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Accounting for Scope 3 emissions for cities through a LCA approach

The City of Fredericia as a case study

(Akifeva, 2020)

Aalborg University

Urban, Energy and Environmental Planning - Cities and Sustainability

MASTER'S THESIS

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PREFACE

This master's thesis was developed for the conclusion of the Master's in Urban, Energy and Environmental Planning, specialization in Cities and Sustainability at Aalborg University. The thesis was done as an individual project carried out during the last semester of the master's, in an academic environment, supported by a supervisor and a co-supervisor.

The project intended to apply the knowledge acquired during the 2 years of the degree to a concrete and real-life example. It was also part of the continuous process of learning to deeply understand some of the tools and concepts previously learned.

The covered topic relates to the application of Life Cycle Assessment to account for indirect, meaning scope 3, Greenhouse Gas emissions on a city scale, using a specific city as a case of analysis.

ACKNOWLEDGMENTS

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I would like to extend my sincere thanks to my co-workers from 2.-0 LCA consultants, for assisting me with their expertise any time I needed and for facilitating me the means and tools to develop this project.

Lastly, I would like to acknowledge the essential emotional support of my family and friends, especially three of my master's colleagues, who encouraged me to proceed and gave some tips to finish the project.

ABSTRACT

Climate change, as one of the main threats to global society nowadays, is mainly driven by human activities in urban areas. In that context has become extremely relevant to account for cities' Greenhouse Gas (GHG) emissions and to apply proper, accurate and trustworthy methodologies for that.

This project explores the general challenge for cities to account for their emissions, defining the two different perspectives: the direct perspective (scopes 1 and 2) and the indirect one (scope 3). It is used a specific case study, the city of Fredericia, in order to calculate scope 3 emissions for the transportation sector and to analyse the city's Climate Plan. The applied methodology uses the Life Cycle perspective and tools for calculations, together with desk research and interviews with two representatives from the municipality.

The total GHG emission from the transportation sector in the city of Fredericia in 2021, calculated for scope 3, is 835,56 ton CO2-eq/capita which is higher than the results for scopes 1 and 2. Comparing the modes of transport, Road transport is the one emitting more GHG emissions, followed by Flight mode and Rail transport.

This project also calculates one scenario based on one of the goals for the transportation sector from Fredericia's Climate Plan. The total GHG emission from the Cars category in the city of Fredericia, calculated for the scenario on scope 3 is 45238,811 ton CO2-eq. This value is higher than the baseline and even higher than the total amount of emissions of the whole transportation sector in 2021. The highest contributors are cars run by diesel.

The climate plans are currently elaborated based only on the direct emissions, excluding an important part of the total emissions of a city and leaving important sectors out of their mitigation strategies. On the other hand, accounting for the indirect ones requires some methodologies that are difficult to apply given the areas of influence that the municipalities can act upon.

This project's approach allows to understand how cities can use scope 3 to calculate emissions to obtain more accurate results and elaborate more effective and comprehensive climate mitigation plans.

LIST OF ABBREVIATIONS

CO_2 Carbon Dioxide

CH_4 Methane

e.g. Example

EUR Euro

FU Functional Unit

GPC Global Protocol for Community-Scale Greenhouse Gas Emission Inventories

GWP Global Warming Potential

GHG Greenhouse Gases

H_2 Molecular Hydrogen

IO Input-Output

IPCC Intergovernmental Panel on Climate Change

kWh Kilowatt-hour

LCA Life Cycle Assessment

LCIA Life Cycle Impact Assessment

MEUR Million Euros

MJ Megajoule

N_2O Nitrous Oxide

PAS Publicly Available Specification

SDG's Sustainable Development Goals

UN United Nations

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1. Introduction

Climate Change and IPCC Scenarios

United Nations (UN) claims that "we are at a defining moment" to prevent the catastrophic events that may occur due to climate change. Although the world is already experiencing the consequences of those changes such as floods, cloudbursts, or inconsistent food production, the problem will be exacerbated if no actions are taken. (United Nations, n.d.-a)

Climate change is the consequence of emitting Greenhouse Gases (GHG) to the atmosphere, produced by human activities. The main GHGs are Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and Molecular Hydrogen (H_2) (World Meteorological Organization, n.d.). The one produced in the highest quantity is CO_2, mainly as a result of the combustion of fossil fuels to power human activities, in industries, energy production and transport (United Nations, n.d.-a).

The UN Intergovernmental Panel on Climate Change (IPCC) launches a report every 7 years with the assessment of the current state of the knowledge on climate change, the present and future impacts according to different emission scenarios, and possible courses of action to reduce the climate change pace (IPCC, n.d.). The IPCC models estimate the increase in global surface warming in the range of 2 to 6 ◦C for the next century depending on the scenario. Figure 1, presents the three different scenarios (high, moderate and low) for the variation of emissions, influenced by the extent of the use of fossil fuels. (NASA, 2007)

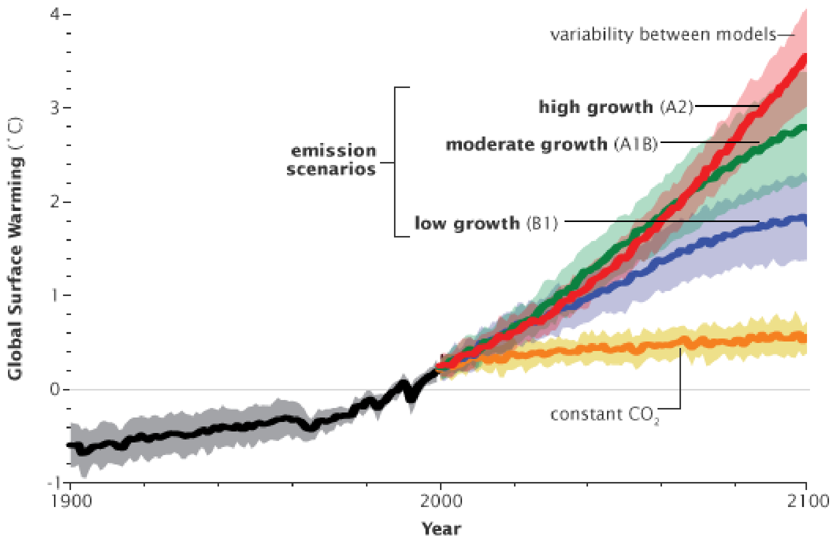


Figure 1 - Variation of the Global Surface Warming according to 3 different scenarios of CO2 emissions (NASA, 2007)

The last IPCC report was launched in 2023, and says that climate change is undoubtedly putting ecosystems and the worldwide population at risk, especially if it exceeds 1,5◦C global temperature. Therefore, the sources of emissions should be identified and there should be a transition to low-emissions and more sustainable systems (United Nations, n.d.-a). In that regard, the IPCC report identifies "land, energy, industry, buildings, transport, and cities" as the areas that should be acted upon, establishing targets of reducing CO_2 emissions to 45% from 2010 levels by 2030 and being carbon zero in 2050. To achieve those goals, UN promoted international agreements such as the "Kyoto Protocol" and the "Paris Agreement" (United Nations, n.d.-a).

Cities

Cities are the basis of the developed countries' economy, centralizing the majority of the population, services, technologies and infrastructures (European Commission, 2020; Eurostat, 2011). Cities represent one of the core places, as they represent the main drivers of climate change, with 60% of the total GHG emissions coming from activities that take place in urban areas (Harris et al., 2020).

More than half of the population currently live in cities, and this number is expected to increase in the next decades. Cities represent the place for opportunities to develop climate change mitigation strategies, since they bring together citizens, organizations, and public institutions with the knowledge and technology to perform a turnover of the current emissions trend (Crane et al., 2021; European Commission, 2020). Therefore, the quantification and documentation of GHG emissions for urban areas are crucial, so that climate change mitigation strategies are suitable and effective (Lombardi et al., 2017).

In that context, it is important to base the strategies on accurate and quality data, which is not currently the case. According to the literature "Decisions on climate are currently based on missing, outdated, misleading, inconsistent, untransparent, proprietary data and populism." (Schmidt, 2023). So, there is a general need for better methods, meaning the development of accurate and trustworthy accounting systems to improve urban planning strategies.

The combination of "Cities" and "Climate action" is part of the Sustainable Development Goals (SDG's), stated by the United Nations. SDG 11 – Sustainable Cities and Communities and SDG 13 – Climate Action (Figure 2), integrate the need for Climate Change mitigation strategies to develop more resilient global communities (United Nations, n.d.-b).

Figure 2 - SDG 11: Sustainable Cities and Communities and SDG 13: Climate Action

Accounting GHG on a city level

However, the awareness of the need to account for accurate and trustworthy emissions on a city scale remains a flaw in the scientific and political systems. IPCC published some methods to account GHG emissions, but they are suitable on a country level (Dahal & Niemelä, 2017), meaning that there is a need to narrow them down to a city level.

To achieve the global targets of decreasing emissions, cities should also account for their GHG emissions and state their own goals to apply adequate policies to decrease those emissions. However, this remains a challenge, due to the great diversity of activities and sectors interlinking with each other in the urban realm, making it a very complex system to deal with. Furthermore, cities also interact with external activities and resources to sustain their living standards, which adds one more level of complexity to the analysis. (Dorr et al., 2022)

In light of the issues described, some of the big cities in the world, came together to build a solution, translated into the creation of climate plans (the C40 project). The goal was to achieve a common ground so each city would be able to account for its emissions and develop a climate plan that goes according to the Paris Agreement goals, stating an approach of concrete measures to reduce half of their emissions by 2030. (C40 Cities, n.d.).

However, there is another challenge arising from the climate plans, which is the assessment of the impact of the implemented measures and the calculation of their decarbonization value. Another issue in calculating such emissions is the lack of existing tools that integrate all cities sectors. (Dorr et al., 2022) Adding to that, there is a general confusion in the field because throughout the years, researchers and political institutions have been using different methods to gather data and define what should be accounted for the total GHG emissions on a city scale. The lack of a standardized method led to the use of different names for the same concepts and the impossibility of comparison between cities, contributing to high uncertainty and a lack of effective policies. (Lombardi et al., 2017; Osei-Owusu Kwame et al., 2020)

The current state of accounting - Scopes 1 and 2

GHG emissions can be grouped into 3 scopes, according to the source of emissions and the accounting method. The most common methodology in the literature and European regulations for cities is the accounting of scope 1 and 2 emissions. Scope 1 accounts for the emissions produced by the activities that are controlled by the entity in question, or inside its defined boundary (e.g. fuel combustion). Scope 2 refers to the emissions coming from an energy source outside the boundaries but that is used by the entity (e.g. purchase of electricity from an external producer). Scope 1 and 2 are, in that regard, called “direct” GHG emissions. (EPA, 2023a; Wei et al., 2020) Scope 3 emissions will be further explained in the chapter.

In the city context, scopes 1 and 2 are translated into “territorial-based” emissions, meaning that they represent the emissions occurring inside the city borders, by all the activities occurring in the defined urban limited space together with the energy produced somewhere else but used inner the urban area. (Harris et al., 2020)

Although IPCC launched the guidelines to account for GHG emissions on a national level, the “2006 IPCC Guidelines for National Greenhouse Gas Inventories” (refined in 2019), there was still a lack of methodologies to be able to be applied on a local level which were universally recognized as compliant with IPCC guidelines, so the “Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC)” was created to meet that need (C40 Cities Climate Leadership Group, n.d.; IPCC, 2019; Marques, 2014).

The published methodologies, developed for cities to account for their emissions, are mainly based on direct sources, restricting the boundaries of the system to the inventory of the activities happening inside the urban realm, such as transportation, energy, produced waste, agriculture and industries (Eichel et al., 2021). Using such an approach, which only focuses on territorial and production-based emissions, raises issues on the accuracy of the accounting on a city level because a city does not exist in an isolated space but in a global-wide context, meaning that this “direct” approach fails to look at the entire city’s supply chain (Harris et al., 2020).

To sustain the city households or the population's lifestyle, and also to support most services and industries, the activities happening in the city have to rely on outside sources and not only on its pure geographic or administration borders. This way, cities end up outsourcing a significant part of their emissions, meaning that accounting for the emissions exclusively based on territorial inventories does not translate the reality. (Marques, 2014)

Furthermore, the products consumed inside the city, are integrated into a supply chain that carries environmental impacts along the way, which accounting from a simple territorial perspective does not include. That situation is then translated by the fact of moving to somewhere else the emissions of what is consumed in the city but produced outside its borders, which most cases have a greater impact (Ivanova et al., 2017). To overcome these issues, and be able to reflect outside trades, methodologies should rely on a consumption-based approach instead (Dahal & Niemelä, 2017; Dorr et al., 2022; Harris et al., 2020).

