] Tokyo
Destination: [City district] [mx] Ciudad de México
Cargo weight: 200 ton (t/TEU: 10)

Detailed description of the calculated transport services

Transport service TS 1 - 17,369.4 km

Origin: [City district] [jp] Tokyo

Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 10.67 km

Via: [jp] Tokyo (UN/LOCODE: JPTYO)

Sea ship (BC Other global trade (35-120k dwt) General,LF: 55.0%,SR: 21%,Scac: null#) - 16,967.43 km

Via: [mx] Veracruz (UN/LOCODE: MXVER)

Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 391.3 km

Destination: [City district] [mx] Ciudad de México

Energy consumption and greenhouse gases (GHG) in accordance with EN 16258

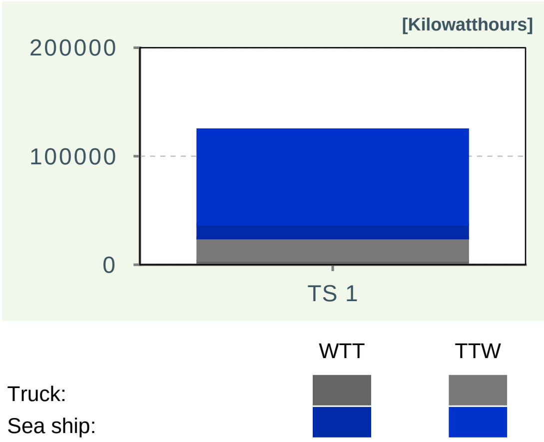
Energy consumption

WTW [Kilowatthours]

	TS 1
Truck	24,541
Sea ship	99,907
Sum	124,448

TTW [Kilowatthours]

	TS 1
Truck	20,616
Sea ship	87,205
Sum	107,821



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

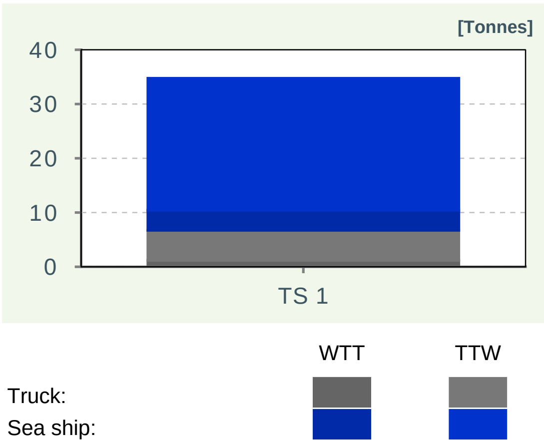
GHG emissions (calculated as CO2 equivalents)

WTW [Tonnes]

	TS 1
Truck	7
Sea ship	28
Sum	35

TTW [Tonnes]

	TS 1
Truck	6
Sea ship	24
Sum	30



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

These four results (TTW and WTW energy consumption and TTW and WTW GHG emissions) have been established according to the standard EN 16258:2012. Please consult this standard to get further information about processes not taken into account, guidelines and general principles. If you wish to make comparisons between these results and other results calculated in accordance with this standard, please take particular care to review the detailed methods used, especially allocation methods and data sources.

Your selected parameters for the calculation of energy consumption and greenhouse gas emissions (GHG emissions) in EcoTransIT World are displayed above in the detailed description of the transport services. The energy and GHG conversion factors (e.g. MJ or kg CO2 equivalent per litre diesel) for the EcoTransIT World calculation are taken from the appendix A of the standard EN 16258 without changes. For European trucks a biofuel share of 5 % is considered for diesel. For train transports the European standard does not contains specific energy and GHG conversion factors. Therefore EcoTransIT World uses own country specific conversion factors which are documented within the methodology report [http://www.ecotransit.org/basis.en.html].

For the allocation of energy consumption and GHG emissions to the individual transport services the parameter tonne-kilometre (tkm) is used. But the European standard allows also other allocation parameters if this is common for the transport mode considered. EcoTransIT World uses deviant allocation parameters for container ships (TEU-km) and ferries (number of decks and vehicle length). All data sources used for the calculation are documented at the appendix of this document. A comprehensive documentation of all data sources and default values aew used for EcoTransIT World as well a detailed description of the methodology can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html].

Carbon emissions and air pollutants

The European standard EN 16258 does not contain methodological guidelines for the calculation of CO_2 and air pollutants. For comparability with the results for energy consumption and GHG emissions the calculation of CO_2 and air pollutants is based on the same methodology as the European standard. Further information about the calculation approach used by EcoTransIT World for CO_2 and air pollutants can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html].

