Executive Summary

Cargo sous terrain: Updated life cycle analysis report confirms the positive sustainability data of 2015

Cargo sous terrain (CST) has carried out a new Life Cycle Assessment (LCA) for its entire logistics system. Just like our first Life Cycle Assessment, carried out in 2015, the present assessment was carried out and audited by an independent party.

An LCA examines the environmental impacts, resource usage, and energy balance of a technical system or product "from cradle to grave." All resources throughout the entire life cycle, from construction to operation, replacement, and disposal of components of the first section of CST, were examined, quantified, and compared with reference scenarios without CST.

The main finding from the first life cycle assessment has been confirmed by the new study in 2023: CST exhibits significantly lower environmental and climate impacts compared to road transport, even in a future with new heavy-goods vehicle (HGV) propulsion technologies.

Compared to Quantis' first LCA, the consulting firm Carbotech was able to rely on updated, more in-depth fundamentals and evaluation methods to model the CST system. The study and results were verified by Empa St. Gallen through a critical review during the course of the study.

Beyond the impacts identified in the LCA, CST yields additional benefits that cannot be quantified fully, if at all, even with the updated LCA methods. These other factors include certain key CST co-benefits such as the reduction of congestion and accidents. Another factor that is outside the parameters of sustainability modelling concerns the space efficiency that CST customers can benefit from, or the bundling effects which, thanks to the digitally controlled pre-sorting of goods in the CST tunnel system, also come into play in the last-mile delivery of increasingly small goods, especially in urban contexts.

For example, a scientific study by the ZHAW has shown that the CST tunnel, combined with higher capacity utilisation through consolidated fine distribution, can reduce truck mileage in the city of Zurich by 25% per day, and therefore greatly relieve the city of traffic. Current traffic analyses show that CST will already reduce heavy freight traffic on the A1 between Härkingen and Zurich by up to 30% with the opening of the first section in 2031. An older study, carried out on behalf of the Federal Office of Transport, concluded that CST will reduce congestion time at critical points on the A1 by 5-10%, due to the reduction in traffic volume and the speed differential between passenger cars and trucks. This corresponds to over 1,000 hours of congestion avoided on a daily basis.

By offering new solutions for a reliable, resilient, and sustainable goods supply in Switzerland, CST's advantages over road transport become as evident as its environmental benefits, indicated by this new LCA.

Since the LCA is based on material and energy flows, it does not directly evaluate social, economic, and technical factors. These aspects must be further analysed via specific scientific studies and then incorporated in the LCA models. CST wants to capture these effects as soon as possible using, generally accepted methods.

CST remains dedicated to its long-standing commitment to operate the system with certified renewable electricity, and maintains transparent communication regarding its environmental impacts and the state of knowledge, including addressing any outstanding matters.

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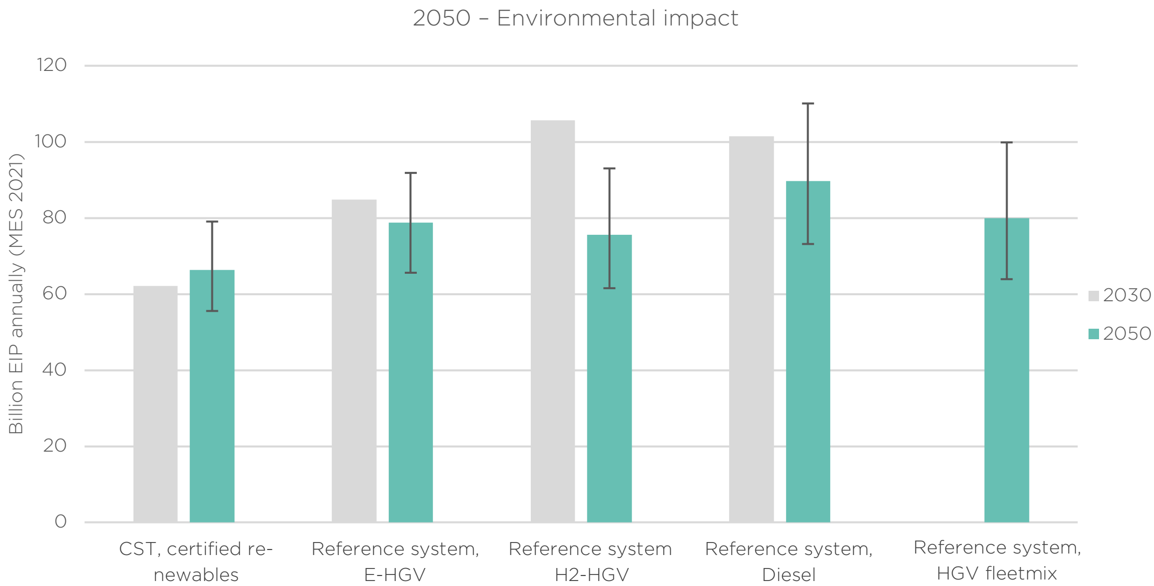

Figure 1 - Annual environmental impact of CST, the reference systems, and the forecast fleet for 2050. Most important is the comparison with the expected fleet mix, not the comparison with individual drive types, which cannot cover the entire transport volume.

Disclaimer

This is a translated version of the CST Life Cycle Assessment 2023. The original German version by Carbotech AG is authoritative for all content, including illustrations and data, and can be found here: https://www.cst.ch/wp-content/uploads/2023/10/CST_LCA_Auszug231026.pdf

CustomLCA

Life Cycle Assessment Cargo sous terrain

Life cycle analysis of the construction and operation of the Cargo sous terrain system and comparison with conventional freight transport

Summary

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Number of pages: 30
Basel, 7 September 2023

Imprint

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Version
1.1

Basel, 7 September 2023

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Summary

Cargo sous terrain (CST) aims to shift a portion of the freight traffic on Switzerland's most heavily traveled routes underground. In order to do that, the aim is to build a system that spans from Geneva to St. Gallen, and from Basel to Lucerne, with an additional section towards Thun. The first section to be constructed will lead from Neuendorf, via Zurich city, all the way to Zurich Airport.
The project's environmental impact has already been analysed in a Life Cycle Assessment (LCA) (Zah & Del Duce, 2015). This study also carries out a Life Cycle Assessment of the first section of CST, using more up-to-date databases and methods, and relying on the fact that the project's planning process is more advanced at this stage.
All emissions associated with the construction and operation of the first section of CST were examined from the perspective of their environmental impact. Their impact was analysed using the 2021 Method of Ecological Scarcity (MES 2021), the IPCC 2021 method, as well as the Environmental Footprint Method 3.1 (EF 3.1). This summary only covers the evaluation based on the first two of these methods. The full confidential report includes not only the exact inventory and results of the different variants, but also the results of the EF 3.1. analysis.

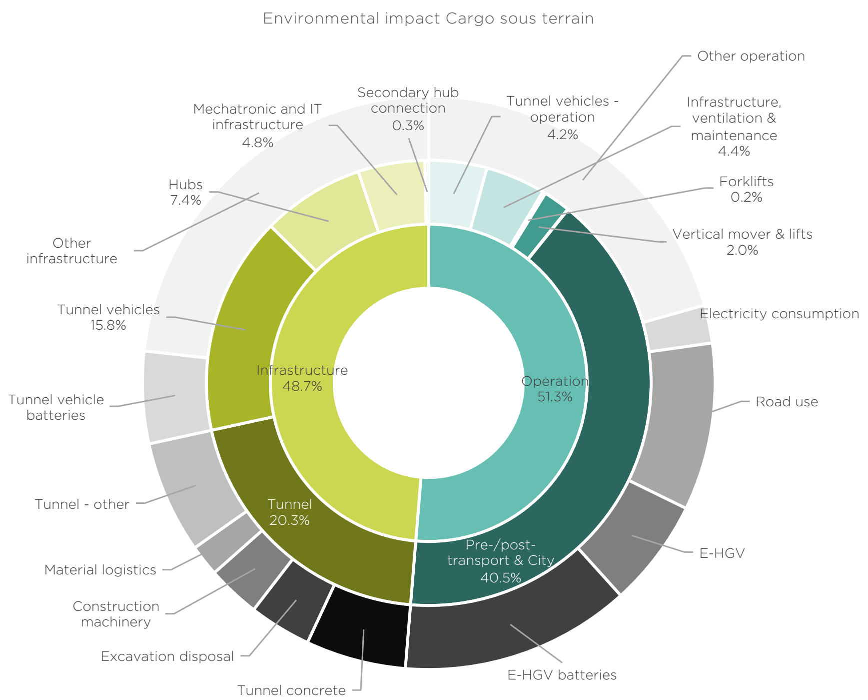

Figure 1: Distribution of CST's environmental impact (annually, MES 2021)

Half of CST's annual environmental impact will be due to the system's infrastructure and half due to its operation. The majority of the latter will be due to last-mile fine distribution using electric heavy-goods vehicles (HGVs). From the infrastructure perspective, it will be tunnel construction and tunnel vehicle production that will have the most important environmental impact.

The environmental impact of CST was compared to the environmental impact that would result from transporting the same volume of goods by heavy goods vehicles (HGVs, 90%)

and by rail (10%). As the CST system will be built in the near future, the years 2030, 2040, and 2050 have been selected as reference years. With regard to propulsion technologies, diesel HGVs, electric HGVs and hydrogen-powered (H2) HGVs were studied. In the case of CST and HGVs with alternative driving technologies, the influence of the electricity mix was also analysed.

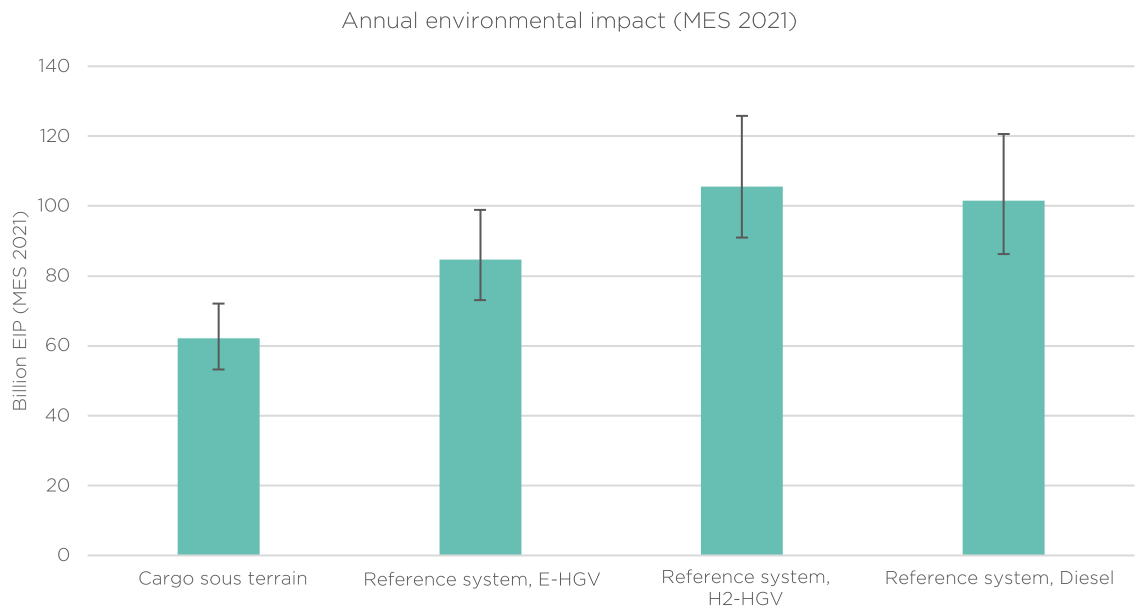

Figure 2: Environmental impact during one operational year for Cargo sous terrain and the reference scenarios (MES 2021)

If the overall environmental impact is analysed using the 2021 Ecological Scarcity Method, then Cargo sous terrain, using certified renewable electricity, has a much better environmental footprint than the reference system using diesel trucks. CST also has a significantly better LCA compared to electric HGVs and H2-HGVs, assuming these reference systems are operated using the average Swiss electricity mix.