Scope 3

This approach means taking into account the GHG emissions of the life cycle of the goods and services consumed in the city, allocating the emissions to the consumers instead of the producer. The life cycle of a product means the inclusion of all the phases from the extraction of raw materials, manufacture, transport, retail, use and disposal, which allows the integration of the emissions occurring in the area outside the city borders, linking the city with a global context of environmental impacts. (C40 Cities Climate Leadership Group et al., 2018; Dahal & Niemelä, 2017; Ivanova et al., 2017)

The consumption-based approach is connected with the scope 3 emissions. Scope 3 relates to the activities not controlled by an entity but that are essential to support its activity, meaning that they are indirectly influenced by it. That means that scope 3 includes the emissions outside of the organization's borders. It is extremely relevant to look at because, most of the time, scope 3 emissions are actually higher than scopes 1 and 2, and they can represent the majority of the emissions that an organization has. (EPA, 2023b)

In the context of a city, scope 3 refers to the accounting of emissions of goods and services purchased and consumed by citizens and organizations in the city but produced outside its boundaries, which inevitably represents a significant amount of GHG emissions induced by it. The report of these types of emissions is then aggregated into categories of consumption rather than sources of emissions per sector as scopes 1 and 2 do. The categories stated on the "Greenhouse Gas Protocol corporate value chain scope 3 reporting standard" are the following:

- capital goods;
- fuel- and energy-related activities;
- transportation and distribution;
- waste;
- business travel;
- end-of-life treatment of sold products.

(C40 Cities Climate Leadership Group et al., 2018)

Figure 3, illustrates the boundaries of the 3 scopes applied to a city according to the C40 Cities Climate Leadership Group, where scope 3 emissions are mainly generated from waste, energy and transportation lying outside the physical borders of the city but generated from the activities occurring in it.

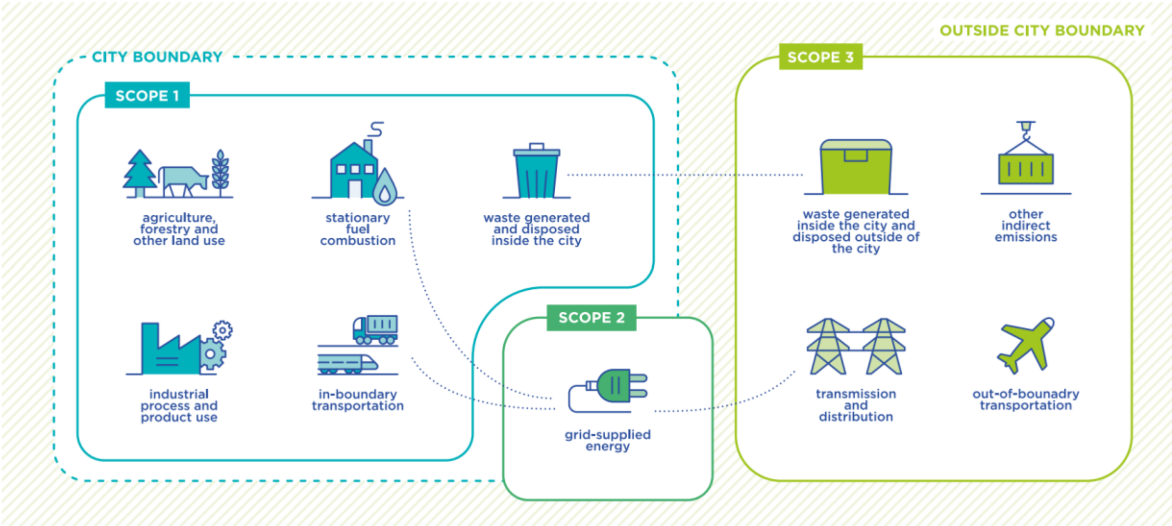


Figure 3 - Boundaries of scopes 1, 2 and 3 for a city (C40 Cities Climate Leadership Group et al., 2018)

The scope 3 accounting systems are gaining relevancy in the literature. Studies show that consumption-based emissions are actually increasing in the European Union countries because the climate mitigation measures that have been applied are only based on direct or territorial approaches (Dahal & Niemelä, 2017). This shows how altering consumption can play a relevant role as a strategy to decrease emissions (Mirabella et al., 2019). Furthermore, the literature defines consumption-based calculations as more accurate because they represent a more comprehensive approach (Lombardi et al., 2017). Moreover, studies on scope 3 results usually show a higher footprint when compared to the results obtained for scopes 1 and 2 (Minter et al., 2023). Table 1 summarizes the main differences between direct (scopes 1 and 2) and indirect emissions (scope 3).

As an example of the increasing literature available on indirect emissions, a study was conducted for 10 big European cities such as Barcelona, Copenhagen, and Lisbon, where the production-based GHG accounting was compared with the consumption-based one (Harris et al., 2020). Moreover, Sweden developed a publicly available digital tool for cities to map the consumption-based emissions of Swedish households (The one planet Network, 2022).

Table 1 - Differences of the accounting system between scopes 1, 2 and 3 (Adapted from (Lombardi et al., 2017)*)*

	Direct Emissions	**Indirect Emissions (Life Cycle Based)**
Scope	1, 2	3
Accounting system	Territorial	Consumption-based

Currently, there is only one internationally recognised standard to account for scope 3 emissions in cities. Such methodology is described in PAS 2070, which bases the calculations on the expenditures on goods and services by households and the government. It then applies Input-

Output economic trade tables and multiplies by emission factors to obtain the GHG total emissions. (C40 Cities Climate Leadership Group et al., 2018)

This methodology was applied to the cities member of C40, and it showed the relevancy of consumption-based GHG emissions, once they have been proved as being higher than the sector-based accountings. It also proved that cities have an impact on a global scale and how much they are indeed dependent on the trade of goods beyond their boundaries, meaning that there is a large amount of traded emissions that are usually not accounted for. (C40 Cities Climate Leadership Group et al., 2018)

Nevertheless, this scope is not being accounted for in most cities, especially with a medium and small size, because there is no demand for the reporting of these emissions in international regulations yet (Mirabella et al., 2019). That is translated into the lack of strategic measures to reduce them. City climate plans are still strictly built based on scope 1 and 2 calculations and thus develop strategies only to mitigate direct emissions, missing an important part of the emissions and producing ineffective climate change mitigation policies. (Dahal & Niemelä, 2017)

Another reason for the lack of scope 3 accountings in cities is the difficulties that Municipalities face when applying the methodologies. It is more accessible to gather data and apply actions on the sources they can directly control (C40 Cities Climate Leadership Group et al., 2018). The consumption patterns relate to external drivers, such as lifestyle habits, economic power, and the private sector, which are complex systems, difficult to gather data and act upon. This also raises questions on how and what areas the public sector can really influence or control (Minter et al., 2023).

When applying the life cycle thinking to city dimensions, and specifically the Life Cycle Assessment (LCA) tool, three main areas represent a current challenge:

- Definition of study boundaries
- Gathering data and assess its quality
- Definition of the functional unit

(Mirabella et al., 2019)

The definition of proper system boundaries concerns the city definition and what an urban area includes, which varies according to different authors. The urban area can either be based on population density, administrative, functional, or morphological boundaries (Albertí et al., 2017). The administrative approach is connected with the political area of administration, while the functional approach refers to the aggregation of certain economic activities and the morphological one relates strictly to the territorial boundary such as land use, cover or the built environment (Mirabella et al., 2019).

The data collection is a very important part of the methodology but remains a big challenge for the accuracy of the calculations in cities. There is a lack of available data on a regional level, meaning that most of the cities use proxy data from the country level. There are also small quantities and irregular consumptions for certain products that are not reported, which makes the inventory incomplete. Furthermore, it is difficult to gather data on consumption patterns by households or private sectors due to credibility and confidentiality concerns. (C40 Cities Climate Leadership Group et al., 2018; Ivanova et al., 2017)

The functional unit is hard to define for a specific city, once it depends on the sectors assessed and scale. Because a city is a multifunctional space it is not clear what is the “function” of a city and even harder to quantify it, so the functional unit can have different meanings according to the approach, e.g. “neighborhood”, “per habitant”, “household”, etc. (Dorr et al., 2022)

To overcome the challenges of applying scope 3 emissions to a such border scale, meaning to an entire city, some authors applied the methodology to a specific sector, such as energy, buildings, transportation, waste and water management. (Dorr et al., 2022)

Transportation and Urban Planning

One crucial tool to mitigate climate change in the city context is Urban Planning. With industrialization, the number of population and the need for infrastructure, such as transport or housing, increased. This pressure in the urban areas led to environmental damage, traffic congestion, and public health problems, that forced the creation of regulations to control cities' growth and development. So, Urban Planning appeared during that period, to address the problems caused by the chaotic development of urban areas. (Chigudu et al., 2021).

Currently, Urban planning serves the same principle and it is translated by political laws and regulations that define the specifications of land use and other physical infrastructures, to ensure a sustainable and organized use of the space and resources, according to the needs of the current and future population. It is planned to integrate the national and the local level, bringing together different sectors such as transport, energy, housing or industry. Environmental considerations are also an important part of city planning. (Chigudu et al., 2021)

The city's shape and physical structure highly influence the citizen’s behaviour and the need to consume resources, which can consequently have impacts on the environment (Høyer & Holden, 2003) and potentially drive climate change through the emission of GHG. For that reason, it is crucial to plan the urban space better, in order to apply proper strategies to mitigate climate change impacts.

The transportation sector is one of the sectors that are highly dependent on urban shape and city planning. It is also one of the sectors most responsible for the emissions of GHG and consequently one of the main drivers of climate change nowadays. The transportation sector is, as an example of relevancy, the second with the highest consumption footprint in Denmark. (Minter et al., 2023)

The use of transportation modes comes from the need for travelling from one point to another, making transportation one of the pillars of the city’s socioeconomic relations. For that reason, land use planning and transport are co-dependent, once the first regulates the demand for the second (Freire et al., 2001). The way cities are built nowadays translates a high demand for motorized vehicles that emit GHG. On the other hand, evidence shows that communities with a specific city shape (usually higher density and greater connectivity with a high mix of uses) are more willing to use soft modes of transport such as walking or biking, than low-density and single-use neighbourhoods (Saelens et al., 2003).

1.1. Problem formulation

Climate change is an increasing threat to our societies which may have devastating effects if mitigation actions were not taken. It is a consequence of emitting GHG produced by human activities, being crucial to re-think how society works on a comprehensive and global scale so we find more sustainable procedures.

Cities are at the core of the problem, not only because the population living in cities, and the activities occurring there, are the main drivers of climate change but also because cities are the centre of knowledge and stakeholders with the power to put into practice those mitigation actions.

Such actions require accounting of GHG emissions, so they can be suitable and effective. In that regard, there is a need for accurate and trustworthy accountings, but currently, that is not the case. It has been revealed a challenge to apply proper methodologies on a city scale, given the complexity of activities interacting with each other.

For the time being, climate mitigation plans and strategies are only based on direct emissions, meaning scopes 1 and 2, that centre the accounting on the activities occurring inside the city borders and producing GHG emissions. However, the literature supports another method as suitable and more accurate, which is the accounting of indirect emissions instead, meaning scope 3 emissions. This method would be based on a Life Cycle perspective, which translates a more comprehensive way of accounting for emissions on an urban scale, once it places the city in a global context through the product's entire chain, including the emissions demanded by the activities occurring in the city but produced somewhere else.

Nevertheless, it remains a problem to apply such methodology to cities, because they face methodological challenges mainly in defining proper city boundaries, data collection and defining a proper functional unit. In order to overcome these issues, some authors purposed to apply the method to the sectors of the city separately. This project is then focused on the transportation sector for being one of the sectors with the highest GHG emissions on a city scale and for being co-dependent of Urban planning.

Taking into account the problem exposed, the present project followed the guidance of the main research question (RQ):

How could the accounting of GHG emissions of cities translate a more comprehensive approach, to improve the city climate mitigation plans in the transportation sector?

To help answer the main question, three sub-research questions were posed, tackling two sides of the problem. One with a theoretical approach that intends to open the discussion and debate on scope 3 accountings on a city scale and another as a practical approach, where calculations on scope 3 for the transportation sector were used to show concrete results:

Sub RQ 1: How are the accounts currently made and how are climate mitigation plans currently developed for cities?

Sub RQ 2: How life cycle thinking and the use of IO tables can be applied to contribute to the accounting for scope 3 emissions?

Sub RQ 3: What information scope 3 emissions add to the climate mitigation plans of a municipality and to what extent can they elaborate strategies for those sectors responsible for such emissions?

This project followed the structure summarized in Figure 4, starting the problem on a broader scale and narrowing it down to a more specific scale. Once the problem is formulated, methods that will be further described in the next chapter are applied to answer the Research Questions. Once obtained the results, the discussion section intends to bring back the broader scale of the project.