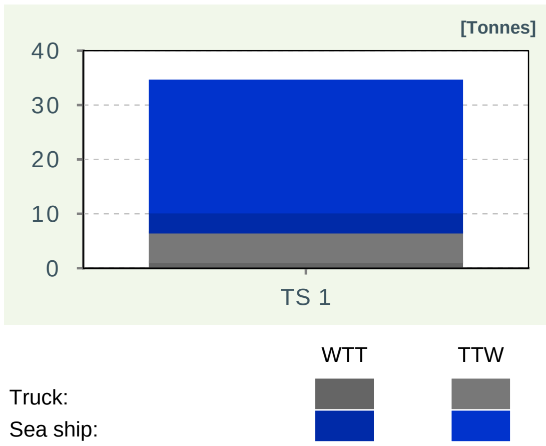
Carbon dioxide (CO_2)

WTW [Tonnes]

	TS 1
Truck	7
Sea ship	28
Sum	34

TTW [Tonnes]

	TS 1
Truck	5
Sea ship	24
Sum	30



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

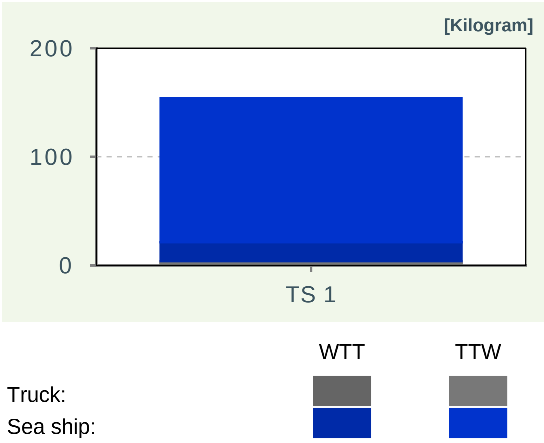
Sulfur dioxide (SO2)

WTW [Kilogram]

	TS 1
Truck	4
Sea ship	150
Sum	154

TTW [Kilogram]

	TS 1
Truck	2
Sea ship	133
Sum	134



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

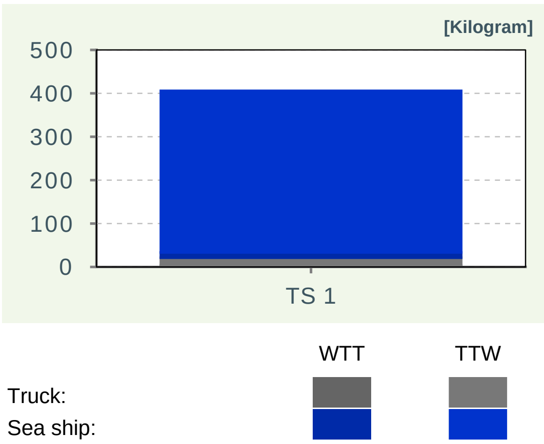
Nitrogen oxides (NOx)

WTW [Kilogram]

	TS 1
Truck	21
Sea ship	384
Sum	406

TTW [Kilogram]

	TS 1
Truck	18
Sea ship	372
Sum	391



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

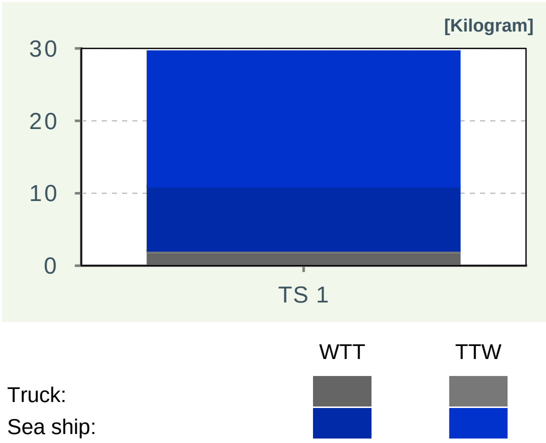
Non-methane hydrocarbon (NMHC)

WTW [Kilogram]

	TS 1
Truck	2
Sea ship	27
Sum	30

TTW [Kilogram]

	TS 1
Truck	0.3
Sea ship	18.6
Sum	18.9



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

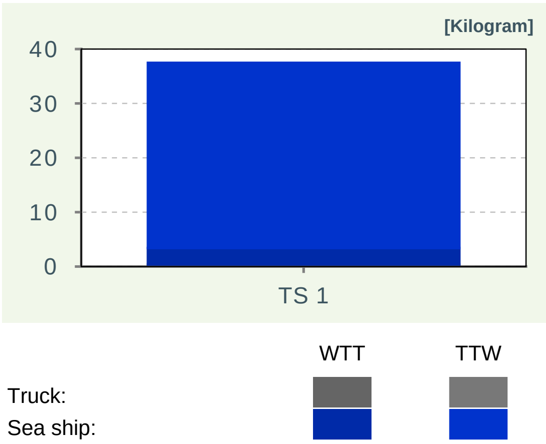
Particulate matter (PM10)

WTW [Kilogram]

	TS 1
Truck	0.4
Sea ship	37.1
Sum	37.5

TTW [Kilogram]

	TS 1
Truck	0.3
Sea ship	34.1
Sum	34.3



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

EcoTransIT World entries

Input mode:	Extended
Ferry routing:	Normal
Version ETW:	Unknown (Unknown)
Version data base:	etw_db_2022r6v1 (2022-10-31 22:10:17.000)

Appendix: Documentation of the data sources used (in accordance with EN 16258)

The following table summarizes in accordance with the standard EN 16258 the data categories (individual measured values, specific value of the shipper, fleet values of the shipper, default values) and data sources of default values used. A detailed description of the methodology, the data sources and the default values can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html]. If the user changed the default values of EcoTransIT World, it will be shown at the following table as Customer specific values.