An evaluation using the IPCC 2021 and EF 3.1 methods comes to broadly similar results.

A comparison with reference year 2050 also demonstrates that CST tends to have the best results. However, the differences between reference scenarios at that point become less significant, as the standard Swiss power mix is poised to improve leading up to 2050. At the same time, as we look further into the future, our modelling becomes more uncertain.

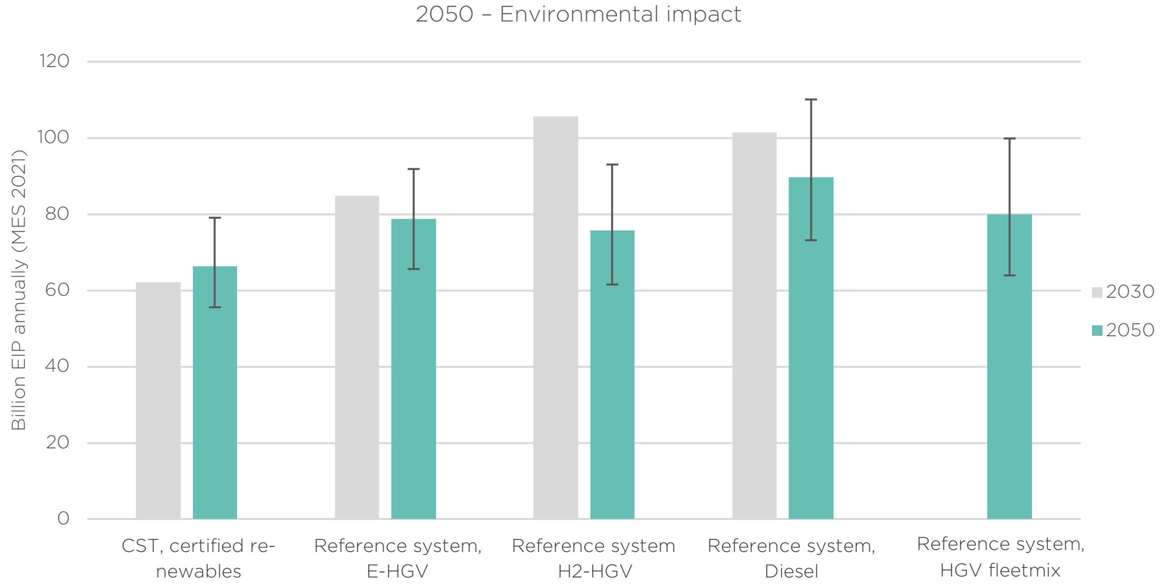

Figure 3: Annual Environmental Impact in the year 2050 for CST and the reference scenarios (MES 2021)

Overall, CST will produce lower emissions compared to the current transport system, which relies principally on diesel-powered HGVs. Compared to electric and H2-HGVs, CST is projected to achieve a better result, if the 2030 reference scenario uses the current average electricity mix. CST also tends to achieve a better result in 2050. However, the uncertainty of the results is then greater than the difference between the variants.

The present study only considers the ecological effects of the CST system. For a holistic assessment of CST, the social and economic aspects of sustainability should also be taken into account. For instance, the ZHAW study assumes that thanks to CST, truck mileage in the city of Zurich can be reduced by 25%. 30% of heavy traffic (and thus 3% of all traffic) could disappear thanks to CST (B+S AG, 2023), which in turn should lead to a 5 to 10% reduction in congestion at critical road network points (Maibach et al., 2016). However, the results of the present study also show that some of these demonstrable co-benefits of Cargo sous terrain — such as avoided traffic jams, accidents, and more efficient use of traffic areas — can only be partly quantified with the existing carbon footprint methodology.

Glossary and Abbreviations

CST	Cargo sous terrain
Cut-off approach	Method for assessing the environmental impact (allocation) of recyclates during the recycling process. In the cut-off approach, the life cycle of the first product ends at the moment of collection (cut-off). All further expenses from collection are assigned to the recyclate. There is no credit for the replacement of primary material.
EF 3.1	Environmental Footprint: Evaluation method developed for the European context.
ERS	Electrified Road System
Functional unit	Reference quantity for comparison/analysis. Reflects the function of the product.
GWP	Global warming potential: potential greenhouse gas emissions.
IPCC	Intergovernmental Panel on Climate Change: UN body dealing with climate change.
ISO 14'040 ff	ISO standards on the preparation of environmental assessments
LCA	Life Cycle Assessment
MES 2021, Method of Ecological Scarcity 2021	Total aggregating valuation method, based on environmental policy objectives. Result: Environmental Impact Points (EIPs). Ecological scarcity is used as a weighting factor for the effects: ratio of current emission freight in Switzerland to the maximum tolerable freight (critical freight). (BUWAL 1990 or Braunschweig et al. 1993, updated on behalf of the FOEN: 1997, 2006, 2013 and 2021).
Eco-inventory	Contains all environmentally relevant, quantitative information about a product, process, or service in the form of inputs and outputs.
Inventory analysis	Representation of shock fluxes and energy consumption in physical quantities.
EIP, Environmental Impact Point	Environmental Impact Point is the unit in which the results of the calculations are rendered using the ecological scarcity method.
DETEC 2021	Life Cycle Assessment database, based on ecoinvent v2.2, and updated and adapted to the Swiss context.
Life Cycle Impact Assessment	In the context of the Life Cycle Impact Assessment, the results of the inventory analysis are assessed regarding certain effects on the environment, such as greenhouse or ozone formation potential. This is achieved by using weighting factors as part of a weighting model.
Effect	Impact of emissions or use of resources on the environment.

1 Background and objectives

Switzerland's transport infrastructure is reaching its limits on more and more routes. In the coming decades, both passenger and freight transport are likely to continue to increase (Federal Office for Spatial Development, 2022).

Cargo sous terrain (CST) aims to shift part of this freight traffic to an underground network. For this purpose, a first section of the network between Neuendorf and Zurich, including 11 hubs, is to be established by 2031.

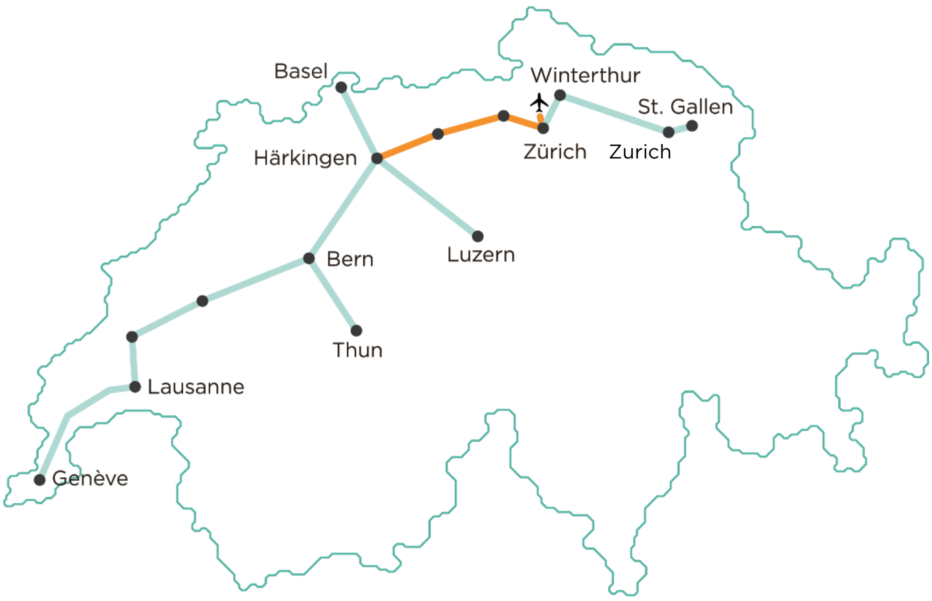

Figure 4: Planned CST network when construction is completed. Graphic: CST

In 2015, a Life Cycle Assessment analysis of CST was carried out by Quantis (Zah & Del Duce, 2015). That report found that CST can bring about a significant reduction in the environmental impact of goods transport, compared to reference scenarios.

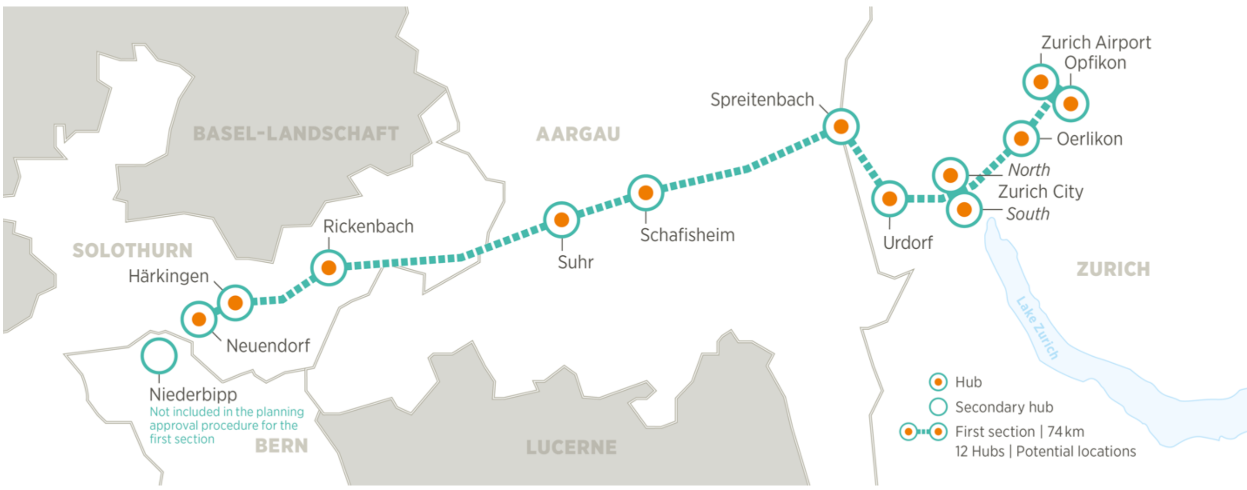

Figure 5: First section. Graphic: CST

In the meantime, planning has progressed at CST, and many of the parameters that were still uncertain at the time of the previous study have now been clarified. The LCA database and assessment methods have also undergone various updates in the meantime. For these reasons, this study is intended to re-assess the CST system from an ecological point of view using up-to-date methods and data.