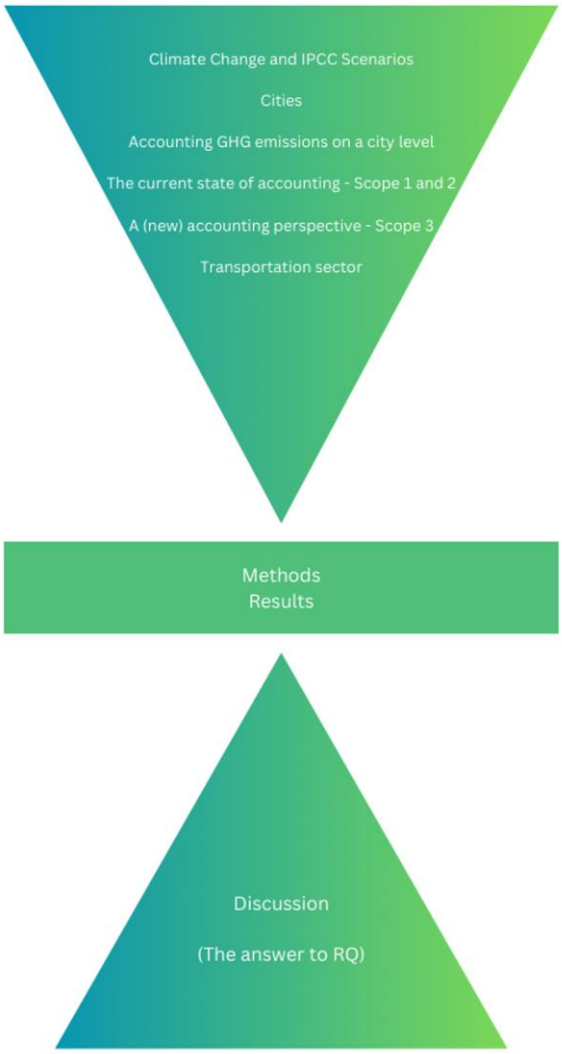


Figure 4 – Project's structure

2. Methods

This project uses the city of Fredericia, in Denmark, as an example and a case of analysis. Fredericia is an example of medium-sized cities, which have a lack of studies in the literature on scope 3 emissions accounting. Fredericia is a relevant case of analysis, as it currently accounts only for scopes 1 and 2 emissions, facing challenges to account for its indirect ones (scope 3). Narrowing down to a specific sector of analysis, which is a possible methodology perspective stated in the literature, this project has a focus on the transportation sector in Frederica. This sector is the second with the highest emissions in the city, and it will be analysed based on the accountings of its GHG emissions and in the light of Fredericia's climate mitigation plan.

Table 2, shows which method was used to answer each Research Question.

Table 2 - Methods applied to answer the Research Questions

RQ: How could the accounting of GHG emissions of cities translate a more comprehensive approach, to improve the city climate mitigation plans in the transportation sector?	
Sub research question	**Method**
1 How are the accounts currently made and how are climate mitigation plans currently developed for cities?	-Desk research -Interviews
2 How life cycle thinking and the use of IO tables can be applied to contribute to the accounting for scope 3 emissions?	-Life Cycle Assessment (LCA)
3 What information scope 3 emissions add to the climate mitigation plans of a municipality and to what extent can they elaborate strategies for those sectors responsible for such emissions?	-Life Cycle Assessment (LCA) -Interviews

2.1. Life Cycle Assessment (LCA)

The analysis and accounting for scope 3 emissions in the transportation sector in Fredericia are based on Life Cycle Assessment (LCA). LCA is an environmental impact assessment tool, that calculates the environmental impact of products and services throughout its entire chain. It is a tool with a holistic view and it is considered a scientific trustworthy method to assess sustainability (Mirabella et al., 2019). It integrates the indirect sources, retrieving more accurate data when applied to GHG accounting (Lombardi et al., 2017) and making it suitable for supporting better policies and strategies for sustainable development (Mirabella et al., 2019).

This project uses LCA, for being supported by the literature as a suitable tool to account for GHG in a city context and assess urban climate planning. A full LCA is not conducted in this project, yet the LCA framework is explained once it represents the basis of the method applied to calculate GHG emissions of the transportation sector of Fredericia, together with Life Cycle Thinking concepts to analyse the city's climate plan.

LCA can be conducted with two different approaches, attributional and consequential. Attributional is when the system is modelled directly or portioning attributing the inputs and outputs to the functional unit of the product, while consequential links the activities of a product system to the consequence of changing the demand of the functional unit of a product (Consequential LCA, n.d.). This project is aligned with the consequential view. The consequential approach allows a more holistic view of a system, suitable to assess on a global scale, which is represented by the city inserted in a global economy, where indirect emissions (or scope 3 emissions) are translated by the consumption-based footprint related to imported and exported emissions, translating the consequences of changes in demand of the products and activities occurring in the city on a global scale.

Goal and Scope:

One of the requirements when conducting an LCA project is to define the Goal and Scope. The goal of applying the LCA analysis in this project is to determine the GHG emissions from the transportation sector in the city of Fredericia including indirect emissions, both for the sector as a whole and to assess a specific goal of the climate mitigation plan.

The system boundary is the physical boundary of the city of Frederica, specifically, the commuting modes used by the inhabitants of the city. The analysis has the intent of comparing the calculated results for scope 3 with the values already obtained by the municipality on scopes 1 and 2. This would allow to understand what accounting for indirect emissions would add to the climate mitigation planning of the city. The calculations were made for the year of 2021, being the functional unit 1 year of emissions (2021) per inhabitant of Fredericia.

Inventory:

Another section of LCA is the analysis of the inventory. The data for the transportation sector was facilitated by the public local authority of Fredericia. It was the same data used to perform the calculations for direct emissions of the city, once it was the best available one, up to the data collection phase of this project. This sector was the one with more reliable data, and the one with the best potential to be transformed to apply the tools to calculate scope 3 emissions. The data was provided in Energy units, MJ, used per each type of transport by the inhabitants of the city, according to the type of fuel. The transportation modes included in the analysis are Road Transport, Rail Transport and Flight Transport. Table 3, shows those types of transport and the corresponding type of fuel and energy used, called the foreground data. All data is for the year of 2021.

Table 3 - Fredericia's foreground data

Fredericia's foreground data - Transportation		
Mode of transport	**Type of fuel**	**Energy used (MJ)**
ROAD TRANSPORT		
Cars		
Passenger car	Gasoline	540 207 189,8
Passenger car	Diesel	532 808 947,0
Passenger car	Gasoline hybrid	9 894 637,0
Passenger car	Electricity	1 950 728,9
Van	Gasoline	1 355 750,8
Van	Diesel	202 873 370,0
Truck	Diesel	443 556 594,3
Motos		
Scooter	Gasoline	703 019,9
Motorcycle	Gasoline	3 283 229,3

Mode of transport	Type of fuel	Energy used (MJ)
ROAD TRANSPORT		
Buses		
City route bus	Gas (LNG)	32 266 566,8
City route bus	Diesel	42 632 261,4
Tourist and private	Diesel	8 100 107,1
RAIL TRANSPORT		
Regional train	Electricity	3946145,0
Regional train	Diesel	8709421,3
Intercity train	Electricity	6466173,2
Intercity train	Diesel	16662176,7
Speed train	Electricity	4950882,5
Speed train	Diesel	12312395,1
FLIGHT TRANSPORT		
National and International	Aviation fuel	79974731,0

This project's approach to LCA is based on supply-use tables, which are a complete representation of the entire economy of a given country allowing to cover different economic sectors, giving a holistic approach. This analysis is made based on an environmental extended Input-Output (IO) database, that covers the emissions estimated for different industries in different countries. (European Environment Agency, 2019)

The database used in this project is EXIOBASE, version 3.3.16 b2, which is a multi-regional IO database with data for 164 product categories for 43 countries and other 5 regions, allowing a good coverage of countries and their major trade partners. IO databases are built in monetary units, meaning that all the Energy units provided from the raw data were converted to monetary units. This EXIOBASE version works with units applied to the year of 2011 in Million Euros (MEUR2011).

To convert all units in MEUR2011, it was first calculated the corresponding total of Liters used, dividing by the energy content of each type of fuel found in the literature. Table 4 shows the energy content in MJ/L for the fuels used in the different modes of transport in Fredericia. For the ones powered by electricity, it was directly converted from MJ to kWh considering that **1 kWh = 3,6 MJ**.

Table 4 - Energy content of each type of fuel used in the transportation sector

Type of fuel	Energy content (MJ/L)
Diesel	38(1)
Gasoline	33,6(2)
Gas (LNG)	22,2(3)
Aviation Fuel*	36,86(4)

(1) (Giddings, 2016) (2) (Bureau of Transportation Statistics, n.d.) (3) (Reference Guides, n.d.) (4) (The Physics Factbook, n.d.)

*Aviation fuel was considered as Jet-fuel kerosen. Jet fuel is one of the main types of aviation fuel used in general aviation, being the type of Jet-A the most common one, which is composed of kerosen and has similar properties to diesel fuel. (National Aviation Academy, n.d.)

Thereafter, the total price in Euros spent on each type of fuel for the different modes of transport was calculated using the average prices per Liter from statistics for the year of 2011 in Denmark, Table 5 details those prices. Once the final unit needed was million euros the total prices were converted from euros (EUR 2011) to million euros (MEUR2011), those results will be find in the Results Chapter.

Table 5 - Average prices of fuels and electricity in Denmark in 2011

Type of fuel	Average price (EUR/L)
Diesel	1,42(1)
Gasoline	1,62(2)
Electricity (households)*	0,32(3)
Electricity (non-households)*	0,085(4)
Gas (LNG)	2,78(5)
Aviation Fuel**	0,568(6)

(1) (Statista, 2023a) (2) (Statista, 2023b) (3) (Statista, 2023c) (4) (Statista, 2023d) (5) (Trading Economics, 2023) (6) (index mundi, n.d.)

*Electricity prices for households applied to the cars powered by electricity, because they are private and personal passenger cars. Electricity prices for non-households applied to trains, once they are part of a commercial transport mode.

**The price of Aviation fuel (Jet fuel) is an average of the prices per month in the year of 2011 from the literature. Furthermore, prices were converted from EUR2011/gallon to EUR2011/L, knowing that 1 gallon = 3,78541 L (index mundi, n.d.)

To conduct LCA projects, there are available a few types of Software in the market, this project uses SimaPro, version 9.4.0.2. This software delivers the environmental impact results for a given product or service. This project applied the same approach to a product or service, using the different modes of transport as activities linked to the database to calculate the environmental impacts, more specifically, GHG emissions in CO_2-eq.

The level of aggregation of the chosen database for the different types of sectors can be a drawback, but it suits the current project analysis, once it is applied to a broad category of transport modes. Furthermore, EXIOBASE was the database used in the literature to calculate scope 3 for some European cities for being specifically designed to perform environmental analysis. Table 6, shows the background data, meaning the activities selected for each mode of transport in EXIOBASE.

Table 6 - Bridge table

Mode of Transport	EXIOBASE activity
Road Transport	122 Other land transport {DK} (product market, monetary units, purchaser price)
Rail transport	121 Transport via railways {DK} (product market, monetary units, purchaser price)
Flight Transport	126 Air Transport (62) {DK} (product market, monetary units, purchaser price)

SimaPro links each activity with the database, so an activity was created for each mode of transport according to the type of fuel. To have a proper balance of units, it was used 1 MJ of each fuel, and 1 kWh for the electricity. For that, it was necessary to calculate the price in

MEUR2011 per MJ. The created activities can be seen in Appendix A and the obtained values in the Results section.

To calculate the total impact of the transportation sector, all modes and corresponding types of fuel, in energy units (MJ and kWh) were linked to 1 year of transport (see appendix A). The focus of this master's thesis is to obtain the total amount of GHG emissions for the sector. To assess carbon footprints in LCA, the results are obtained in terms of Global Warming Potential (GWP) and units in CO_2 equivalent (CO_2 –eq), meaning that the other gases are converted in the same unit which translates the same amount of CO_2 with the same global warming potential, giving an aggregated result of the whole GHG. The method selected in SimaPro to analyse the activities and obtain the results in CO_2 –eq was IPCC 2013 GWP 100a (see Appendix A).

Scenario

The described method is also suitable to assess the goals delineated by the cities to mitigate climate change. In that regard, the same methodology was applied to assess one of the goals from Fredericia's climate plan on transportation, which is to have 20% of cars running on electricity in 2030.

First, the baseline was calculated by finding the contribution of each fuel used in the cars category (according to the categories description on Table 3) for the year of 2021, in percentage. Those percentages of the baseline were calculated based on the energy data, in MJ, provided by the municipality for the type of fuels used by the "cars". Afterward, the scenario was made by re-distributing the percentages by the other types of fuels (gasoline and diesel) attributing 20% to electricity.

Using the percentages of the baseline and the scenario, the energy consumption in energy units for the new scenario was found. The same procedure previously described to convert the energy units in MJ to Million Euros, was used to calculate the impacts for the new hypothetical situation. Furthermore, the same EXIOBASE activities for Road transport were used in the software once the prices per MJ are the same, linking it with "Cars-baseline" and "Cars-scenario", which can be seen in Appendix A.