	Truck	Train	Barge	Sea ship	Ferry	Airplane
General information						
Freight details: Weight, Unit, Amount TEU, t/TEU	Customer specific values	Customer specific values	Customer specific values	Customer specific values	Customer specific values	Customer specific values
Transport distance	Calculated with EcoTransIT (consideration of street type and topography)	Calculated with EcoTransIT (consideration of traction type, topography and line type)	Calculated with EcoTransIT (port-to-port distance, consideration of inland waterway classes)	Calculated with EcoTransIT (port-to-port distance, consideration of canal sizes)	Calculated with EcoTransIT (port-to-port distance)	Calculated with EcoTransIT (airport-to-airport distance)
Transport mode specific data						
Emission standards	Country specific emission standards based on analyses of ETW	No differentiation on emission standards (at diesel traction)	No differentiation on emission standards	No differentiation on emission standards	No differentiation on emission standards	Emission standard depends indirectly from the plane type
Load factor	Assumptions based on statistical data	Based on data from European railway companies	Assumptions based on statistical data	Based on data from UNCTAD Maritime Reviews	Assumptions based on statistical data	Data based on International Civil Aviation Organisation, DEFRA und aviation companies
Empty trip factor	Based on statistical data	Based on data frin European railway companies	Empty trips are considered within the load factor	No empty trips	No empty trips	No empty trips
Maximum payload	Europe: Handbook Emission Factors for Road Transport (HBEFA 3.2); USA: Department of Transport; Other countries: Application of HBEFA values	Results directly from the train type, based on the data of European railway companies	Vessel type depends on the river type and is automatically selected by ETW	Ship type depends on trade lane and is automatically selected by ETW	Data from Network for Transportation and Environment (NTM)	Based on specifications from IATA
Miscellaneous		Traction type: Electrified (Calculated by ETW according to the selected route)		Speed reduction: Analyses based on data from searate.com		Mix Bellyfreight/ freigter based on data from IATA

	Truck	Train	Barge	Sea ship	Ferry	Airplane
Fuel consumption						
Specific energy consumption (Diesel, Heavy fuel oil, Kerosene, Electricity)	Europe: Handbook Emission Factors for Road Transport (HBEFA 3.2), USA: Motor Vehicle Emission Simulator (MOVES), Other countries: Application of HBEFA values	Europe: Based on data of European railway companies; train types outside Europe: literature review	Based on own ETW calculation (compare methodology report)	Based on own ETW calculation (compare methodology report)	Average of the applied ferry type	Data from Small Emitters Tool of Eurocontrol
Share of biofuel	Europe: 5% biofuel content in conventional diesel; outside of Europe: biofuels aren't considered	no biofuel	no biofuel	no biofuel	no biofuel	no biofuel
Energy and GHG emission factors	EN 16258	Diesel: EN 16258 Electricity: ETW calculated based on Ecoinvent	EN 16258	EN 16258	EN 16258	EN 16258

EcoTransIT World

EcoTransIT World (Ecological Transport Information Tool for Worldwide Transports) calculates the environmental impacts for any freight transport service. EcoTransIT World provides energy consumption and GHG Emissions for trucks, trains, ships and airplanes in accordance with the European standard EN 16258:2012. Additionally carbon dioxide (CO2) and the most important air pollutants (nitrogen oxide, non-methane hydrocarbons, sulfur dioxide and particulates) can be calculated with EcoTransIT World. Below you will find all information about your transport service selected and data sources used as well as the results of your calculation.

General Information

Creation Date:	01.11.2022
Origin:	[City district] [ar] Buenos Aires
Destination:	[City district] [mx] Ciudad de México
Cargo weight:	200 ton (t/TEU: 10)

Detailed description of the calculated transport services

Transport service TS 1 - 12,158.46 km

Origin: [City district] [ar] Buenos Aires

Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 8.91 km

Via: [ar] Buenos Aires (UN/LOCODE: ARBUE)

Sea ship (BC Other global trade (35-120k dwt) General,LF: 55.0%,SR: 21%,Scac: null#) - 11,758.24 km

Via: [mx] Veracruz (UN/LOCODE: MXVER)

Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 391.3 km

Destination: [City district] [mx] Ciudad de México

Energy consumption and greenhouse gases (GHG) in accordance with EN 16258

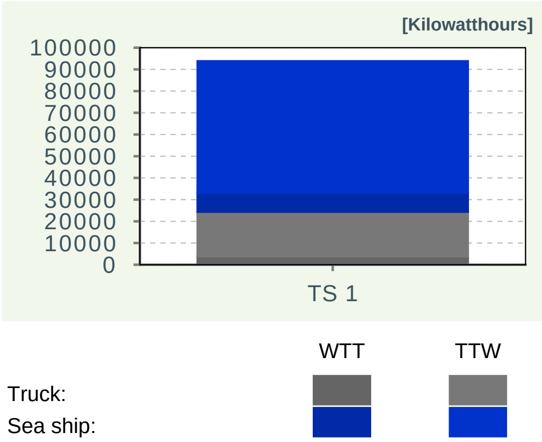
Energy consumption

WTW [Kilowatthours]