Like the previous study, the present study aims to analyse the annual ecological impact of freight transport using CST. These effects are compared to various reference scenarios, which examine what would happen if the CST system were not constructed. In particular, this study operates on the assumption that the type of energy used by HGVs will continue to evolve in the future. For this purpose, various scenarios, including ones where HGVs operate using electricity or hydrogen fuel cells, were considered.

Due to new methods available to the study team, the following additional aspects have been taken into account: evaluation of the noise reduction by CST, evaluation of the reduction of microplastics thanks to CST's closed system, and reduction of land use due to the relocation effect and the correspondingly lower pressure on the above-ground transport infrastructure.

The findings of the study also aim to help identify the project's potential for improvement. For this purpose, the most relevant components of CST are identified and possible alternatives to address these issues are assessed from an ecological perspecive.

This summary outlines the most important findings of the main study, which is confidential.

2 Methodology and approach

There is nowadays a broad consensus that a Life Cycle Assessment is the most comprehensive and meaningful method for assessing the environmental impact of products and systems. Therefore, this is the method that has been used here in order to determine the environmental impact of the CST system.

2.1 Outline of the Life Cycle Assessment approach

Life Cycle Assessment is a method for assessing and recording the impact of specific human activities on the environment, while also indicating areas with a potential for improvement. Due to the complexity of nature and the global economic system, it is not enough to consider only individual problematic substances or local effects. In order to result in comprehensive assessment, any assessment method should comply with a series of requirements. It should:

- take the various environmental impacts into account as comprehensively as possible,
- consider a product's or system's entire life cycle,
- quantify a product's or system's environmental impact,
- assess the various impacts as a basis for decision-making, and
- be scientifically backed, to ensure reliability and acceptance.

The Life Cycle Assessment approach is the method that best meets these requirements today. The results of the Life Cycle Assessment can be used:

- as a decision-making tool when faced with multiple options,
- to adequately capture a product's or system's environmentally relevant effects,
- to determine the main influencing factors,
- in strategic planning, as a way to identify a product's or system's optimisation potential,
- for assessing various measures and solutions,
- as a basis for eco-design or
- to determine a preferred course of action.

2.2 Approach to Life Cycle Assessment

After defining the scope and outline of the system to be analysed and formulating the appropriate questions to be asked, we proceeded to document the system's flow of goods, materials, and energy, as well as its needs in terms of resources. Based on that, the system's environmental impact was determined with the help of selected indicators. The aim of this study is to summarise the results using key figures, to facilitate the assessment process. To do so, the evaluation of the project's various environmental effects was carried out based on appropriate weighting calculations.

According to ISO 14040/44 (ISO, 2006; ISO/TC, 2006), a Life Cycle Assessment comprises the following steps:

- Goal and scope definition (framework conditions)
- Life cycle inventory analysis (LCI)
- Life cycle impact assessment (LCIA)
- Interpretation

- Optimisation measures

As Figure 6 shows, this is not a linear process, but an interactive insight-and-optimisation process.

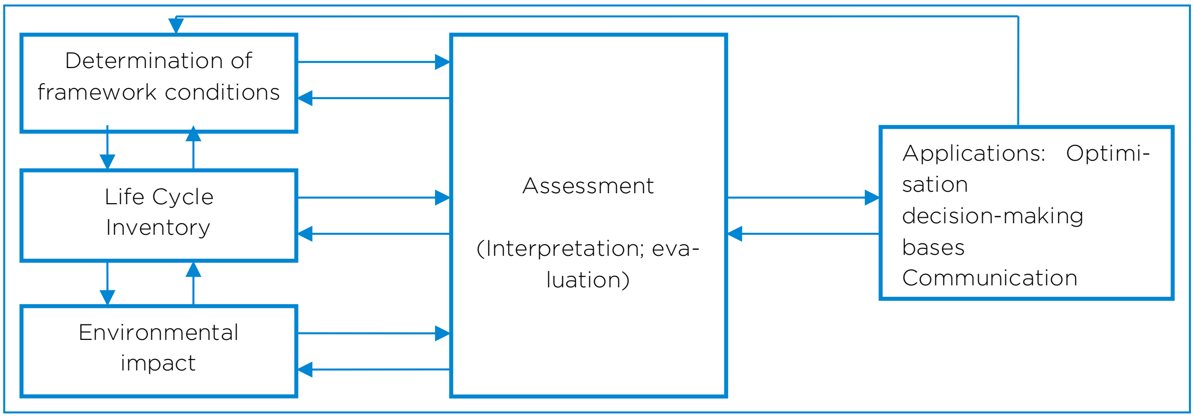

Figure 6: Steps of a LCA according to ISO 14040/44

The present study is based on the ISO 14040 Standard; however, when using overall aggregating methods, the present study diverges from the Standard.

2.3 External review

The study was subjected to a critical review based on ISO 14040/44 (2006a, b). This task was entrusted to an independent external expert, rather than a review panel. The review was carried out during the study.

Roland Hischier was called in as an expert from Empa, St. Gallen.

2.4 Objectives and framework conditions

The definition of the system's scope depends largely on the purpose of the analysis and the relevant questions that ought to be answered. Based on these questions, the study defined its framework conditions and the system's scope and boundaries for the purposes of the study. The system scope defines which processes, including upstream processes, are taken into account. For example, this is how the study determines the timeframe of the data used, as well as the nature of the environmental impact to be studied.

2.4.1 Objectives

The aim of this study is to assess the environmental impact of freight transport via the Cargo sous terrain system. This takes into account both the construction and the operation of CST. These effects are to be compared with the transport of the same amount of goods via the existing above-ground freight transport system.

2.4.2 Functional unit

The quantity to which the analysis refers is referred to as the functional unit.
The functional unit in this study is defined as the quantity of goods transported in one year on a section of the transport network.

2.4.3 Application and target group of the study

This summary is primarily aimed at Cargo sous terrain, the client, but is made available to interested members of the public as well.

2.4.4 Scope

The present Life Cycle Assessment considers the ecological effects of the project "from cradle to grave". In accordance with the LCA approach, this includes all environmentally relevant processes within the system boundary, from the extraction of raw materials to their processing into the materials and components used, including transport processes, use, and disposal of materials involved.

The scope of the present study thus essentially includes the material and energy flows of the following processes and services considered relevant (see Figures 7 and 8):

- Provision and production of materials for Cargo sous terrain and reference systems,
- Transport of raw materials to the construction site,
- Waste and its treatment along the production chains; provision of auxiliary materials and energy,
- Energy supply: heat and electricity, energy sources such as oil, natural gas, coal, etc. for the processes involved.

For all these processes, the impact of these emissions on soil, air, and water is taken into account, as are the processes' requirements in terms of resources (e.g. energy resources or land use). The transported goods themselves are not taken into account.

The report also assumes that there will be an increase in the amount of transported goods in the future. However, it does not study whether CST itself could have an indirect influence on such fluctuations (e.g. by offering lower/higher prices for providing faster/slower transport services).

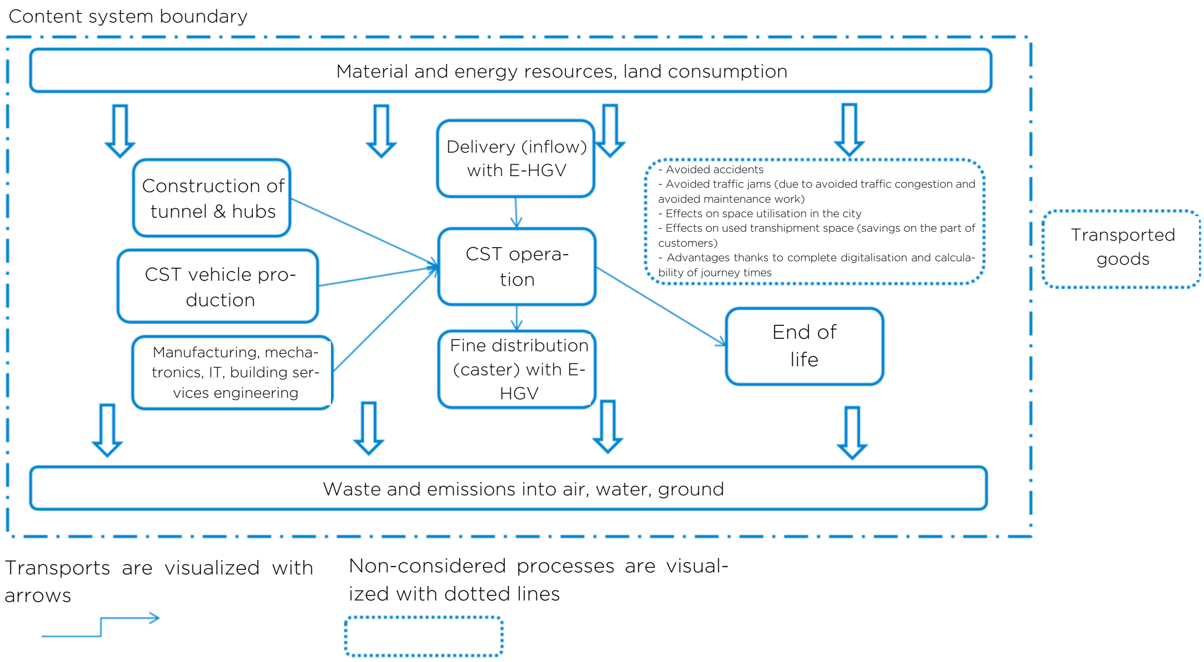

Figure 7: Schematic representation of the CST system processes considered in this study

In the reference systems as well, every effort was made to consider all relevant processes. This includes the production and disposal of vehicles, and all emissions caused by the operation and use of road infrastructure. The study also considered the fact that reference systems also require space and infrastructure for handling purposes. As an approximation, CST's surface and building requirements were used proportionally for this purpose. The number was reduced by 30%, if 30% of transports are direct and do not require cross-docking. The transported goods themselves are not part of the reference systems analysis, as they were not considered for the analysis of the CST system either (see Figure 8).