Both activities in SimaPro, the baseline (the current situation for the year of 2021 of GHG in CO_2 –eq emissions for cars) and the scenario (hypothetical situation of having 20% of the cars powered by electricity instead) were compared in order to assess if there was a significant change on the impact on GHG emissions when achieving that goal. The construction of this scenario has also the purpose of showing another way of assessing cities' Climate Plan goals (based on indirect emissions).

2.2. Desk research

It was done a document review of scientific papers, official public reports and websites from the Danish Energy Agency, the South Denmark Region and the Climate Plan from Frederica Municipality to understand the global context of the city and to gather information on the state of the accounting of emissions for Fredericia.

In more detail, research was conducted on papers about the municipality published by the South Denmark Region to gather information about the city of Fredericia and to assess its socio-economic context. The emissions trend and the results per sector for Fredericia (scopes 1 and 2) are publicly available on the Danish Energy Agency website, so they were used to compare the results (scope 3) and to understand the status of emissions accountings for Fredericia. The climate mitigation plan written by Fredericia's Municipality was assessed in light of the scientific literature about accounting cities emissions and through an interview that will be following described.

The literature was also central to understand what scope 3 emissions would add to the urban emissions accountings and how it can be used to improve the climate mitigation plans. The results obtained in this project, are further assessed by the values found in the literature.

2.3. Interviews

To get an insight into the methods of accounting GHG emissions for cities in a real case, and in particular, to understand the context of Fredericia, two interviews were conducted with two city representatives working at "Fredericia Kommunne" (Municipality). The meetings occurred both online, and they were meant to collect both qualitative and quantitative data to be used to answer the research questions.

The method used was a semi-structured interview, in which the topic was addressed without posing closed questions, but guiding the discussion based on an open-question format. The selected people are considered stakeholders in the process of climate planning of the municipality and in the process of purchasing products to be consumed under the municipality's jurisdiction, which constitute one of the bases of scope 3 accountings. The answers were noted, and they are integrated comprehensively, stated in different parts of the report.

The first interview was conducted with Lisbet Kristensen, the Climate coordinator of Fredericia Municipality. Lisbet Kristensen works with climate-related projects within the municipality and she is part of the climate plan elaboration (DK2020). The second was made with Lars Jull Achton-Boel, who is among other tasks, in charge of controlling the register of the municipality's purchases.

Both interviews were central to acquire information on the emissions calculation methodologies and who were the main entities involved in the process of accounting. It was also relevant to understand how Fredericia assesses the sectors to include in the Climate Plan, and defines climate mitigation goals for the city. Furthermore, the future plans to improve the methodologies and update the goals and related strategies together with the main challenges faced in all the processes were also topics tackled in the interviews. It was also crucial to recognize which areas of influence the municipality has and to what extent it can influence and cooperate with other stakeholders.

3. Case study description – The city of Fredericia

3.1. About Fredericia

The municipality of Fredericia is located in the Southern Region of Denmark (Figure 5), being part of the "Triangle Region" together with its neighbouring cities, with important economic connections and common planning strategies. It has approximately 52.000 inhabitants according to data from 2021 and the population increased 1,8% between 2017 and 2022 being expected to continue with this trend within the following years (Region Syddanmark, 2022).

Figure 5 - Location of the city of Fredericia (maps Denmark, 2023)

The socioeconomic status can translate the purchaser power of the population, which highly influences the consumption patterns of households, and as a consequence scope 3 emissions. Fredericia's socioeconomic status, represented in Figure 6, shows the majority of the population as working force, 70,1 %, which is approximately the same percentage as the rest of Denmark (Region Syddanmark, 2022).

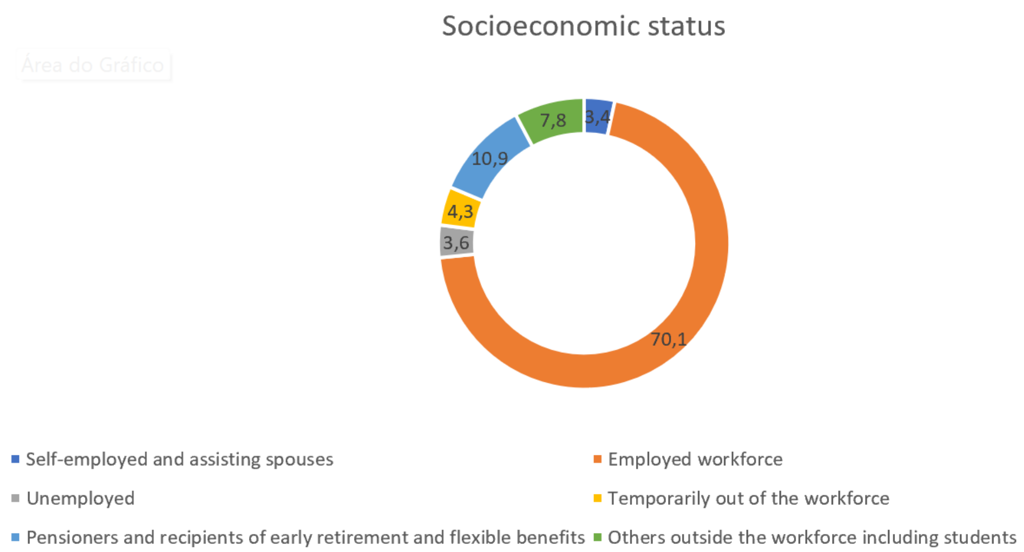


Figure 6 - Distribution of the socioeconomic status (%) for Fredericia's inhabitants (between 25-66 years old) (Adapted from (Region Syddanmark, 2022))

Fredericia is a crucial point for transport and trade in Denmark, as it is located in a coastal and very central area of the country. It represents not only a national but also a European hub where different modes of transportation of goods and people are possible. Fredericia links two important regions of Denmark in terms of economy and population, by car and by train through easy access to two of the most important bridges for mobility in the country. It is also the place of one of the largest commercial ports, making it one of the busiest traffic spots of Denmark and also a crucial point for the establishment of different companies and types of business. It counts with more than 2000 private and public companies such as Carlsberg, Arla, the Shell refinery, Ørsted A/S, Google, and several transport and logistics companies. (Municipality of Fredericia, 2020)

3.2. Accounting CO_2 emissions for the city of Fredericia

With such relevant sectors in the municipality, that are known as high CO_2 emitters, such as energy production and transport hub, it is crucial for the municipality of Fredericia to account for its GHG emissions and to plan the city according to mitigate such impact.
Currently, the calculations are in charge of the energy national public department (part of the Danish Ministry) which is responsible for the development of a national tool called "CO_2 and Energy calculator" funded by an yearly payment by each Danish municipality. That means that each year the municipality receives the calculation of the emissions applied to its territory together with a detailed explanation of what are the (main) GHG sources of the municipality. Such data is then publicly published on a website (Kristensen, 2023). The method, which is applied on a national level, is exclusively based on scopes 1 and 2 emissions, and the results are then reported to the European Union by Denmark. (Region Syddanmark, 2022) Before this tool, each municipality was using different methods and tools, so it was not possible to compare results or measures. South Denmark Region then invested in standardizing the method for all the municipalities which is currently in place (Kristensen, 2023).

The data used in the calculations comes from national indicators and statistics, scaled down for the number of Fredericia's inhabitants (although some of the data can be introduced in the tool by the municipality), which makes it to some extent unreliable or incomplete, according to the opinion of the Climate coordinator of Fredericia Municipality (Kristensen, 2023). As an example, transport is based on interviews on how citizens use the different means of transport and they have only a few interviews to base the data on, meaning that it can be not a fair representation of the habits of the entire population of Fredericia. (Kristensen, 2023)

The calculation method consists of multiplying the data collected by emission factors to obtain the GHG emissions per sector. As mentioned, the results only account for the direct emissions sources within the municipality's borders and the discriminated sectors are: energy, transport, livestock and land use, chemical processes, waste landfill and biogas and wastewater. It is also shown the comparison between sectors and with other years to evaluate the municipality's trend. It is through those results that climate mitigation strategies are created and the already applied climate measures are assessed. (Kristensen, 2023)

Based on the current accountings made for Fredericia, meaning scopes 1 and 2, the city has a total of CO_2 emissions of 701,874 ton CO_2-eq, which represents 13,69 ton CO_2-eq per inhabitant (The Danish Energy Agency, 2021). Comparing the trend between 2020 and 2021, Figure 7, shows a decrease in the total CO2 emissions in the municipality. This is mainly due to the increase in the share of renewable energy sources. Figure 8, discriminates the distribution of the total emissions per sector, in percentage.

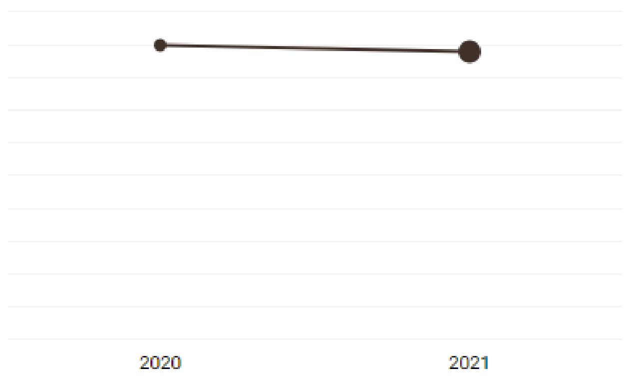


Figure 7 – Trend of the total GHG emissions (in CO_2-eq) of Fredericia between 2020 and 2021 (The Danish Energy Agency, 2021)

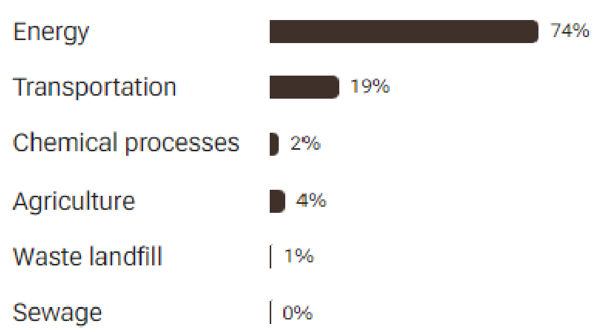


Figure 8 - Total GHG emissions distributed per sector for Fredericia (The Danish Energy Agency, 2021)

In Fredericia, Energy accounts for more than half of the emissions, with 74%. Transportation is also a relevant sector, being the second with the highest emissions, 19%. The rest of the sectors, Chemical processes, agriculture, waste landfill and wastewater represent only a small portion of the emissions, when using the direct emission accounting method. (The Danish Energy Agency, 2021)

The transportation sector refers to all transport that takes place within the municipality's borders as well as citizens' air transport, and it accounts for 130,586 ton CO_2-eq. Road transport is the one contributing the most, where the highest emissions come from the use of personal vehicles powered by diesel. Following the rail transport and the flight mode is the one with the lowest impact, although they have similar impact results (The Danish Energy Agency, 2021)

3.3. Fredericia's Climate Plan

Following the inspiration of the C40 framework, the current state of climate planning in Denmark is materialized in the project DK2020, where the Danish municipalities came together to build a strategy to plan for climate change mitigation for each municipality, based on a global direction. The climate plan is focused on the sectors within each municipality, identifying all the main CO_2 sources, and describing strategies and actions to achieve the targets and goals to decrease those emissions. (CONCITO, n.d.).

DK 2020 is extended to almost all Danish municipalities, and Fredericia finished their climate plan in 2020, with the purpose of exploring measures on how to be climate neutral in 2050. Although the GHG emissions accountings made by the energy national public department are reported every year, climate plans are subject to periodic revision (2 years) in light of the current situation, not only in the city context (e.g. the increase of the share of renewables) but also in a global context (e.g. energy crisis due to political conflicts), where there is a revision of the targets and investigated what should be changed according to the current global, national and local situation.

The municipality prepares the climate plan based on the data and results delivered by the Energy National Public Department, meaning that it does not perform any calculations. They "(…)try to see where there is a bigger problem(…)" (Kristensen, 2023), meaning that they just use the comparisons between the sectors with higher emissions and then choose the actions for that. (Kristensen, 2023)

Fredericia's climate plan is divided into 11 chapters where at first it gives a perspective of the position of the city in a global context, stating the municipality as playing a role in the world goals and climate action. Secondly, the sources of emissions are analysed and some action plans together with goals per sector are presented. Only the main sectors, meaning the ones with higher emissions, such as energy or transport, are analysed in more depth. It also refers to some specific measures in areas where the municipality has a direct influence on managing and other actions in cooperation with external stakeholders.

Fredericia's Goals:

Fredericia's goals are inserted in the global context of the National and EU directives. Figure 9, shows the main framework followed by the municipality in its climate plan.