	TS 1
Truck	24,467
Sea ship	69,235
Sum	93,701

TTW [Kilowatthours]

	TS 1
Truck	20,554
Sea ship	60,432
Sum	80,986



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

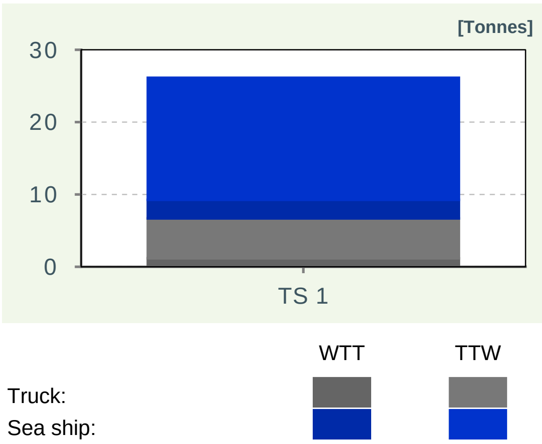
GHG emissions (calculated as CO2 equivalents)

WTW [Tonnes]

	TS 1
Truck	7
Sea ship	19
Sum	26

TTW [Tonnes]

	TS 1
Truck	6
Sea ship	17
Sum	22



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

These four results (TTW and WTW energy consumption and TTW and WTW GHG emissions) have been established according to the standard EN 16258:2012. Please consult this standard to get further information about processes not taken into account, guidelines and general principles. If you wish to make comparisons between these results and other results calculated in accordance with this standard, please take particular care to review the detailed methods used, especially allocation methods and data sources.

Your selected parameters for the calculation of energy consumption and greenhouse gas emissions (GHG emissions) in EcoTransIT World are displayed above in the detailed description of the transport services. The energy and GHG conversion factors (e.g. MJ or kg CO2 equivalent per litre diesel) for the EcoTransIT World calculation are taken from the appendix A of the standard EN 16258 without changes. For European trucks a biofuel share of 5 % is considered for diesel. For train transports the European standard does not contains specific energy and GHG conversion factors. Therefore EcoTransIT World uses own country specific conversion factors which are documented within the methodology report [http://www.ecotransit.org/basis.en.html].

For the allocation of energy consumption and GHG emissions to the individual transport services the parameter tonne-kilometre (tkm) is used. But the European standard allows also other allocation parameters if this is common for the transport mode considered. EcoTransIT World uses deviant allocation parameters for container ships (TEU-km) and ferries (number of decks and vehicle length). All data sources used for the calculation are documented at the appendix of this document. A comprehensive documentation of all data sources and default values aew used for EcoTransIT World as well a detailed description of the methodology can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html].

Carbon emissions and air pollutants

The European standard EN 16258 does not contain methodological guidelines for the calculation of CO2 and air pollutants. For comparability with the results for energy consumption and GHG emissions the calculation of CO2 and air pollutants is based on the same methodology as the European standard. Further information about the calculation approach used by EcoTransIT World for CO2 and air pollutants can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html].

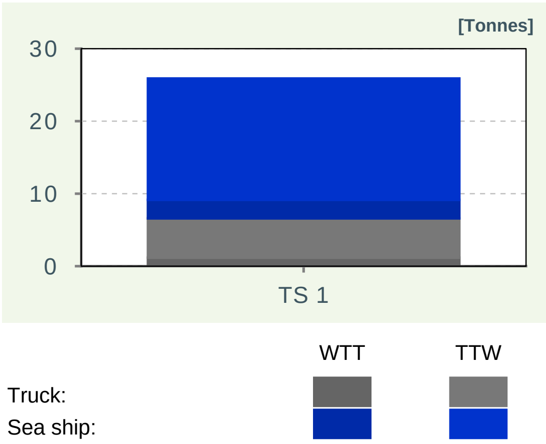
Carbon dioxide (CO2)

WTW [Tonnes]

	TS 1
Truck	7
Sea ship	19
Sum	26

TTW [Tonnes]

	TS 1
Truck	5
Sea ship	17
Sum	22



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

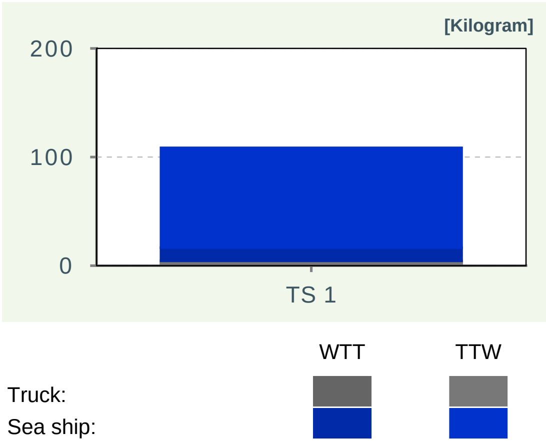
Sulfur dioxide (SO2)

WTW [Kilogram]