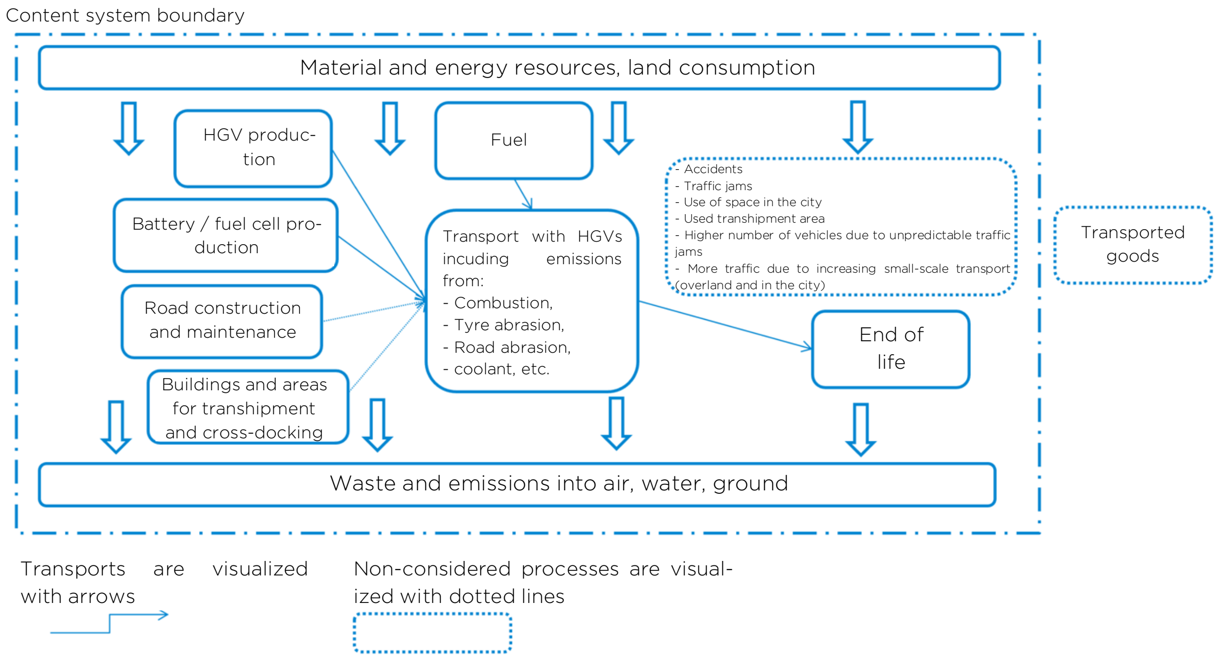

Figure 8: Schematic representation of the reference systems processes considered

2.4.4.1 Geographical scope

As the section in question is entirely on Swiss soil, this study primarily considers Swiss processes and technologies.

2.4.4.2 Timeframe

As this analysis pertains to future technology that is still to be fully developed and expected to be in use for decades to come, the focus of this study lies in the future as well. In coordination with the client, it was decided to use the year 2030 as a reference year. Additionally, we considered possible developments for 2040 and 2050.
This means that we have had to rely on future-oriented modelling for the technology used by the reference systems, in particular regarding the energy used by heavy goods vehicles and the nature of the Swiss electricity mix (see 2.5.2.1 Reference system).
The aim for 2050 with regard to the Swiss electricity mix is to achieve the goals of the "ZERO Basis der Energieperspektiven 2050+" scenario, established by the Federal Department of Energy (2020). This takes into account an 11% rise in electricity use in comparison to 2019. Electricity would be mostly produced using hydropower (51.7%) and photovoltaics (41%). Reference years 2030 and 2040 are considered to be logical midpoints between 2019 and 2050. This is aligned with the decreasing CO2 emissions of Swiss electricity

production, according to the above-mentioned ZERO scenario. Table 1 below shows the values that were used for the modelling purposes of this study.

Table 1: Evolution of electricity mix until 2050

	2030	2040	2050
Hydropower	54.6%	53.0%	51.4%
Nuclear	22.7%	11.3%	0.0%
Fossil fuels	1.7%	0.9%	0.0%
Wind	1.9%	3.5%	5.1%
PV	16.4%	28.6%	40.8%
Biomass and biogas	1.0%	1.3%	1.6%
Geothermal	0.1%	0.2%	0.2%
Other renewables	1.6%	1.2%	0.9%

2.5 Material flow analysis

2.5.1 Modeling of the product system

In a material flow analysis, a model for the system to be assessed is designed, and the energy and material flows associated with the processes are recorded. These include:

- the relationships of a process with other processes within the technosphere, such as the quantity of raw materials, auxiliary materials, energy requirements, transportation, or recycling and disposal systems, and
- the relationships of a process with its natural environment in the ecosphere, such as the need for resources (fossil fuels, land resources, etc.) and emissions, such as CO_2, VOCs, methane, nitrogen oxides, and others.

The material flow analysis was carried out using the life cycle assessment software SimaPro Version 9.5 (PRé Consultants, 2023) and served as the basis for the impact assessment.

2.5.2 Foreground data

Data pertaining to the CST system was mainly provided by CST itself. For reasons of confidentiality, these are only listed in the comprehensive main report.

2.5.2.1 Reference system

The aim of Cargo sous terrain is to shift above-ground freight traffic underground. This study is therefore based on the assumption that it is primarily HGV journeys that will be replaced by CST. However, as it is not possible to predict how the HGV fleet mix will evolve in the next 10 (let alone 30) years, various propulsion technologies were studied in comparison. A common feature in all variants is that they assume a mix of 90% HGV transport and 10% rail transport (based on the assumption from Zah & Del Duce, 2015). Additionally, while CST aims to make last-mile distribution and urban logistics more efficient, the distances that goods must travel may eventually be longer because, for many transport routes, CST represents a detour due to its less flexible routing. For this reason, the reference systems assumed 6% shorter distances (based on the CST assumption). On the other hand, it was taken into account that CST results in a 30% reduction in trips in the urban, pre- and post-haul areas. Specifically, calculations were based on 512,472,489 tkm/year.

Regarding noise emissions, inventory data from the background database were used for the reference systems. These data are assessed only in the 2021 ecological scarcity method. This assessment uses, as a reference, the number of *strongly annoyed persons.* For the part of the CST system that is underground, the noise factor was set to 0. For the above-ground part, the factors for HGV transport were used.

Diesel HGVs

The base inventory used was *transport, freight, lorry 32-40 metric ton*, *EURO 6/tkm/RER*. The inventory includes all emissions related to vehicle manufacturing, maintenance, and disposal. Additionally, tire wear, brake wear, the contribution to road wear, and noise emissions are taken into account.

Since CST will be constructed in the near future, the inventory had to be extrapolated into the future. For this purpose, data from De Haan, Peter & Zah, Rainer (2013) were used, which assume that internal combustion engines will reduce fuel consumption by approximately 30% by 2050 compared to 2020[1]. Based on this, a linear reduction of 10% for 2030 and 20% for 2040 can be calculated. For this purpose, the inventory for diesel HGVs was duplicated, and the fuel consumption and resulting emissions were adjusted accordingly.

Furthermore, a refrigerated version will be created, which will have 20% higher fuel consumption and emissions, as well as coolant emissions in accordance with the ecoinvent inventory for refrigerated HGVs. The split between non-refrigerated and refrigerated vehicles was set as 68% to 32%, the same as in the CST system.

E-HGV

Since this is still an emerging technology, there is no electric HGV (E-HGV) in the common eco-balance databases. For this reason, an E-HGV was modeled based on literature references (Mareev et al., 2017) and the inventory for diesel HGVs.

It was especially considered that the battery must be replaced once over the lifetime of 540,000 vehicle kilometers. Specifically, the modeled battery weighs 5,440 kg.

For the extrapolation into the future, only the respective electricity mix for recharging the batteries was considered. It was not taken into account whether battery technology improves. This is primarily because this technological development is currently difficult to predict. Also, an improvement in battery technology affects both the reference system E-HGV and the CST system (fine distribution via E-HGV and the batteries of tunnel vehicles).

H2-HGV

Like the E-HGV, the hydrogen HGV (H2-HGV) had to be modeled. The heavy goods vehicle (Vijayagopal, 2016), the hydrogen tank (Elgowainy et al., 2012), and the battery

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[1] It must be noted that the phase-out of internal combustion engines for passenger cars in the EU is a done deal. no similar decision has yet been made for HGVs, so there is a small probability that internal combustion engine HGVs may still exist in 2050.

(Unterlohner, 2020) were modeled based on literature references. The fuel cell could be taken from existing eco-balance inventories.

The production of hydrogen has a significant impact on the eco-balance of H2-HGVs. Hydrogen from steam reforming tends to perform the worst. In contrast, hydrogen from electrolysis has a better eco-balance depending on the electricity mix used (Conrad et al., 2022). For this analysis, hydrogen from electrolysis with future Swiss standard electricity was assumed. Production with certified electricity was also considered as a sensitivity analysis.

2.5.3 Handling of product components

2.5.3.1 Background data

For modeling, background data from KBOB:2022 was used (UVEK 2021). This is an eco-balance database based on ecoinvent 2.2, which is created and continually developed on behalf of Swiss federal offices. In particular, data related to petroleum, natural gas, nuclear fuel, electricity provision, transportation and disposal services, as well as forestry and the wood industry were updated. ecoinvent, in turn, is the most comprehensive and established eco-balance database.

2.6 Impact Assessment

In this step, the inventory is assessed for its environmental impact. The calculation of the impact assessment includes the following two sub-steps:

- Classification (categorisation of substances from the inventory based on their impacts), and
- Characterisation (calculation of environmental impacts): Substances are weighted against each other based on their potential to cause harm in relation to a reference substance. This results in the potential for a specific environmental impact. For the greenhouse effect potential, CO2 is used as the reference substance, and contributions from other greenhouse gases such as methane and nitrous oxide are converted into CO2 equivalents.

At the impact assessment level, the greenhouse effect potential (CO2 footprint) is considered according to IPCC 2021, GWP 100a. This method only takes into account the environmental impact of global warming. For each climate-relevant substance, the greenhouse effect potential is determined over 100 years. From the ratio to the greenhouse effect potential of CO2, the impact on the climate of each emission can be expressed as a corresponding quantity of CO2. This results in data presented in so-called CO2 equivalents (CO2-eq).

The result of the impact assessment is a compilation of various indicators, each describing an aspect of environmental impacts. To obtain a solid basis for decision-making, the different impacts can be weighted and summarised into a single indicator. The weighting of various environmental impacts is a process that incorporates values and, therefore, must have broad support to ensure high acceptance.

2.6.1 The method of ecological scarcity

This study used the method of ecological scarcity 2021 (Frischknecht et al., 2021). The method of ecological scarcity was developed with the cooperation of the Swiss Federal Office for the Environment and is a well-established practice in Switzerland. The results are expressed in environmental impact points (EIPs).

The method was chosen because it takes into account both the environmental situation and the environmental goals of Switzerland for the assessment (see Figure 9), making it broadly supported in terms of values. Regarding the use of the overall aggregating methods, the present study is not based on ISO standard 14040, but goes beyond it[2].

This method not only reflects the values of Swiss environmental policy; it also enjoys broad international acceptance.