	COMMITMENT AND OBJECTIVES	LEGISLATION OR AGREEMENT
NATIONAL GOALS	Reduction of greenhouse gas emissions by 70% in 2030 compared to 1990. Climate neutrality in 2050.	CLIMATE LAW
	55% renewable energy in 2030 in the final energy consumption.	ENERGY AGREEMENT 2018
	No use of coal in electricity production in 2030.	
	Over 100% renewable energy in electricity consumption and at least 90% of district heating consumption is based on forms of energy other than coal, oil and gas in 2030.	
EU OBJECTIVES AND DIRECTIVES	Requirements for preparation for or establishment of charging stations for electric vehicles in existing construction, new construction and major conversions based on the number of parking spaces.	EU DIRECTIVE
	30% renewable energy in 2020 in total final energy consumption.	EU 2020 OBJECTIVES
	20% reduction in greenhouse gases in 2020 from the non-quota sector (compared to 2005): buildings, agriculture and transport.	
	14% renewable energy in the transport sector in 2020.	
	39% reduction in greenhouse gases in 2030 from the non-quota sector (compared to 2005): buildings, agriculture and transport.	EU 2030 OBJECTIVES
	43% reduction in 2030 compared to the 2005 emissions from the major emitters of CO_2covered by the EU's CO2 trading system$_2$- quotas such as power plants and the oil and gas sector.	

Figure 9 - Based framework for Fredericia's Climate Plan Goals (Municipality of Fredericia, 2020)

The National Goals and EU directives have to be translated on the city level, so the municipality of Fredericia uses the global framework to create goals and measures to achieve those goals in the city scale. As an example, the focus of the climate plan is mainly in the energy sector with the increase of electrification and the use of renewable sources, as EU and national targets.

The main goal of the city of Fredericia is to reduce 70% of GHG emissions when compared to the 1990 level within its borders by 2030, and to be net zero by 2050. For the Municipality as an institution, it set the goal of being CO_2 neutral by 2030. (Municipality of Fredericia, 2020)

As mentioned before, Fredericia emissions come mainly from the energy and transportation sector (see Figure 8), so these sectors have the main focus in the climate plan. Nevertheless, Fredericia's climate plan includes a set of more detailed goals in order to achieve the main one for other different sectors. Figure 10 shows the division of the different targeted sectors and states a summary of the goals delineated for Transportation, Heating and Electricity Supply, Companies, and the municipality as a group. They are currently updating the climate plan, which is predicted to be launched in the spring of 2024 with more ambitious goals, especially in the energy sector (climate neutral by 2033 instead of 2050).

GOAL	
TRANSPORTATION	• **20% of cars run on electricity or other renewable energy in 2030 - 100% in 2050.** • **Car ownership in 2030 is at the same level as in 2017** This must be achieved through the following sub-goals: - The share of journeys made by bicycle, walking and public transport is 50% in the municipality as a whole in 2030 - The share of journeys made by bicycle, foot and public transport is 60% in the city center in 2030 - The proportion of journeys in the municipality that take place by bicycle is 20% in 2030 - The proportion of commuting journeys made by public transport is 5% in 2030 - 10% of all commuting journeys by car in the municipality are made by carpooling before 2030. - Car sharing available within 500 meters in all urban areas with apartment buildings.
HEATING AND ELECTRICITY SUPPLY	• Phasing out of the remaining consumption of fossil fuels in TVISvarmen (however excluding the contribution from waste incineration) in 2030. • 50% reduction in the emission of $CO_2$from waste incineration in 2030 (compared to 2017), 100% reduction in 2050 • All oil boilers are phased out in 2030 • Households' heat consumption is reduced by 10% in 2030, and 30% in 2050 (compared to 2017)
COMPANIES	• 30% reduction of CO_2- the emissions from the municipality's energy-intensive companies (compared to 2017). • 85% reduction in the use of fossil fuels for processes at the remaining companies (compared to 2017) and 100% reduction in 2050. • Establishment of PtX plant and CO_2-capture at the Skærbæk plant (Carbon Capture and Utilization) • 40% of trucks and buses run on hydrogen, electricity or other renewable energy in 2030 – 100% in 2050
FREDERICA MUNICIPALITY AS GROUP	• CO_2-neutral group in 2030

Figure 10 - Main goals of Fredericia's Climate Plan for each sector (Municipality of Fredericia, 2020)

The transportation chapter in the climate plan is described as having a relevant role for decreasing emissions in Fredericia. It is very much focused on the car use, because this is the category with the highest GHG emissions, so it is also the main target of the climate goals.

Following the global trend, car ownership in Fredericia has been increasing, being responsible not only for the increase of GHG emissions but also for causing problems of noise and particle pollution, together with accessibility challenges with the increasing congestion in the city.

The climate plan also focuses on comparing the use of private cars with other soft modes of transport, such as walking and biking. So, the goals prioritize the use of alternative modes to substitute the need of the car. Nevertheless, the electrification of the car fleet, together with the support of infrastructure such as charging stations, is also supported as an important mitigation strategy. Furthermore, it is stated in the plan the need to create easily accessible transport hubs and the creation of car sharing schemes which will help to decrease the emission per habitant. Finally, there is also a focus on the improvement of public transportation to make citizens choose that mode of transport instead of private vehicles.

3.4. Scope 3 accounting for the city of Fredericia

At the current moment, neither Fredericia municipality nor other private entity, account for scope 3, meaning indirect emissions, for the city of Fredericia. Although it is recognized by the municipality to be a relevant part of climate planning and mitigation, it remains a big challenge for them. (Kristensen, 2023)

According to the Climate coordinator of Fredericia Municipality, the municipality has the intention of accounting for them soon. They already work with actions that should reduce the emission from scope 3, but they cannot evaluate if they are succeeding or establishing priorities because they do not know the real values. She also mentioned that the first focus will be to account for scope 3 for the municipality as a city hall and for public institutions they manage (such as schools and day care centres). (Kristensen, 2023)

There is already an available private tool in the market to calculate scope 3 emissions that have been purchased by some Danish municipalities, but this tool only accounts for the emissions connected with the public institutions, based on their purchases, so it does not account for the entire city, such as households' consumption, meaning that it will remain a challenge to understand the consumption emissions for the city level as a whole. It is, however, very difficult to gather such detailed data with a high level of accuracy, and within the municipality's power, it would also have a high level of uncertainty. (Kristensen, 2023)

One of the easiest and most direct sectors to control is the procurement sector, meaning the purchases of the municipality for public institutions such as schools or day care centres. According to the responsible for controlling the register of the municipality's purchases, there is a possibility to choose "greener", "ecological", and "more sustainable" products but when it comes to understanding if they are really as they are labelled, that represents another challenge. Furthermore, there is a high political instance limitation with prices and fidelity to some brand or supplier for a certain period of time which makes the change of purchasing a different product very difficult. That also means that decision-making now, will only see an impact in the future.

There is also a challenge related to the way they collect data, as it is difficult to accurately analyse the products they are buying in the first place. They make a list where they track all the purchases of the municipality, but it is not currently used for anything other than economic purposes, which means that sustainability or the environmental impact of the products they consume is not exactly a priority at the moment. So, monetary limitations and political decisions are the ones running what is bought and they have very limited room for change or decision-making at the municipality level. (Achton-Boel, 2023)

"When collecting the data there is a degree of uncertainty and a margin of error on the correct categories of the products because it is an automated system doing the list." (Achton-Boel, 2023). They do the list using the United Nations Standard Products and Services Code (UNSPC) meaning that the categories have some degree of aggregation that can be too broad or then too detailed, making it difficult to analyse the entire list of purchases.

4. Results

4.1. Calculations on scope 3 for the city of Fredericia – Transport sector

Scope 3 emissions were calculated for the Transport Sector of the city of Fredericia. Following the methodology previously described (Chapter 2), the energy units on the data provided by Fredericia municipality were converted to MEUR2011. To maintain the balance, it was also calculated the MEUR2011 per energy unit. Tables 7-9 show all the results of the unit conversions for each mode of transport.

Road Transport

- Includes cars (passenger cars, trucks and vans), motos (scooters and motorcycles) and buses (city route buses and touristic private buses) – adapted from the municipality classification. Gasoline hybrid cars were considered as only gasoline, because those vehicles still need to be filled up with gasoline in most cases.

Table 7 - Unit conversions from Energy (MJ) to Monetary units (MEUR2011) for Road Transport

FUEL	MJ	L	EUR 2011	MEUR2011	MEUR2011/MJ
Diesel	1229971279,85	32367665,26	45962084,67	45,9620847	3,73684E-08
Gasoline	555443826,86	16531066,28	26780327,37	26,7803274	4,82143E-08
LNG	32266565,76	1453448,91	4040587,97	4,04058797	1,25225E-07
		kWh			**MEUR2011/kWh**
Electricity	1950728,88	541869,13	173398,12	0,17339812	3,20E-07

Rail Transport

- Includes Regional trains, Intercity and Speed trains – classification according to the municipality data

Table 8 - Unit conversions from Energy (MJ) to Monetary units (MEUR2011) for Rail Transport

FUEL	MJ	L	EUR 2011	MEUR2011	MEUR2011/MJ
Diesel	37683993,11	991684,03	1408191,32	1,40819132	3,73684E-08
		kWh			**MEUR2011/kWh**
Electricity	15363201,72	4267556,03	362742,26	0,36274226	8,50E-08

Flight Transport

- Includes national and international flight travel - classification according to the municipality data, which comes from national statistics scaled down to Fredericia's number of inhabitants

Table 9 - Unit conversions from Energy (MJ) to Monetary units (MEUR2011) for Flight Transport

FUEL	TJ	MJ	L	EUR 2011	MEUR2011	MEUR2011/MJ
Aviation fuel	79,97473098	79974730,98	2169688,85	1233273,85	1,233273852	1,54208E-08

Life Cycle Impact Assessment (LCIA)

The total GHG emission from the transport sector in the city of Fredericia, calculated for scope 3 is 43031520 kg CO_2-eq, which corresponds to **43031,52 ton CO_2-eq** in the year of 2021. Appendix B, shows the results obtained through the software. Table 10 represents the result for the city in total and per inhabitant, divided by the population in Fredericia (51500) in 2021. This value is higher compared to the **130,586 ton CO_2-eq** stated for scopes 1 and 2, calculated for the city of Fredericia.

Table 10 - Results of total GHG emissions for Fredericia's Transportation sector (for 1 year, 2021)

GHG emissions – Transport sector in Fredericia			
43031520	kg CO_2-eq	835,56	kg CO_2-eq /capita
43031,52	ton CO_2-eq	0,84	ton CO_2-eq /capita

To use as a basis of planning either for climate mitigation plans, either to draw urban planning strategies, it is relevant to evaluate the contribution of each sector to the total emissions. Understanding which sectors have the highest emissions allows to establish priorities and more suitable and specific goals. Figure 11 shows the contribution for the total emissions of each type of transport, in percentage.

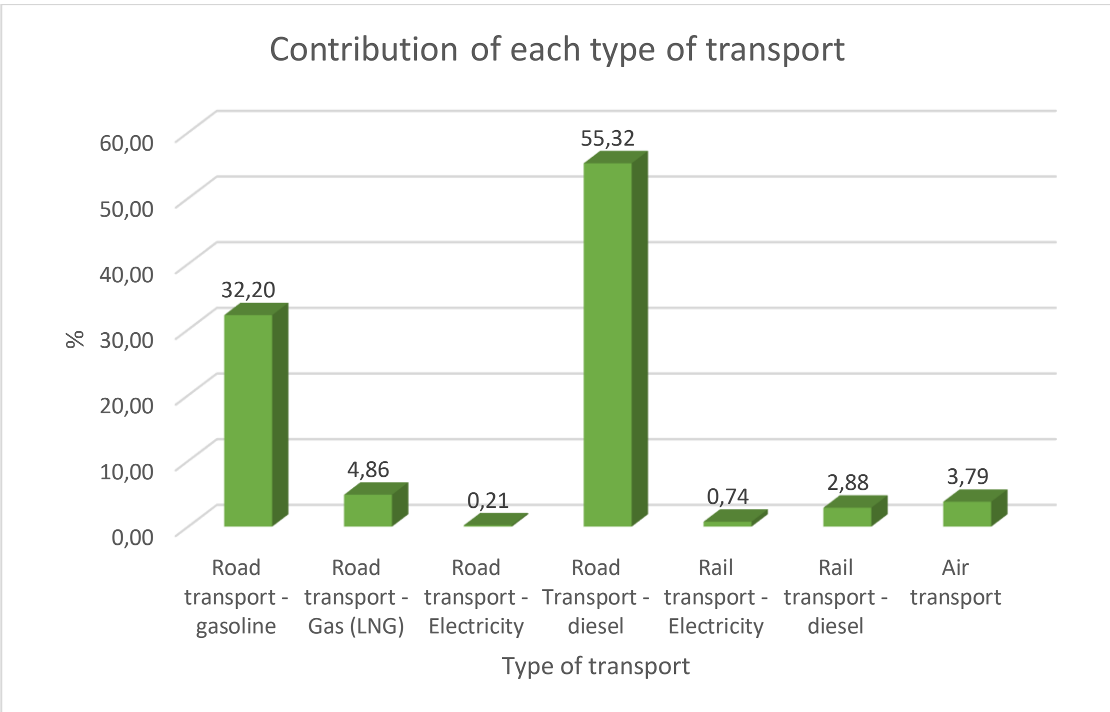


Figure 11 - Contribution of each type of transport for the total GHG emissions

The highest contributor to the emissions is Road transport using diesel and gasoline as fuel, while the lowest contributor is Road transport powered by electricity. Comparing the modes of transport, Road transport is the one emitting more GHG emissions, followed by the Flight mode and Rail transport (which is the one contributing the lowest). The accountings made for Fredericia on scopes 1 and 2 validate the results, where the contributions in percentage are almost the same, although rail transport has a slightly higher impact than the flight mode. The main contributors to the road transport powered by diesel and gasoline are cars and buses. Cars are mainly connected with the private sector, while buses are connected with the public sector.