	TS 1
Truck	4
Sea ship	104
Sum	108

TTW [Kilogram]

	TS 1
Truck	2
Sea ship	92
Sum	94



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

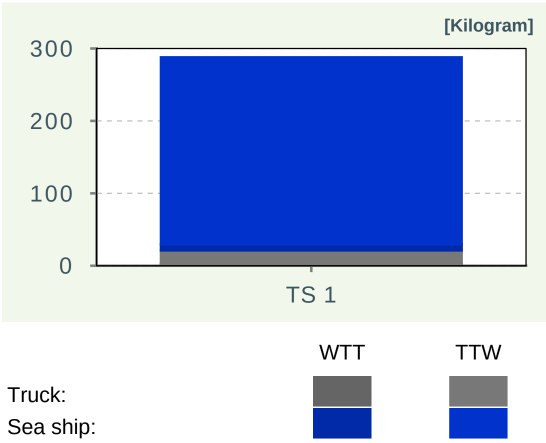
Nitrogen oxides (NOx)

WTW [Kilogram]

	TS 1
Truck	21
Sea ship	266
Sum	288

TTW [Kilogram]

	TS 1
Truck	18
Sea ship	258
Sum	276



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

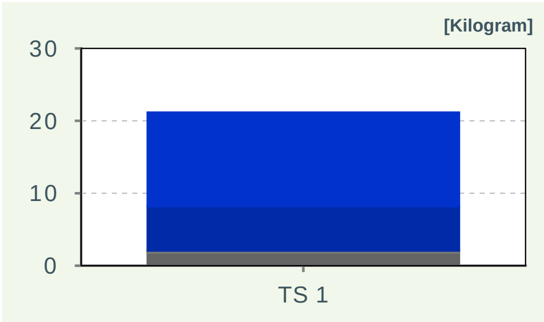
Non-methane hydrocarbon (NMHC)

WTW [Kilogram]

	TS 1
Truck	2
Sea ship	19
Sum	21

TTW [Kilogram]

	TS 1
Truck	0.3
Sea ship	12.9
Sum	13.2



WTT TTW
Truck:
Sea ship:

Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

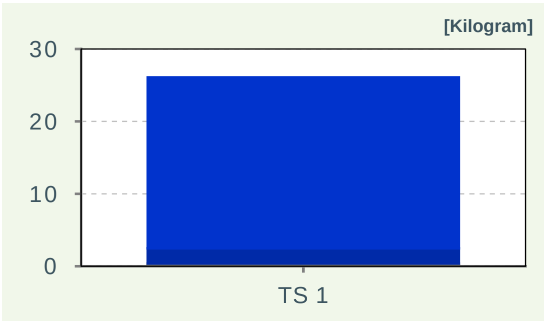
Particulate matter (PM10)

WTW [Kilogram]

	TS 1
Truck	0.4
Sea ship	25.7
Sum	26.1

TTW [Kilogram]

	TS 1
Truck	0.3
Sea ship	23.6
Sum	23.9



WTT TTW
Truck:
Sea ship:

Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

EcoTransIT World entries

Input mode:	Extended
Ferry routing:	Normal
Version ETW:	Unknown (Unknown)
Version data base:	etw_db_2022r6v1 (2022-10-31 22:10:17.000)

Appendix: Documentation of the data sources used (in accordance with EN 16258)

The following table summarizes in accordance with the standard EN 16258 the data categories (individual measured values, specific value of the shipper, fleet values of the shipper, default values) and data sources of default values used. A detailed description of the methodology, the data sources and the default values can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html]. If the user changed the default values of EcoTransIT World, it will be shown at the following table as Customer specific values.

	Truck	Train	Barge	Sea ship	Ferry	Airplane
General information						
Freight details: Weight, Unit, Amount TEU, t/TEU	Customer specific values	Customer specific values	Customer specific values	Customer specific values	Customer specific values	Customer specific values
Transport distance	Calculated with EcoTransIT (consideration of street type and topography)	Calculated with EcoTransIT (consideration of traction type, topography and line type)	Calculated with EcoTransIT (port-to-port distance, consideration of inland waterway classes)	Calculated with EcoTransIT (port-to-port distance, consideration of canal sizes)	Calculated with EcoTransIT (port-to-port distance)	Calculated with EcoTransIT (airport-to-airport distance)
Transport mode specific data						
Emission standards	Country specific emission standards based on analyses of ETW	No differentiation on emission standards (at diesel traction)	No differentiation on emission standards	No differentiation on emission standards	No differentiation on emission standards	Emission standard depends indirectly from the plane type
Load factor	Assumptions based on statistical data	Based on data from European railway companies	Assumptions based on statistical data	Based on data from UNCTAD Maritime Reviews	Assumptions based on statistical data	Data based on International Civil Aviation Organisation, DEFRA und aviation companies
Empty trip factor	Based on statistical data	Based on data frin European railway companies	Empty trips are considered within the load factor	No empty trips	No empty trips	No empty trips
Maximum payload	Europe: Handbook Emission Factors for Road Transport (HBEFA 3.2); USA: Department of Transport; Other countries: Application of HBEFA values	Results directly from the train type, based on the data of European railway companies	Vessel type depends on the river type and is automatically selected by ETW	Ship type depends on trade lane and is automatically selected by ETW	Data from Network for Transportation and Environment (NTM)	Based on specifications from IATA
Miscellaneous		Traction type: Electrified (Calculated by ETW according to the selected route)		Speed reduction: Analyses based on data from searate.com		Mix Bellyfreight/ freigter based on data from IATA