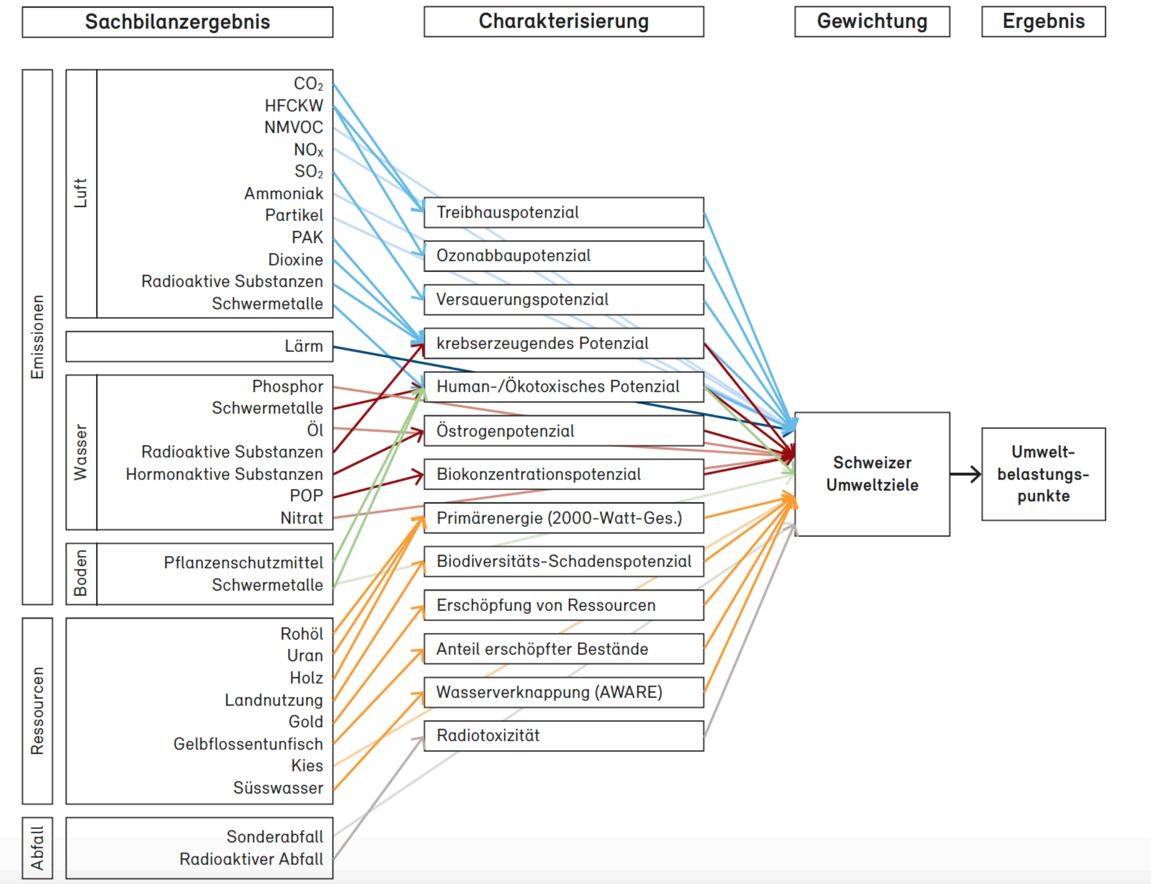

Figure 9: Basic Scheme of the Method of Ecological Scarcity (Image from Frischknecht & Büsser Knöpfel, 2013)

[2] Since the assessment of various environmental impacts depends on value-based criteria, these comprehensive methods are partially rejected, for instance, by the ISO Standard 14044. It should be noted that the selection of environmental impacts is also subjective. If only a portion of the impacts, such as the CO2 footprint, is considered, this is equivalent to assigning a weight of zero to the other impacts. The consideration of individual impact categories can indeed be helpful, such as in identifying the causes of specific impacts and developing potential optimisation opportunities. However, as a basis for decision-making or for the assessment of overall environmental impacts, individual environmental aspects must not be excluded. For this purpose, comprehensive aggregation assessment methods are not only helpful but also necessary (Kagi et al., 2010) to ensure the meaningfulness of the results.

2.7 Uncertainties and sensitivity analyses

Modeling complex systems, as is the case in life cycle assessment, is always associated with uncertainties. The following types of uncertainties are to be distinguished:

- Measurement inaccuracy
  These occur, for example, in data collection due to measurement errors, older data, missing data, or the use of average values.
- Systemic inaccuracy
  In modeling, assumptions must be made, such as regarding average transport distances, methods used, etc.
- Ambiguity or uncertainty

The calculation of environmental impacts is based on models that can only be verified to a certain extent. This may be because forecasts are in the future or the impacts cannot be directly measured, such as human toxicity. Furthermore, the weightings of different impacts are based on societal values that can change.

The inaccuracies in the inventory are provided in the background data and have been captured or estimated and evaluated to the extent possible in the foreground data. These uncertainties are shown in the overview graphics as ranges of results, corresponding to 1 σ standard deviation. These ranges are calculated values from the Monte Carlo analysis with 1,000 runs. It should be noted that these only consider the uncertainties of the inventory and do not include method uncertainties, for example.

3 Results and discussion

This chapter presents the environmental footprint according to the method of ecological scarcity (MES 2021) as well as the climate footprint following IPCC 2021.

3.1 Analysis of Cargo sous terrain

The Cargo sous terrain system causes an environmental impact of approximately 62 billion EIP (environmental impact points) per year. This environmental impact is divided equally between the infrastructure and the operation itself (see Figure 10).

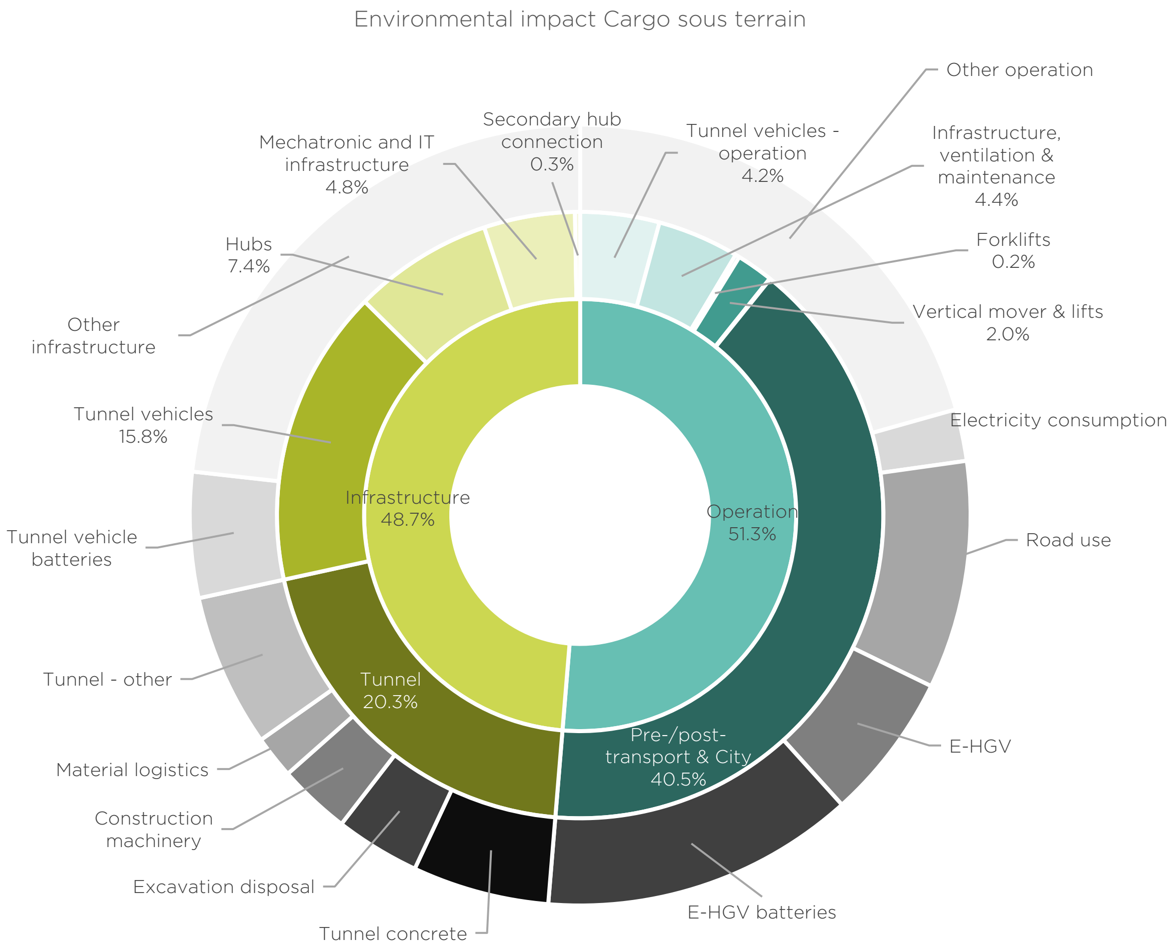

Figure 10: Allocation of the CST system's environmental impact (per year, MES 2021)

On the infrastructure side, the construction of the tunnel is primarily responsible for the project's environmental impact. The production of the required vehicles contributes significantly as well. The construction of hubs and all the technical equipment around the tunnel also has a certain contribution to the project's overall environmental impact.
On the operational side, the fine distribution via E-HGVs (electric Heavy Goods Vehicles) has the most significant impact. This is despite the assumption that certified electricity is used for charging. However, the electricity consumption for the movement of tunnel vehicles and ventilation, among other factors, has a smaller influence on the environmental footprint.