4.2. Scenario

Based on Fredericia's Climate Plan goal for the Transport sector: "20% of cars run on electricity in 2030", a scenario was calculated for scope 3 emissions for cars in Fredericia. Table 11 shows the change from the contributions of the baseline to the contributions of the scenario, when 20% of the cars are powered by electricity, in percentage.

Table 11 - Contributions in percentage of each type of fuel for the baseline and the scenario

Fuel	Baseline (2021)	Scenario (2030)
	%	%
Gasoline	68	55
Diesel	32	25
Electricity	0,1	20

Increasing the percentage of cars powered by electricity from the very small contribution of 0,1% to 20% means decreasing the other type of fuels from 68% to 55% for Gasoline and from 32% to 25% for diesel.

To analyse the GHG emissions, the units were converted first to energy units according to the new distribution of percentages, and finally to million euros, Table 12 shows the results for those calculations.

Table 12 - Unit conversions from Energy (MJ) to Monetary units (MEUR2011) for the scenario

Type of fuel	Energy (MJ)	Liters of fuel	EUR 2011	MEUR2011	MEUR2011/MJ
Diesel	944454458,4	24854065	35292771,87	35,29277	3,73684E-08
Gasoline	441663315,9	13144742	21294481,3	21,29448	4,82143E-08
		kWh			**MEUR2011/kWh**
Electricity	346529443,6	96258178,8	30802617,2	30,80261	3,20E-07

The same was applied to the baseline, so it can be used properly in the software, Table 13 shows the results of unit conversions for car transport.

Table 13 - Unit conversions from Energy (MJ) to Monetary units (MEUR2011) for the baseline

Type of fuel	Energy (MJ)	Liters of fuel	EUR 2011	MEUR2011	MEUR2011/MJ
Diesel	1179238911	31032602,93	44066296,16	44,06629616	3,73684E-08
Gasoline	551457577,6	16412427,91	26588133,21	26,58813321	4,82143E-08
		kWh			**MEUR2011/kWh**
Electricity	1950728,885	541869,1346	173398,1231	0,173398123	3,20E-07

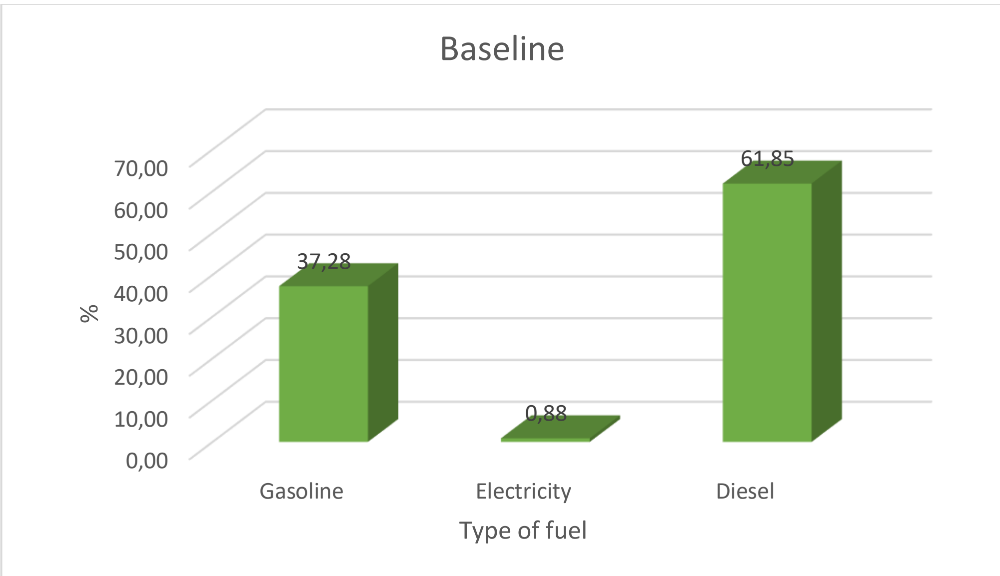
The values obtained for MEUR2011/MJ are giving the same results, working as a confirmation of the results.

The total GHG emission from the Cars category in the city of Fredericia, calculated for scope 3 is 36903847 kg CO2-eq, which corresponds to **36903,847 ton CO2-eq** in the year of 2021. Applying the scenario for 2030, the total GHG emissions from the Cars category in the city of Fredericia, calculated for scope 3 are higher, with 45238811 kg CO-eq, which corresponds to **45238,811 ton CO2-eq**. This result is even higher than the total GHG emissions calculated for the total transportation sector in 2021. In the next chapter, a possible reason for the result will be discussed. The results obtained through the software can be seen in the Appendix B. Table 14 represents the results for each type of fuel for both situations, the baseline and the scenario.

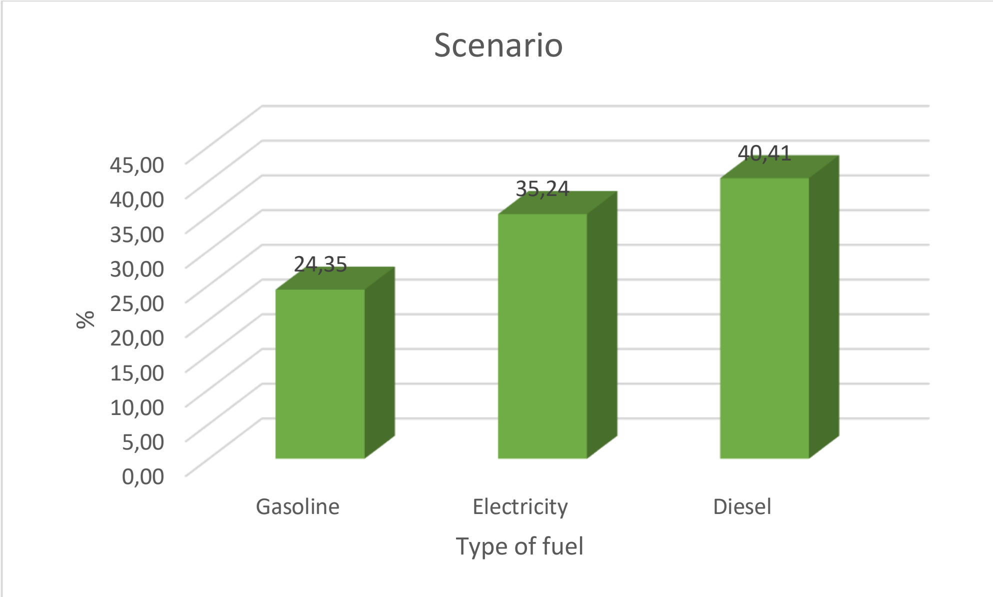
Table 14 - Results of the total GHG emissions for the baseline and the scenario

Type of fuel	Baseline	Scenario
	kg CO_2-eq	
Gasoline	13756007	11017209
Electricity	323058	15941194
Diesel	22824782	18280407
Total	36903847	45238811

To allow a better understanding and comparison of the changes, Figure 12 (a) and (b) illustrates the contribution of each type of fuel for both situations, baseline and the scenario.



(a)



(b)

Figure 12 - Contribution of each type of fuel in percentage for the baseline (a) and the scenario (b)

The higher contribution in the baseline is diesel accounting of 61,85%. The contribution of the cars using diesel remains the highest in the scenario (40,41%), although experiencing a decrease of around 20%. Gasoline cars contribution was the second highest in the baseline (37,28%), meaning that it was higher than electricity cars (0,88%), but when applying the scenario, gasoline cars change to be the ones with the lowest emissions (24,35%), as a result of increasing the percentage of electric cars so much (35,24%).

5. Discussion

Discussion on how the emissions accountings and the Climate Plan for the city of Fredericia are made (SRQ 1)

How are the accounts currently made and how are climate mitigation plans currently developed for cities?

In light of the first sub research question, Chapter 3, explains that city climate plans are developed by municipalities based on the results on GHG emissions made by the public national authority, which are based on direct emissions accountings (scopes 1 and 2) for each sector.

Fredericia, as mentioned, uses the calculations provided by the public energy entity when elaborating the goals and actions for the future in its climate plan, which are focused on direct emissions produced by the activities happening inside of the city borders. That makes the climate plan based only on the direct emissions and also based mainly on sectors with the highest emissions, having as consequence to keep some relevant sectors for the emissions out of the plan. As an example, the agriculture sector, which was claimed as not being relevant for Fredericia, is usually one of the most relevant sectors when looking at consumption-based emissions. The impact is translated by the type of food products consumed by the inhabitants, and in indirect land use changes, which usually have a great CO_2 emissions. This particular sector is a good example of emissions that are not produced inside the city boundaries but they are indirectly demanded by the consumption habits of the citizens and institutions inside the city.

However, the perception of the municipality on the current calculations is very positive, considered the tool used to obtain such results with a "(…) very good." (Kristensen, 2023) level. It translates, in fact, a good perspective on direct emissions, and looking only on that side, it says that the municipality is actually "doing well" on climate mitigation (Kristensen, 2023). They see a positive future, in the sense that they predict to achieve the goals stated in the climate plan. On the other hand, this raises the question if when looking from an indirect emissions perspective, the future looks that positive. There is a general idea from the municipality that they are not performing very well on scope 3 emissions, but since that has not been quantified, there are no concrete goals or assessments on that scope, which creates a gap between the municipality's perception and reality.

The main sectors where the climate plan is focused are Energy and Transportation, meaning that the central goal is built around the transition from fossil fuels to electricity power either in the energy sector either in the modes of transport. That is one of the main reasons why the perception of going in the correct path is coming from, once accounting only for scopes 1 and 2, it gives a decrease in emissions through the electrification based on renewable sources of energy, throughout the years. Despite that, when accounting for scope 3, the consumption of energy and the use of transports, even when changing cars to electric ones, gives higher emissions than expected because this is very much dependent on the source of the energy.

The general approach to the transportation sector may have the expected impact of decreasing GHG emissions if the strategies were mainly based on ditching the car and supporting the softer modes of transport as walking and biking. The increase in the accessibility to transport hubs, allows the facilitation of the use of public transports, also represents a high chance of decreasing emissions in the transportation sector. Applied to the cars category, in a scope 3 perspective, one of the more effective actions would be to apply measures to limit car ownership and invert the current situation of purchasing cars.

Discussion on the results obtained for Scope 3 for the Fredericia's transportation sector (SRQ 2)

How life cycle thinking and the use of IO tables can be applied to contribute to the accounting for scope 3 emissions?

Life Cycle thinking approach, which methodology was based on IO tables, can be applied to the data gather for a given sector of the city and to assess climate plan goals, so scope 3 is included to obtain more comprehensive results.

Fredericia represents an important national transportation hub, making it relevant to access the emissions of that sector. The results on scope 3 show higher emissions for the transportation sector than the ones calculated for scopes 1 and 2. The higher results for scope 3 show the underestimated emissions accounts that are currently being used to establish goals and elaborate climate plans. It is important to have in mind that the concept of scope 3 emissions should act as a way of acknowledging there are other emissions that we are not aware of, but they exist because of our consumption patterns.

Assessing the obtained results, they are in the same range as previous calculations made by the literature on scope 3 emissions coming from transportation for cities similar to Fredericia (Harris et al., 2020).

Using the information given by scope 3 calculations, goals and climate mitigation actions would have a more comprehensive approach and be based on more accurate results, that give a more realistic perspective of the current state of the emissions in the city, as well as a more accurate comparisons between sectors to choose priorities. One example is the focus on measures to increase electric cars, but not mentioning strategies to decrease the use of vehicles powered by fossil fuels, when actually the contribution of electric cars to the total emissions is still very residual.

Furthermore, when accounting for direct emissions the use of electric cars in the city borders will have the effect of decreasing GHG emissions, nevertheless, when accounting for indirect emissions, results showed that the impact will actually increase. One reason for that is the fact that they are linked to the country's electricity mix, which is dependent on the source of the electricity. Adding to that, if accounting indirect emissions based on the consumption of households and government, the purchase of the vehicle will also affect the total emissions.

Moreover, more studies should be done to support goals and actions, such as studies on why people use that many diesel cars, or who owns most of these types of cars. Being the indirect emissions connected with the consumption patterns, it would be relevant to study the population and conduct better surveys to improve the quality of the data.