	Truck	Train	Barge	Sea ship	Ferry	Airplane
Fuel consumption						
Specific energy consumption (Diesel, Heavy fuel oil, Kerosene, Electricity)	Europe: Handbook Emission Factors for Road Transport (HBEFA 3.2), USA: Motor Vehicle Emission Simulator (MOVES), Other countries: Application of HBEFA values	Europe: Based on data of European railway companies; train types outside Europe: literature review	Based on own ETW calculation (compare methodology report)	Based on own ETW calculation (compare methodology report)	Average of the applied ferry type	Data from Small Emitters Tool of Eurocontrol
Share of biofuel	Europe: 5% biofuel content in conventional diesel; outside of Europe: biofuels aren't considered	no biofuel	no biofuel	no biofuel	no biofuel	no biofuel
Energy and GHG emission factors	EN 16258	Diesel: EN 16258 Electricity: ETW calculated based on Ecoinvent	EN 16258	EN 16258	EN 16258	EN 16258

EcoTransIT World

EcoTransIT World (Ecological Transport Information Tool for Worldwide Transports) calculates the environmental impacts for any freight transport service. EcoTransIT World provides energy consumption and GHG Emissions for trucks, trains, ships and airplanes in accordance with the European standard EN 16258:2012. Additionally carbon dioxide (CO2) and the most important air pollutants (nitrogen oxide, non-methane hydrocarbons, sulfur dioxide and particulates) can be calculated with EcoTransIT World. Below you will find all information about your transport service selected and data sources used as well as the results of your calculation.

General Information

Creation Date:	01.11.2022
Origin:	[City district] [it] Genova
Destination:	[City district] [mx] Ciudad de México
Cargo weight:	200 ton (t/TEU: 10)

Detailed description of the calculated transport services

Transport service TS 1 - 10,916 km

Origin: [City district] [it] Genova

Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 15.11 km

Via: [it] Genoa (UN/LOCODE: ITGOA)

Sea ship (BC Transatlantic trade (35-80k dwt) General,LF: 55.0%,SR: 21%,Scac: null#) - 10,509.57 km

Via: [mx] Veracruz (UN/LOCODE: MXVER)

Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 391.32 km

Destination: [City district] [mx] Ciudad de México

Energy consumption and greenhouse gases (GHG) in accordance with EN 16258

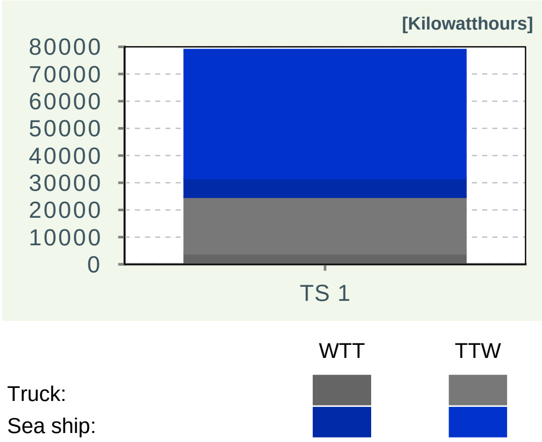
Energy consumption

WTW [Kilowatthours]

	TS 1
Truck	24,857
Sea ship	53,936
Sum	78,793

TTW [Kilowatthours]

	TS 1
Truck	20,835
Sea ship	47,036
Sum	67,872



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

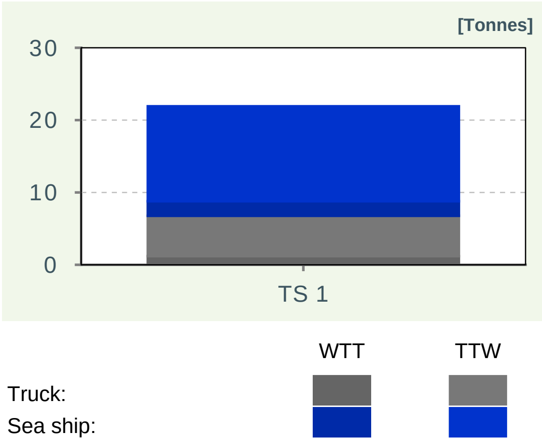
GHG emissions (calculated as CO2 equivalents)

WTW [Tonnes]

	TS 1
Truck	7
Sea ship	15
Sum	22

TTW [Tonnes]

	TS 1
Truck	6
Sea ship	13
Sum	19



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

These four results (TTW and WTW energy consumption and TTW and WTW GHG emissions) have been established according to the standard EN 16258:2012. Please consult this standard to get further information about processes not taken into account, guidelines and general principles. If you wish to make comparisons between these results and other results calculated in accordance with this standard, please take particular care to review the detailed methods used, especially allocation methods and data sources.