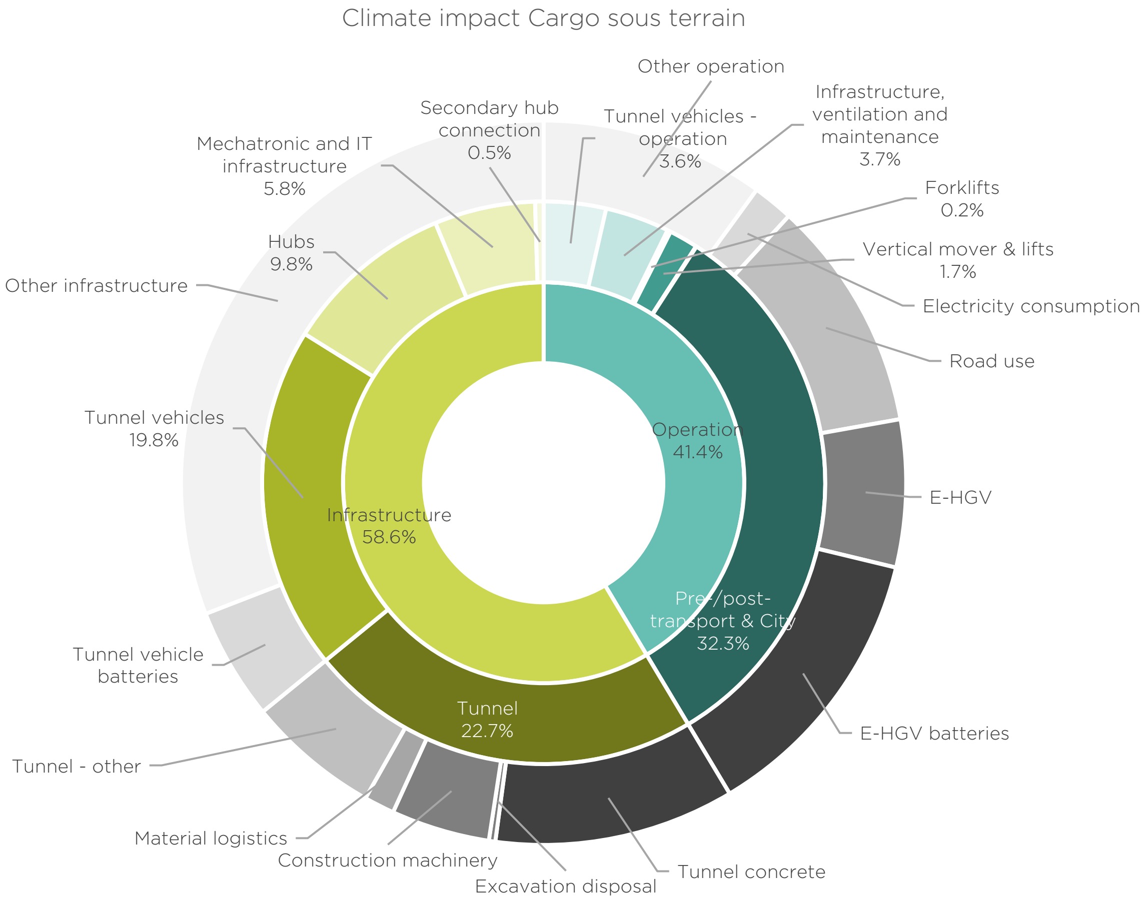

Figure 11: Allocation of the CST system's climate impact (per year, IPCC 2021)

When considering only the project's climate impact, it is notable that the operational component is somewhat lower. This is mainly because the fine distribution via E-HGVs performs better in terms of climate impact.

The infrastructure component has a larger share in terms of climate impact. However, the relative proportion of sub-processes remains similar to the overall environmental impact.

3.2 Comparison between Cargo sous terrain and reference systems in 2030

3.2.1 Total environmental impact

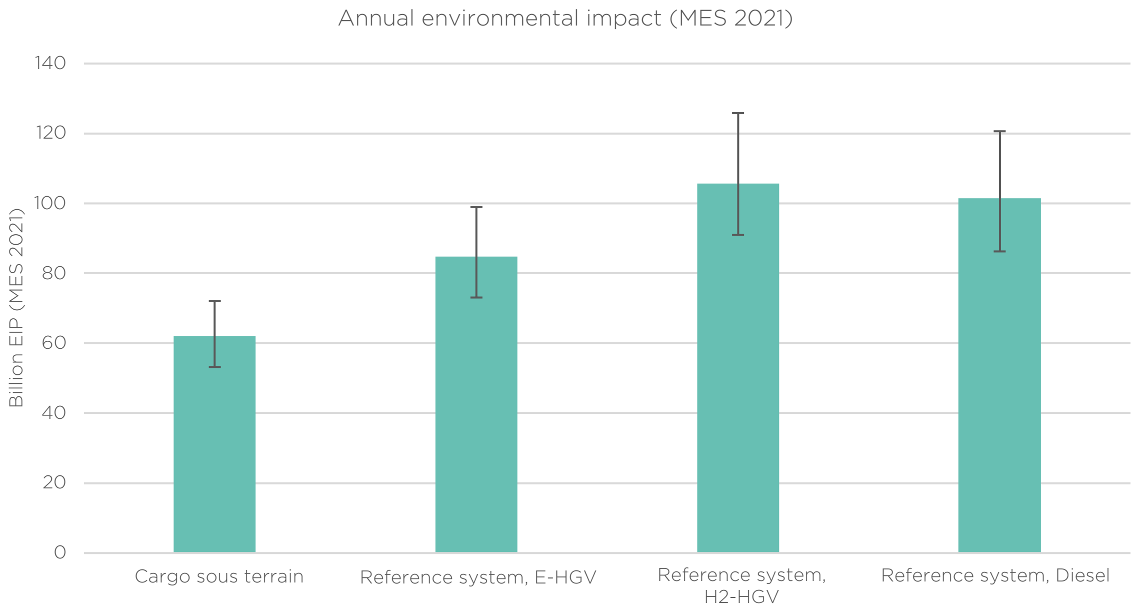

Figure 12: Environmental impact during one operational year for Cargo sous terrain and the reference scenarios (MES 2021)

When analysing the total environmental impact using the 2021 ecological scarcity method, Cargo sous terrain, when using certified electricity, demonstrates a significantly better ecological balance than the two reference scenarios: H2-HGVs (hydrogen fuel cell trucks) and Diesel-HGVs (diesel trucks). The savings compared to the Diesel-HGV scenario amount to over 39 billion EIP per year. A significantly better result is also achieved compared to the reference scenario of electric HGVs.

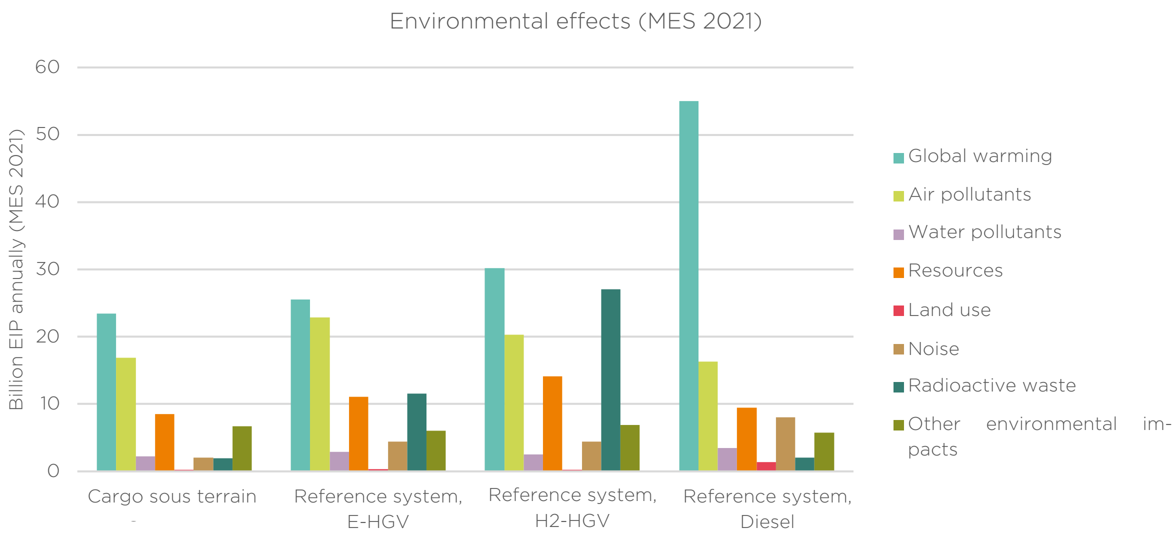

Figure 13: Distribution of the environmental impact of selected scenarios (MES 2021)

As seen in Figure 13, in most variants, a significant portion of the environmental impact is attributable to the effects on climate change. Another dominant source of environmental impact is emissions of air pollutants. In the case of CST, these are mainly attributed to concrete production for the hubs and tunnels, as well as emissions from the fine distribution of E-HGVs (battery production, brake abrasion).

In terms of noise pollution, CST shows clear advantages because a significant portion of the process takes place underground. Hydrogen and E-HGVs also lead to a reduction in noise pollution. However, even with Diesel-HGVs, noise pollution contributes only a small part to the overall environmental impact.

Regarding land use, CST has clear advantages due to its underground concept. The significantly higher land use rating for the Diesel-HGV variant is because diesel contains nearly 5% biofuel diesel, and the cultivation of the required rapeseed results in a substantial land requirement. However, in comparison to the overall environmental impact, land use has marginal relevance.

Microplastics: HGVs have an environmental impact of 2.66 billion EIP per year solely due to microplastics from tire abrasion. In the CST system, this impact is reduced to 1.16 billion EIP per year. This reduction is because the distances traveled by trucks on open roads are more than halved. In the CST system itself, there are no microplastic entries into the biosphere due to the closed filtration system.

3.2.2 Environmental impact

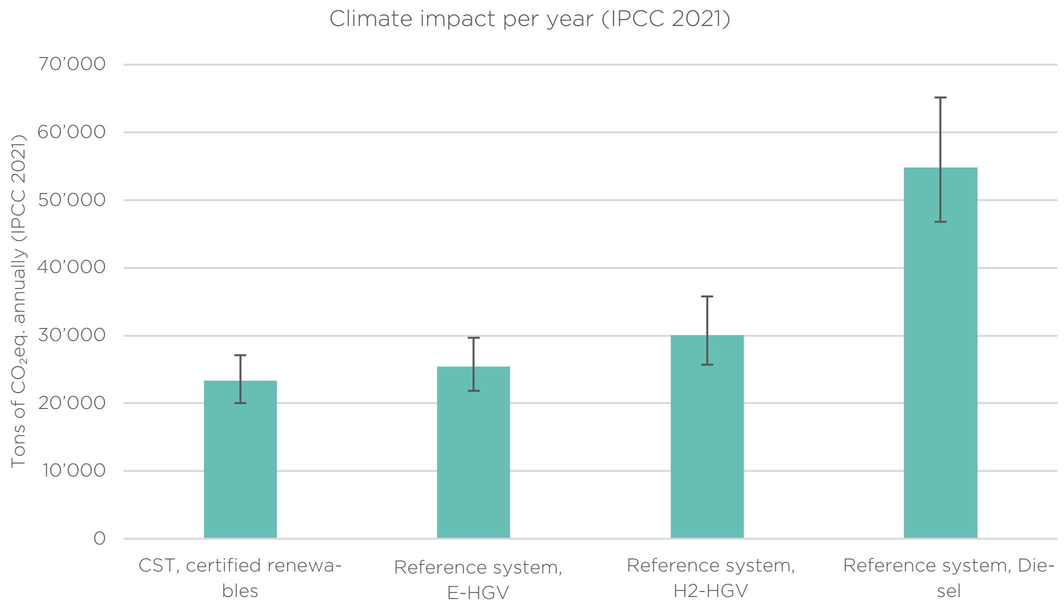

Figure 14: Climate impact during one operational year for Cargo sous terrain and the reference scenarios (IPCC 2021)

When considering only the climate impact, the diesel reference system has by far the worst result. CST has the most favorable climate impact. However, within the uncertainty range, the reference systems E-HGV and H2-HGV have a similarly good climate impact.
It's important to note that the climate impact is just one of many environmental impacts. Interpreting it in isolation should be done with caution, as it can lead to incorrect conclusions from an overall environmental perspective.