The contribution of either gasoline and diesel indeed decreases when applying the goal of increasing the number of electric cars, but in reality, that ends up being translated as having higher emissions coming from the cars powered by electricity than the ones using gasoline. One reason for the high value of electricity can be related to the fact that not come from renewable sources, meaning that there are still high emissions coming from the production of electricity, so perhaps in the future, while the energy transition happens to more clean energy, the cars running by electricity results will not be that high. The results of the scenario showed that it is not that linear the idea of changing everything to be powered by electricity, in fact, the transportation and energy sectors are very much co-related.

As literature shows that scope 3 emissions are actually increasing, while scopes 1 and 2 are decreasing, that it is given to the fact that the GDP of the population is increasing, so the consumption levels are increasing too. Fredericia's number of inhabitants is predicted to increase followed by the power purchase, meaning that the consumption level is highly expected to increase too, making scope 3 emissions increase. For that reason, future actions and goals should focus more on that perspective and address more deeply the impact of consumption.

Limitations of scope 3 emissions calculation results (SRQ 2)

One of the main challenges when accounting scope 3 emissions is the data collection process, as previously explained in Chapter 1. In this project, there was a challenge to gather suitable data for the entire city of Fredericia and there was also a lack of quality data to account for indirect sources, which limited the calculations and the accuracy of the results to some extent.

As stated in the literature, the best method to calculate scope 3 emissions is to combine the total households' expenditures (consumption of goods and services such as food, clothing, electronic equipment, etc.). Fredericia's municipality also struggles to gather such type of data. Once the access to that data was limited, the final use of energy per each mode of transport was the most accurate data to be used. Nevertheless, the high coverage of the database allowed to account for scope 3 with fewer errors.

Although Fredericia works as an important transport hub, where different modes of transportation interlink with each other, the sea transport is not considered in the analyses once there was any data available neither for the public sector neither for the use of this type of transportation by Fredericia's population and companies (private sector).

A second limitation of the results has to do with the conversion from energy units to a monetary one. The data from Fredericia comes for the year of 2021 and the latest year available in the database was 2011, meaning that the calculations were made for the year of 2021 with prices from 2011, which is already quite an outdated year. Furthermore, the results are dependent on the literature used for the energy content of the fuels and the prices per Liter for the year of 2011 in Denmark. The different types of fuels were assumed with the best approximation from the provided data. Hybrid cars were assumed as 100% gasoline, Gas vehicles were assumed as powered with Liquified Natural Gas (LNG) and aviation fuel as Jet-A. The level of aggregation of the databases also introduces some level of uncertainty, once all the air transport, other land transport and railway transport are aggregated in one activity.

For the scenario, its high result when increasing the percentage of electric cars is, most likely, related to the source of the electricity, especially because the results were supposed to happen in 2030, but were based on the situation of 2021, using a database with activities and prices from 2011.

Analysis of Fredericia's municipality areas of influence (SRQ 3)

What information scope 3 emissions add to the climate mitigation plans of a municipality and to what extent can they elaborate strategies for those sectors responsible for such emissions?

Scope 3 accountings adds the total GHG emissions on the indirect emissions that are not included in scopes 1 and 2. In this case the indirect emissions coming from the transportation sector including the country's electricity mix and other sources of energy, and the impact of the mode of transport by itself. If applied to the consumption of households and public institutions, it will translate the impact of the city in a global context, meaning outside its own boundaries, so climate plans are more comprehensive and effective, depending on the areas of actuation of the municipality.

The power of change of the city Climate Plan relates to the fact that the national goals must be translated into measures implemented on a municipal level. An example of the power of the municipality is the source of heat supply or the management of public transportation. However, some measures are only in the power of the national level, as for example taxation on products on CO_2 emissions.

Although the climate plan is meant to be put into practice in cooperation between all the sectors and stakeholders from the city, the municipality must state the goals and delineate the measures to achieve those goals, so in that regard, it is relevant to think and discuss what are the areas of influence of Fredericia's municipality as an entity and to what extent it has the power to change and apply concrete measures in each sector that contribute to the emissions.

As indirect emissions are very dependent on the consumption patterns of the population, individual choices play the main role when decreasing such emissions, so the municipality as an entity has a very limited power of change in this. The level of power is connected to the extent that educational campaigns have to influence the population's consumption habits, or restrict some type of behaviour through for example applying taxes to drive in some parts of the city or on some products. One tool to influence such change specifically in the transportation sector, is Urban Planning. As described in Chapter 1, the physical shape of the city, the way infrastructures are distributed and the level of services offered, influence the need of the population to drive a car or use public transportation as an option.

One question raised is how to change indirect emissions if there is no way of controlling it by the municipality, that can be done through influencing the citizens behaviour and also through being an example with actions for the institutions directly managed by the municipality.

Fredericia municipality has been already implementing some actions to tackle that issue, through educational campaigns and through cooperation with other stakeholders. They implemented a room in the middle of the city to try to get people inside to talk about sustainability, they also visited people where they were through a project to create "green communities", doing targeted action groups for education and actions on sustainability. They also tried to change the food offered in the canteens in cooperation with the public institution's kitchens. There is also a protocol of cooperation with industries to change to more sustainable working habits, like sharing cars. However, some of the actions did not call the attention of the citizens as predicted and the level of achievement is not possible to quantify in such indirect measures. Furthermore, they tried some restrictive measures but it was not well received by the main economic forces in the city, so the municipality approach is more focused on positive reinforcement rather than limiting behaviour.

Analysing the Climate Plan, goals and actions are mostly based on influencing and cooperation to achieve the goals with other sectors, rather than based in areas that the municipality can really change directly. One of the examples is on energy and the type of road transport where they expect to see a change from fossil fuels to electric or renewable sources through action applied by external entities. However, there is a chapter focusing on the procurement sector of Fredericia as a management institution. That means there is a certain degree of power when choosing what products to buy and the supplier or brand they are coming from, having a possibility to choose products with less environmental impact or pressuring the supplier to adopt more sustainable measures. Fredericia Municipality is in effect, part of a tender community and partnership agreements, where sustainability is studied so it can be part of tenders to have more "green" procurement sectors. On the other hand, there is a high political instance limitation with prices and fidelity to some brand or supplier for a certain period of time that rules public purchases.

Another direct action stated in the Climate Plan relates to the Municipality as a management entity of public spaces. In the energy sector, they have for example the influence of applying energy-saving measures in public buildings, and the power of changing the vehicle fleet to more sustainable cars and promoting more sustainable modes of transport of public employees, or changing the type of food available in the public canteens. As manager of daycare centres and schools, there is a close opportunity to apply educational measures with different age groups of the municipality.

In the transportation sector, they have the direct influence on limiting the purchase of vehicles and promote softer modes of transport and sharing rides in the institutions they manage. There is also the acknowledgment of the direct influence of the municipality in the physical planning, through Urban Planning of the city, in Fredericia's climate plan. They have the responsibility of the assignment of areas and the building of infrastructures together with the management of traffic. Through this tool, the municipality can contribute to the green transition, in particular in the transportation sector.

6. Conclusion

Climate change is currently one of the main threats to global society and to the cities. It is driven by the emission of GHG produced by the activities occurring in the urban areas. With the increase in population, it is crucial to mitigate climate change impacts and to set proper goals and strategies.

In that regard, it is extremely relevant to account for GHG emissions and obtain accurate and trustworthy results. Nowadays, there are three main approaches to those accountings, which are scopes 1, 2 and 3. Scope 1 and 2 are based on accounting direct emissions, produced inside of the city borders by the activities inside the city, while scope 3 accounts for indirect emissions, meaning to include the global perspective of emissions produced outside the city borders but demanded by it.

There is a lack of methodologies for accounting for GHG emissions on a city scale, especially on scope 3 approach, which would be a much more comprehensive and proper approach. One of the methods proposed by the literature is to apply the Life Cycle Perspective. Nevertheless, this methodology still carries a set of challenges for the cities to be accounted for.

One of the main sectors contributing to the total GHG emissions of urban areas is the transportation sector, which is related to how citizens commute and how the physical space and infrastructures of the urban area are planned.

The city of Fredericia, used as a case study in this project, elaborated a climate plan where it analyses the GHG emissions per sector and sets goals for climate change mitigation within certain time frames. The sectors contributing the most for the total GHG emissions are energy and transportation.

Fredericia municipality only accounts for scopes 1 and 2 emissions, and they expect to succeed on the goals for those approaches, but they currently face challenges on accounting for scope 3, although they want to focus on it in the near future.

The total GHG emission from the transport sector in the city of Fredericia in 2021, calculated for scope 3, is 835,56 ton CO_2-eq/capita which is higher than the results for scopes 1 and 2. The highest contributor to the emissions is Road transport using diesel and gasoline as fuel. Comparing the modes of transport, Road transport is the one emitting more GHG emissions, followed by the flight mode and Rail transport (which is the one contributing the lowest).

The total GHG emission from the Cars category in the city of Fredericia, calculated for scope 3 is 36903,847 ton CO2-eq in the year of 2021. Applying the scenario for 2030, where 20% of the cars are powered by electricity, the total GHG emission from the Cars category in the city of Fredericia, calculated for scope 3 is 45238,811 ton CO2-eq, higher than the baseline and even higher than the total amount of emissions of the whole transportation sector in 2021. The highest contribution for both situations remains the same as the highest contribution for the total emissions in the transportation sector, which is Road transport (or cars) using diesel as fuel.

This brought into the discussion the general idea of the power of change as a municipality. Fredericia municipality can only influence directly the public institutions they manage, beyond that, they have very limited power of change in the private sector and in the household's consumption patterns, which are the ones mainly contribute for the scope 3 emissions. Even on a municipal/public level, monetary limitations and higher political instance decisions are the ones running what is bought and the decision-making.

Nevertheless, the scope 3 concept should be perceived as a way of acknowledging there are more GHG emissions than the ones that are generally accounted for, and that the climate impact should be perceived in a global and more comprehensive context instead on only looking at a direct producing level.

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APPENDIX A- EXIOBASE activities used in SimaPro

The following tables show all the activities from EXIOBASE used to link Fredericia's foreground data to specify how the method was applied.

Road transport - diesel

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Co
Road Transport - diesel	1	MJ	Energy	100 %		_Fredericia	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	S
122 Other land transport (DK) (product market, monetary units, purchaser price)	0,0000000374	MEUR2011	Undefined	
Add				

Road transport - gasoline

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Co
Road transport - gasoline	1	MJ	Energy	100 %		_Fredericia	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	S
122 Other land transport (DK) (product market, monetary units, purchaser price)	0,0000000482	MEUR2011	Undefined	
Add				

Road transport – Gas (LNG)

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Co
Road transport - Gas (LNG)	1	MJ	Energy	100 %		_Fredericia	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	S
122 Other land transport (DK) (product market, monetary units, purchaser price)	0,0000001252	MEUR2011	Undefined	
Add				

Road transport - Electricity

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	C
Road transport - Electricity	1	kWh	Energy	100 %		_Fredericia	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
122 Other land transport {DK} (product market, monetary units, purchaser price)	0,0000003200	MEUR2011	Undefined
Add			

Rail transport - diesel

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Cor
Rail transport - diesel	1	MJ	Energy	100 %		_Fredericia	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD
121 Transport via railways {DK} (product market, monetary units, purchaser price)	0,0000000374	MEUR2011	Undefined	
Add				

Rail transport - Electricity

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	C
Rail transport - Electricity	1	kWh	Energy	100 %		_Fredericia	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
121 Transport via railways {DK} (product market, monetary units, purchaser price)	0,0000000850	MEUR2011	Undefined
Add			

Air transport

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
Air transport	1	MJ	Energy	100 %		_Fredericia	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD
126 Air transport (62) {DK} (product market, monetary units, purchaser price)	0,000000015420794009	MEUR2011	Undefined	
Add				

TRANSPORT - total

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
TRANSPORT	1	year	Time	100 %		_Fredericia	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Air transport	79974730,98	MJ	Undefined
Rail transport - diesel	37683993,11	MJ	Undefined
Rail transport - Electricity	4267556,03	kWh	Undefined
Road Transport - diesel	1229971279,85	MJ	Undefined
Road transport - Electricity	541869,13	kWh	Undefined
Road transport - Gas (LNG)	32266565,76	MJ	Undefined
Road transport - gasoline	555443826,86	MJ	Undefined
Add			

Method IPCC 2013 GWP 100a V1.03. for 1 year of emissions from the transport sector in Fredericia

Method			
IPCC 2013 GWP 100a V1.03			
Product	**Amount**	**Unit**	**Project**
TRANSPORT	1	year	Fredericia

Scenario

CARS- baseline

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
CARS - baseline	1	year	Time	100 %		_Fredericia	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Road Transport - diesel	1179238911	MJ	Undefined
Road transport - gasoline	551457577,6	MJ	Undefined
Road transport - Electricity	1950728,885	kWh	Undefined
Add			