Your selected parameters for the calculation of energy consumption and greenhouse gas emissions (GHG emissions) in EcoTransIT World are displayed above in the detailed description of the transport services. The energy and GHG conversion factors (e.g. MJ or kg CO2 equivalent per litre diesel) for the EcoTransIT World calculation are taken from the appendix A of the standard EN 16258 without changes. For European trucks a biofuel share of 5 % is considered for diesel. For train transports the European standard does not contains specific energy and GHG conversion factors. Therefore EcoTransIT World uses own country specific conversion factors which are documented within the methodology report [http://www.ecotransit.org/basis.en.html].

For the allocation of energy consumption and GHG emissions to the individual transport services the parameter tonne-kilometre (tkm) is used. But the European standard allows also other allocation parameters if this is common for the transport mode considered. EcoTransIT World uses deviant allocation parameters for container ships (TEU-km) and ferries (number of decks and vehicle length). All data sources used for the calculation are documented at the appendix of this document. A comprehensive documentation of all data sources and default values aew used for EcoTransIT World as well a detailed description of the methodology can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html].

Carbon emissions and air pollutants

The European standard EN 16258 does not contain methodological guidelines for the calculation of CO2 and air pollutants. For comparability with the results for energy consumption and GHG emissions the calculation of CO2 and air pollutants is based on the same methodology as the European standard. Further information about the calculation approach used by EcoTransIT World for CO2 and air pollutants can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html].

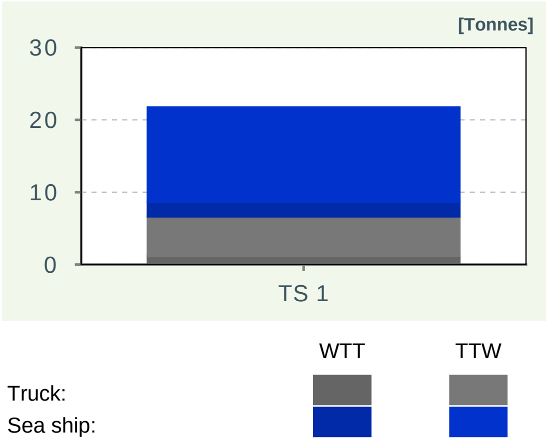
Carbon dioxide (CO2)

WTW [Tonnes]

	TS 1
Truck	7
Sea ship	15
Sum	22

TTW [Tonnes]

	TS 1
Truck	5
Sea ship	13
Sum	19



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

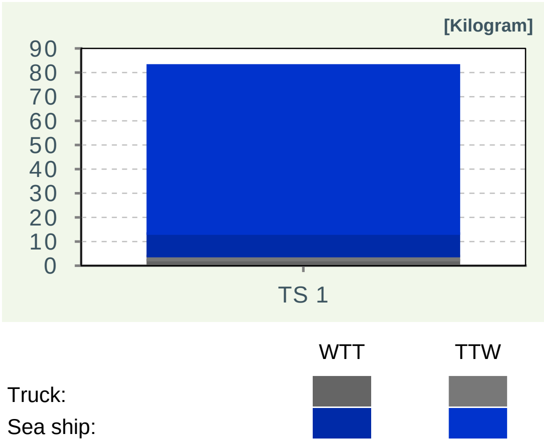
Sulfur dioxide (SO_2)

WTW [Kilogram]

	TS 1
Truck	4
Sea ship	79
Sum	83

TTW [Kilogram]

	TS 1
Truck	2
Sea ship	70
Sum	71



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

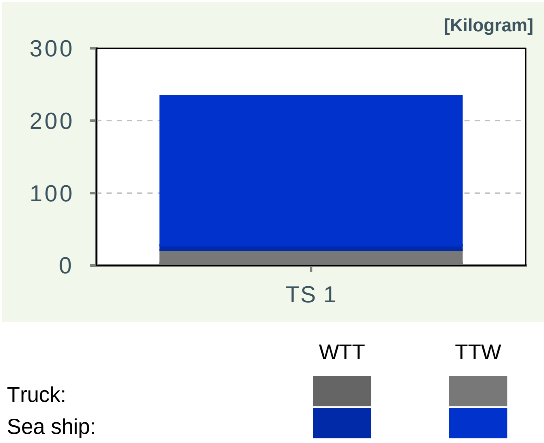
Nitrogen oxides (NOx)

WTW [Kilogram]

	TS 1
Truck	21
Sea ship	212
Sum	234

TTW [Kilogram]

	TS 1
Truck	19
Sea ship	206
Sum	225



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

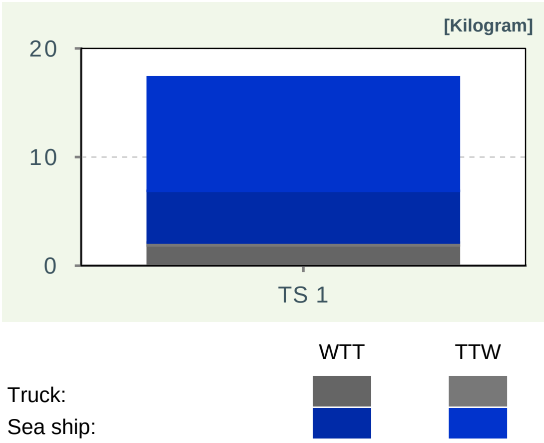
Non-methane hydrocarbon (NMHC)