3.3 Reference scenarios

3.3.1 Development in 2040 and 2050

So far, calculations have been made based on technologies expected to be in use around the year 2030. However, since CST's infrastructure is particularly durable, the comparison was also modelled for potential future developments up to 2040 and 2050.

The development of the Swiss electricity mix plays a significant role in this context. In this regard, calculations were made using the future scenario ZERO, based on the Energy Perspectives 2050+ provided by the Federal Office of Energy in 2020. This electricity mix is relevant for the E-HGV and H2-HGV (energy for the electrolysis of hydrogen) scenarios. Since the standard electricity mix is increasingly approaching the certified electricity mix in the future, calculations with the certified electricity mix were omitted for the future scenarios of the reference systems.

Consideration was also given to the fact that the volume of transported goods will increase in the future. The extent of the increase was determined based on the values from the BASIS scenario of the Transport Perspectives 2050 (Federal Office for Spatial Development (ARE), 2022). These forecast a 6.9% increase in freight transport by 2040, and a 14.1% increase by 2050, compared to 2030.

For the year 2050, the expected fleet mix was also taken into account. According to a study focused on emissions-free transportation until 2050 (Transport & Environment, 2022), it is projected that even in the year 2050, 13% of the vehicles on the road will still be diesel-powered HGVs. The breakdown of non-combustion engine HGVs is projected to be 90% E-HGVs and 10% H2-HGVs, according to a forecast from Transport & Environment (2023).

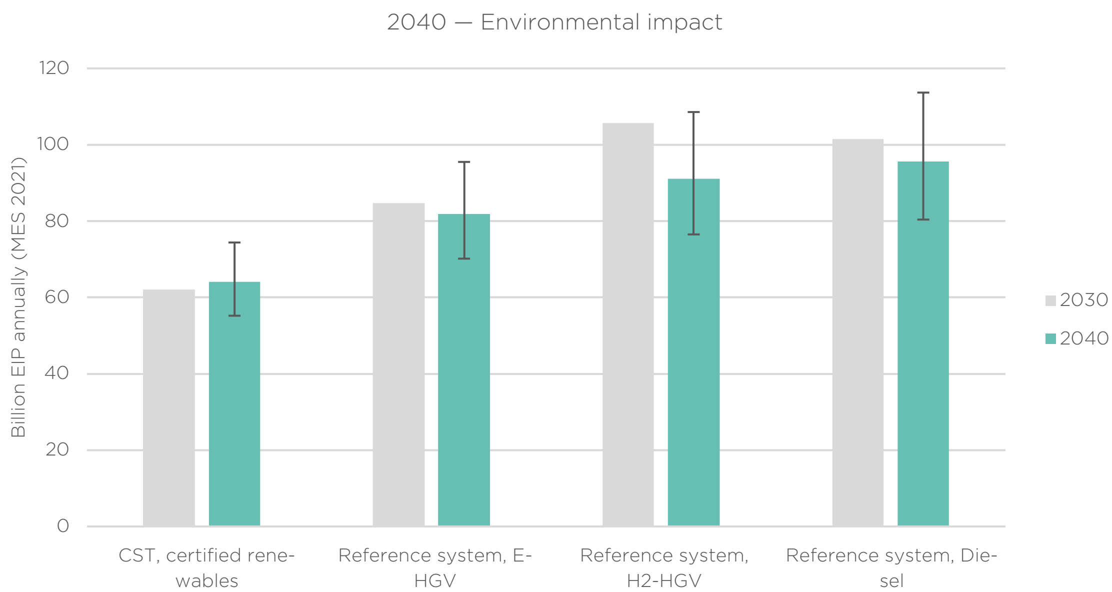

Figure 15: Annual environmental impact in 2040 for CST and the reference scenarios (MES 2021)

In general, the differences between the variants under examination become smaller. On one hand, the volume of transported goods increases, in the case of CST, while the infrastructure remains constant. And on the other hand, the efficiency of the reference scenarios is expected to increase. So, while CST continues to have the lowest environmental impact, it only falls just outside the uncertainty range compared to the H2-HGV and diesel HGV reference scenarios.

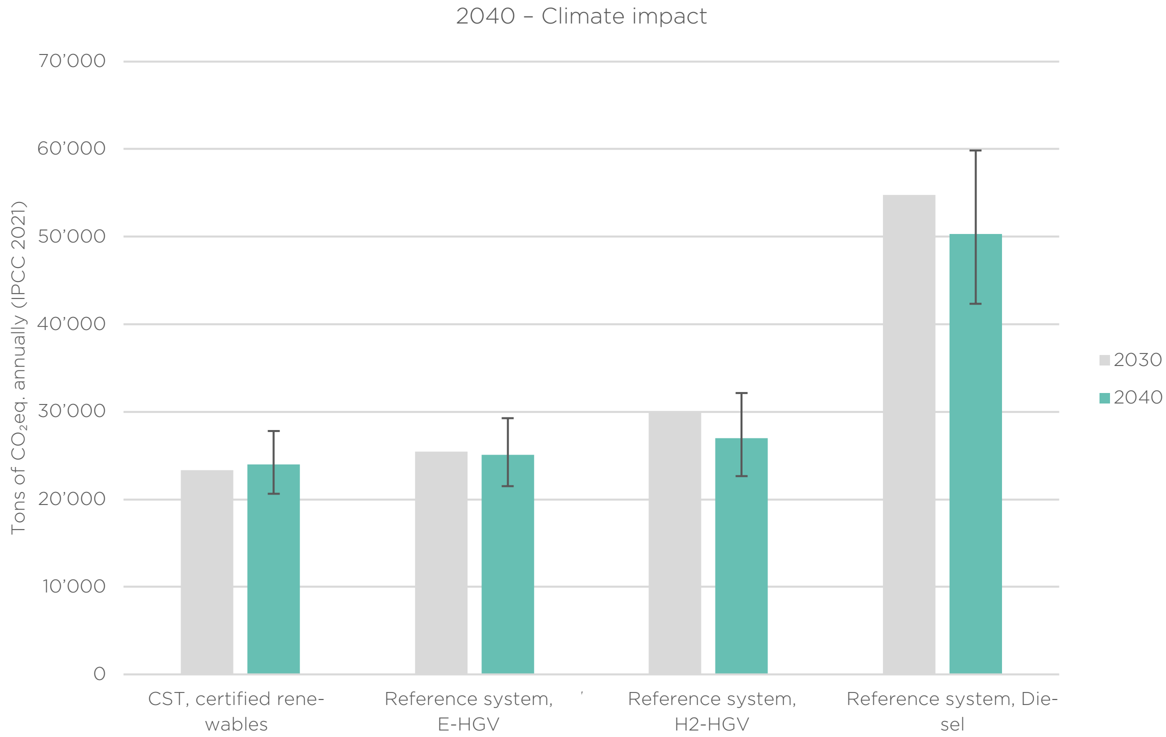

Figure 16: Annual climate impact in the year 2040 for CST and the reference scenarios (IPCC 2021)

Concerning climate impact, the differences between variations become smaller. Although CST still maintains a significantly better climate footprint compared to the diesel reference scenario, the difference is no longer significant compared to the scenarios using E-HGVs and H2-HGVs.

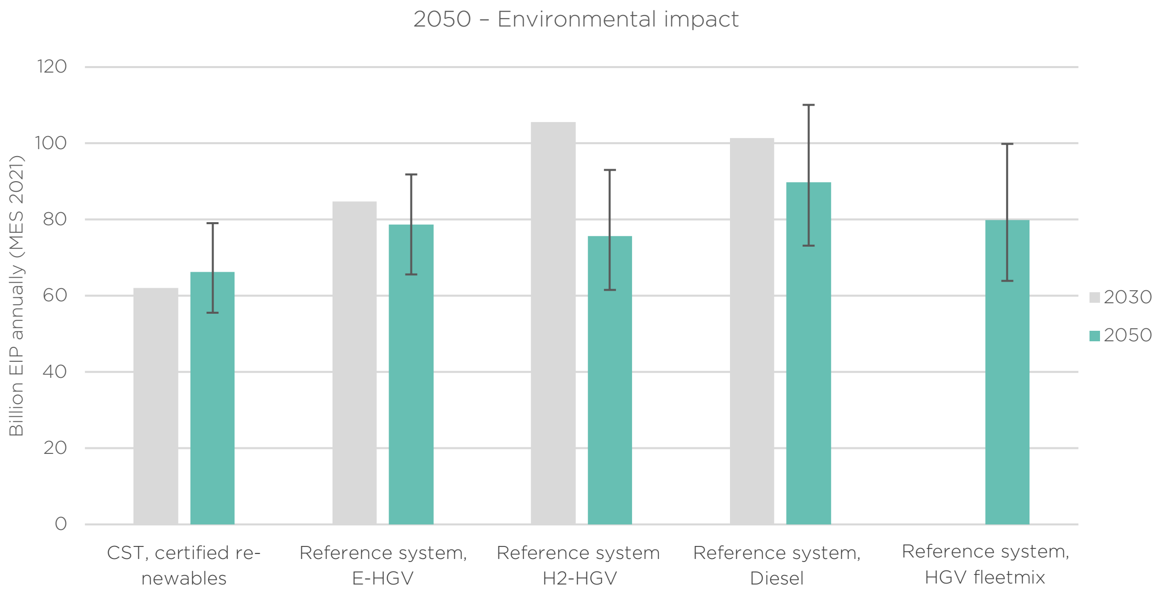

Figure 17: Annual Environmental Impact in the year 2050 for CST and the reference scenarios (MES 2021)

In the year 2050, Cargo sous terrain, operating with certified electricity, tends to show the best result. The Cargo sous terrain system also shows a generally better result compared to the expected HGV fleet mix. However, the differences between the variants are now so small that the increased uncertainty is greater than this difference.