CARS- scenario

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
CARS - scenario	1	year	Time	100 %		_Fredericia	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

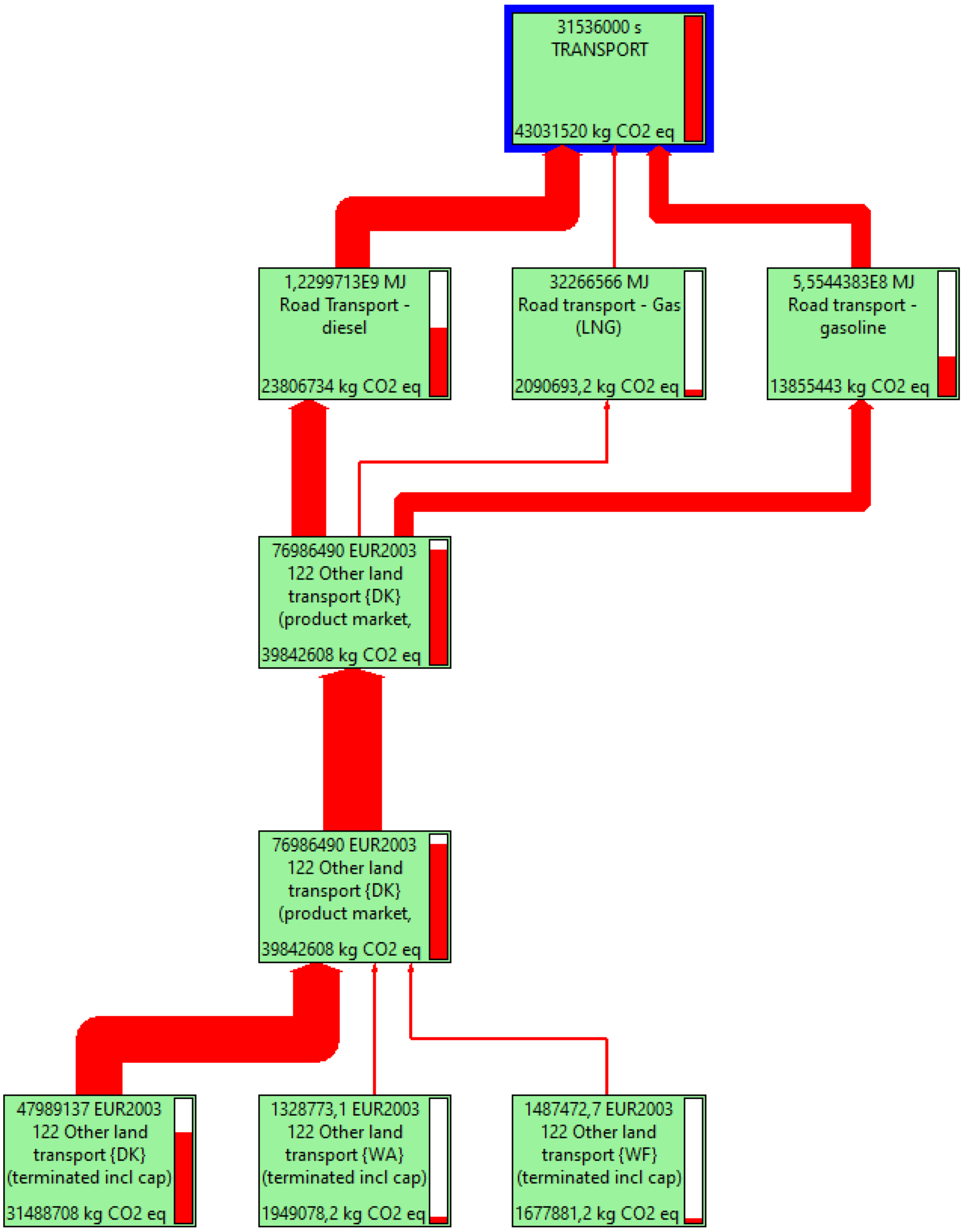
Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Road Transport - diesel	944454458,4	MJ	Undefined
Road transport - gasoline	441663315,9	MJ	Undefined
Road transport - Electricity	96258178,77	kWh	Undefined
Add			

APPENDIX B- LCIA results in SimaPro

The following Figures show the impact and all the contributions used in the LCIA Results section.

Total GHG emissions in 2021 from the transport sector in the city of Fredericia (kg CO_2 -eq)



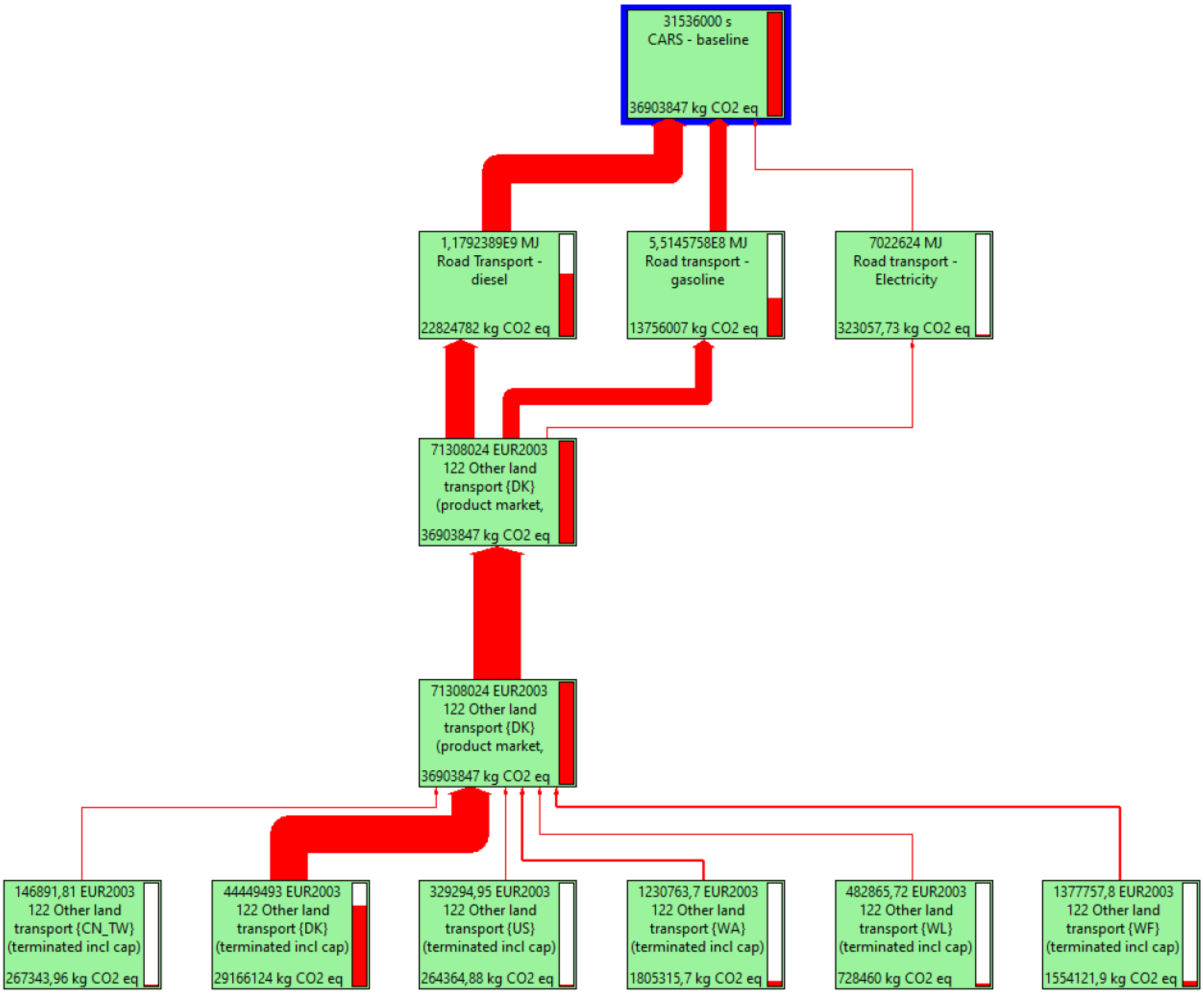
Contribution of each mode of transport

Inflows (7)	Flow	Unit
Total	43031520	kg CO2
Road transport - gasoline	13855443	kg CO2
Road transport - Gas (LNG)	2090693,2	kg CO2
Road transport - Electricity	89738,257	kg CO2
Road Transport - diesel	23806734	kg CO2
Rail transport - Electricity	319101,18	kg CO2
Rail transport - diesel	1239820,4	kg CO2
Air transport	1629989,9	kg CO2

Inflows (7)	Flow	Unit
Total	100	%
Road transport - gasoline	32,198359	%
Road transport - Gas (LNG)	4,8585159	%
Road transport - Electricity	0,20854076	%
Road Transport - diesel	55,323943	%
Rail transport - Electricity	0,74155219	%
Rail transport - diesel	2,8811912	%
Air transport	3,7878977	%

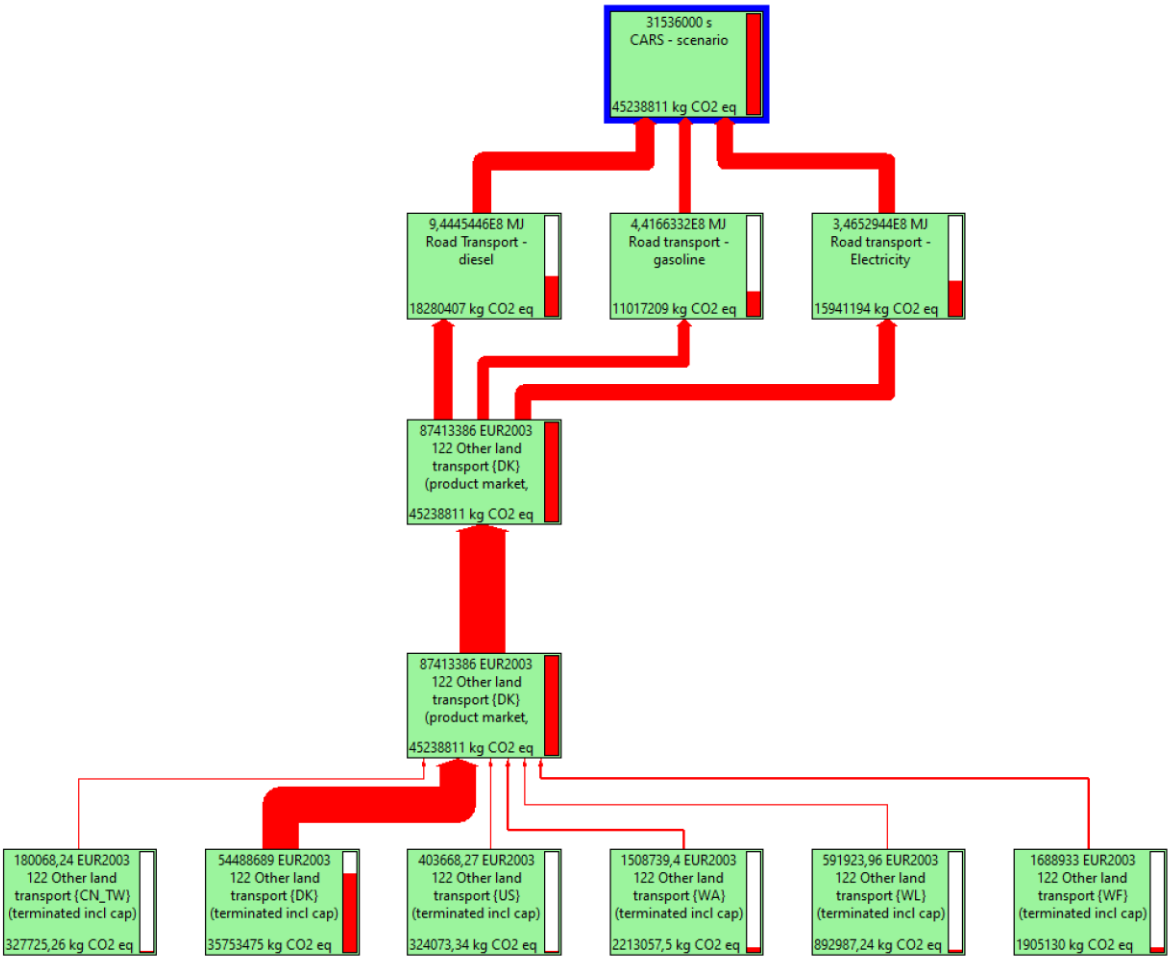
Scenario

CARS- baseline



Inflows (3)	Flow	Unit
Total	100	%
Road transport - gasoline	37,275266	%
Road transport - Electricity	0,87540393	%
Road Transport - diesel	61,84933	%

CARS- scenario



Inflows (3)	Flow	Unit
Total	100	%
Road transport - gasoline	24,353446	%
Road transport - Electricity	35,237872	%
Road Transport - diesel	40,408682	%