WTW [Kilogram]

	TS 1
Truck	2
Sea ship	15
Sum	17

TTW [Kilogram]

	TS 1
Truck	0.3
Sea ship	10.5
Sum	10.7



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

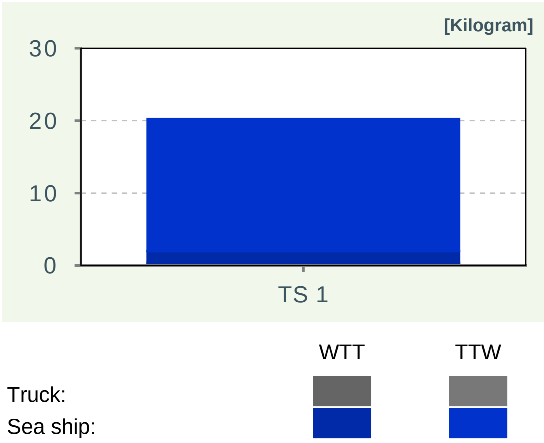
Particulate matter (PM10)

WTW [Kilogram]

	TS 1
Truck	0.4
Sea ship	19.8
Sum	20.2

TTW [Kilogram]

	TS 1
Truck	0.3
Sea ship	18.2
Sum	18.5



Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)

EcoTransIT World entries

Input mode:	Extended
Ferry routing:	Normal
Version ETW:	Unknown (Unknown)
Version data base:	etw_db_2022r6v1 (2022-10-31 22:10:17.000)

Appendix: Documentation of the data sources used (in accordance with EN 16258)

The following table summarizes in accordance with the standard EN 16258 the data categories (individual measured values, specific value of the shipper, fleet values of the shipper, default values) and data sources of default values used. A detailed description of the methodology, the data sources and the default values can be found in the scientific methodology report [http://www.ecotransit.org/basis.en.html]. If the user changed the default values of EcoTransIT World, it will be shown at the following table as Customer specific values.

	Truck	Train	Barge	Sea ship	Ferry	Airplane
General information						
Freight details: Weight, Unit, Amount TEU, t/TEU	Customer specific values	Customer specific values	Customer specific values	Customer specific values	Customer specific values	Customer specific values
Transport distance	Calculated with EcoTransIT (consideration of street type and topography)	Calculated with EcoTransIT (consideration of traction type, topography and line type)	Calculated with EcoTransIT (port-to-port distance, consideration of inland waterway classes)	Calculated with EcoTransIT (port-to-port distance, consideration of canal sizes)	Calculated with EcoTransIT (port-to-port distance)	Calculated with EcoTransIT (airport-to-airport distance)
Transport mode specific data						
Emission standards	Country specific emission standards based on analyses of ETW	No differentiation on emission standards (at diesel traction)	No differentiation on emission standards	No differentiation on emission standards	No differentiation on emission standards	Emission standard depends indirectly from the plane type
Load factor	Assumptions based on statistical data	Based on data from European railway companies	Assumptions based on statistical data	Based on data from UNCTAD Maritime Reviews	Assumptions based on statistical data	Data based on International Civil Aviation Organisation, DEFRA und aviation companies
Empty trip factor	Based on statistical data	Based on data frin European railway companies	Empty trips are considered within the load factor	No empty trips	No empty trips	No empty trips
Maximum payload	Europe: Handbook Emission Factors for Road Transport (HBEFA 3.2); USA: Department of Transport; Other countries: Application of HBEFA values	Results directly from the train type, based on the data of European railway companies	Vessel type depends on the river type and is automatically selected by ETW	Ship type depends on trade lane and is automatically selected by ETW	Data from Network for Transportation and Environment (NTM)	Based on specifications from IATA
Miscellaneous		Traction type: Electrified (Calculated by ETW according to the selected route)		Speed reduction: Analyses based on data from searate.com		Mix Bellyfreight/ freigter based on data from IATA

	Truck	Train	Barge	Sea ship	Ferry	Airplane
Fuel consumption						
Specific energy consumption (Diesel, Heavy fuel oil, Kerosene, Electricity)	Europe: Handbook Emission Factors for Road Transport (HBEFA 3.2), USA: Motor Vehicle Emission Simulator (MOVES), Other countries: Application of HBEFA values	Europe: Based on data of European railway companies; train types outside Europe: literature review	Based on own ETW calculation (compare methodology report)	Based on own ETW calculation (compare methodology report)	Average of the applied ferry type	Data from Small Emitters Tool of Eurocontrol
Share of biofuel	Europe: 5% biofuel content in conventional diesel; outside of Europe: biofuels aren't considered	no biofuel	no biofuel	no biofuel	no biofuel	no biofuel
Energy and GHG emission factors	EN 16258	Diesel: EN 16258 Electricity: ETW calculated based on Ecoinvent	EN 16258	EN 16258	EN 16258	EN 16258