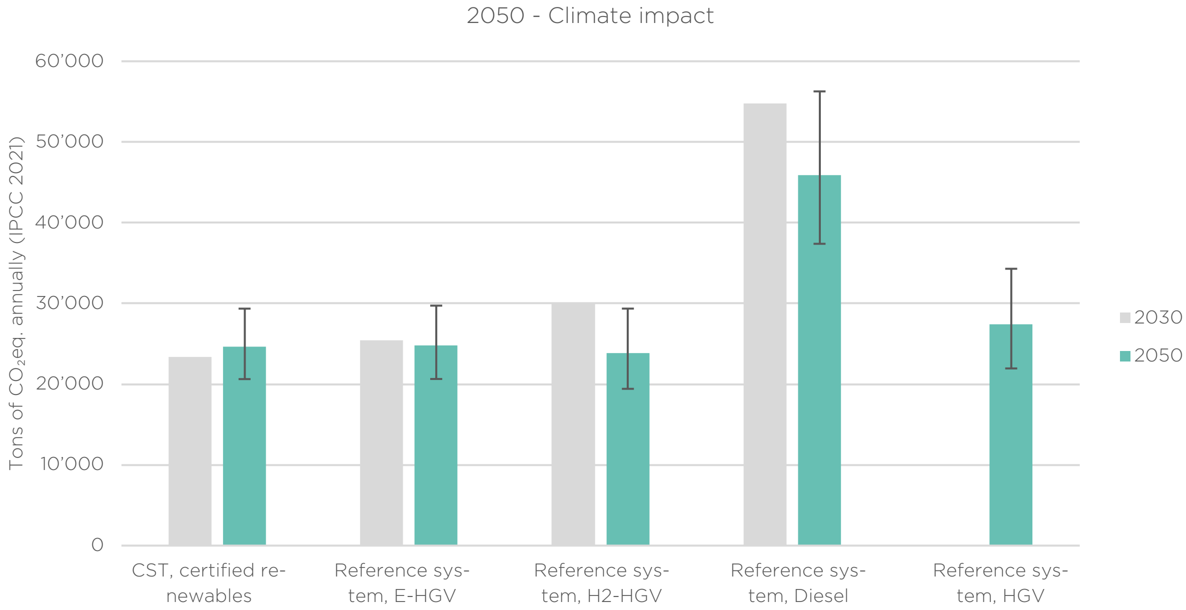

Figure 18: Annual Environmental Impact in the year 2050 for CST and the reference scenarios (IPCC 2021)

Regarding climate impact, in 2050, the diesel HGV variant still has a significantly worse result. CST, together with E-HGVs and H2-HGVs, shows a significantly better result. CST also tends to perform better than the expected HGV fleet mix; however, the uncertainties are greater than this difference.

3.3.2 Utilisation

There is some uncertainty regarding how many goods will ultimately be transported via Cargo sous terrain each year. Since the construction of the infrastructure alone already causes a significant environmental impact, the system's utilisation plays a crucial role. For the calculation of this sensitivity, the electricity consumption for the movement of tunnel vehicles and forklifts for Cargo sous terrain was linearly increased with the amount of cargo. The infrastructure, on the other hand, remained the same. We did not take into account whether larger hubs would be necessary or whether more tunnel vehicles would be needed for goods transport.

In contrast, the reference system already has the infrastructure in place, and it is proportionally allocated to the environmental impact. As an extreme example: if only 1 ton-kilometer is transported via CST, the entire environmental impact of the CST infrastructure as well as the entire operational effort is allocated to that one ton-kilometer. For the HGV scenarios, only the proportion of road, HGV, etc., needed to transport one ton one kilometer is allocated. For these modeling reasons, CST starts with "environmental baggage" in the graphs below (i.e., due to the newly created infrastructure), while the reference scenarios start near zero, because their infrastructure is already in place.

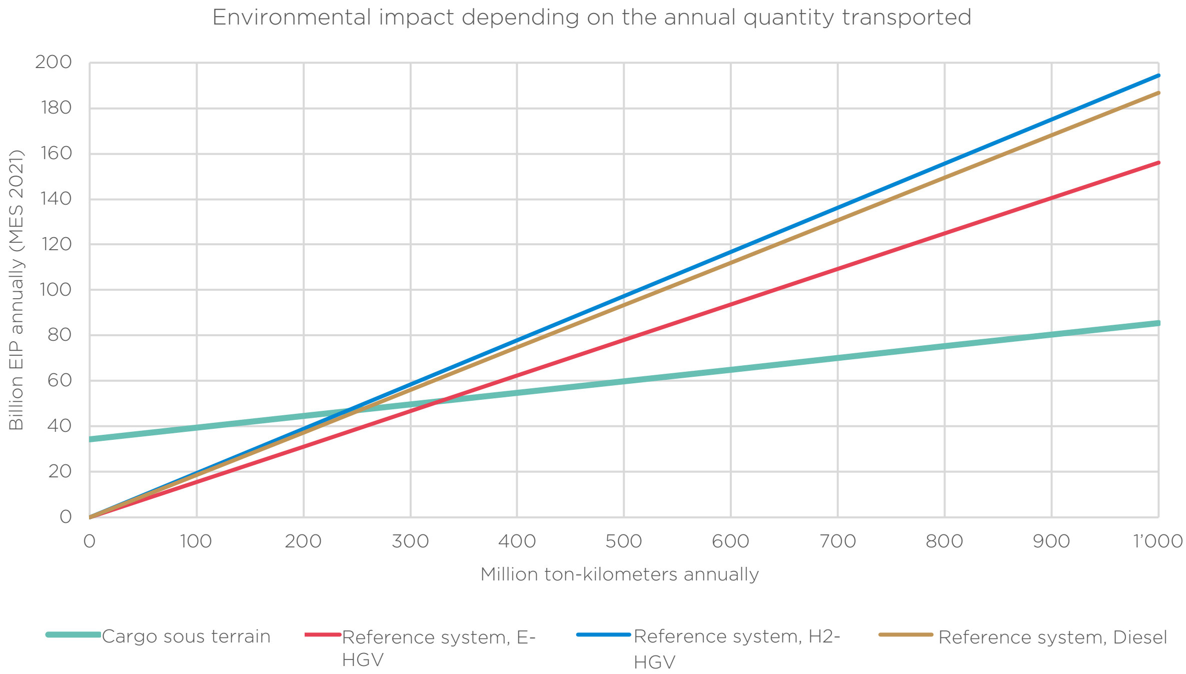

Figure 19: Environmental impact depending on the annual amount of goods transported (MES 2021)

As seen in Figure 19, Cargo sous terrain (CST), using certified electricity, already has a better environmental balance than most of the reference scenarios at an utilisation level of approximately 250–300 million ton-kilometers per year. This corresponds to about half of the planned utilisation of CST.

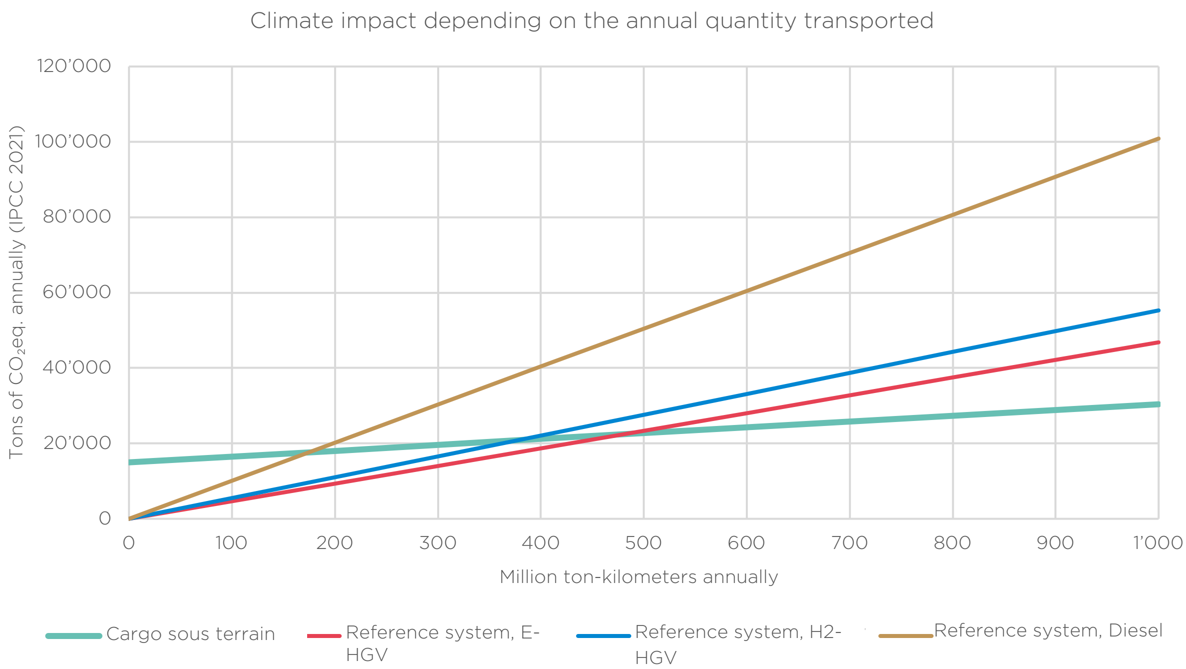

Figure 20: Climate impact depending on the annual amount of goods transported (IPCC 2021)

When considering only the impact on the climate, Cargo sous terrain (CST) using certified electricity already has a better result than the Diesel-LKW reference scenario at a utilisation level of less than 200 million ton-kilometers per year. The scenarios of E-HGVs and H2-HGVs also fall below the planned utilisation of 500 million ton-kilometers per year.

4 Conclusion

From an environmental perspective, we can conclude that CST is likely to result in a reduction of environmental impact compared to the currently predominant logistics system, which relies on diesel-powered HGVs. Without certified electricity, the savings amount to 18,400 tons of CO2-eq. per year; with certified electricity, the savings are in the range of approximately 31,500 tons of CO2-eq. If CST operates using certified electricity, it will achieve a better ecological balance all the way up to reference year 2030, compared to the E-HGV and H2-HGV reference scenarios, if the latter operate with standard electricity.

For the reference years 2040 and 2050, this advantage of CST becomes smaller as the standard electricity mix becomes less environmentally impactful. If the E-HGV and H2-HGV reference systems were entirely operated with green electricity, they would already have a similar ecological balance within the scope of uncertainty as CST, from 2030 onwards.

In general, this study yields similar results to the previous study. The data quality has further improved in this regard. Particularly, the infrastructure itself has been described in more detail, which is why the life cycle assessment of CST tends to be higher.

However, it should also be noted that with the method of life cycle assessment alone, not all relevant sustainability factors are covered. For example, social and economic factors are not taken into account. However, in a century-spanning project of such magnitude, factors such as the impact on employment and the economy should also be considered, as was done, for example, in the ZHAW study (Steiner et al., 2023).

Even indirect effects were only briefly touched upon in this study. For instance, the study has not assessed to what extent there is enough certified electricity available for the operation of CST until 2030. Furthermore, only the linear indirect effects on the road network were examined (e.g., reduction in road usage share), but dynamic indirect effects were not investigated. For instance, the ZHAW study assumes that thanks to CST, truck mileage in the city of Zurich can be reduced by 25%. 30% of heavy traffic (and thus 3% of all traffic) could disappear thanks to CST (B+S AG, 2023), which in turn should lead to a 5 to 10% reduction in congestion at neuralgic points (Maibach et al., 2016). However, the duration of these effects (e.g., compensation through rebound effects) and the extent of the positive ecological impacts need further investigation. To provide credible answers to these questions, adjustments would need to be made to the life cycle assessment methods, and robust foreground data on transportation development and its consequences should be collected.

Considering that a further increase in freight volume is a reality and that capacities on many routes in Switzerland are limited, the Cargo sous terrain system, especially on heavily congested routes, is an overall ecologically sensible addition to the existing mobility system.

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