Thesis 342

Do emission reduction targets limit our shopping alternatives?

An accessibility case study of two Swedish shopping centres with CO_2 as a travel cost indicator

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This thesis analyses how the location of peripheral shopping centres impact accessibility from a CO_2 emissions point-of-view, and how analyses can affect future decisions on localisation of facilities. Different accessibility measures are presented to find a feasible measure.

The foundation of the analysis is a case study of two shopping centres in southern Sweden, using GIS software. To perform the analysis, a contour measure is used with different CO_2 thresholds based on today's national emission levels and future emission targets. Emission factors are used based on each mode's characteristics.

The results of the study show that the most CO_2 accessible modes of transport are bus and train, but they suffer from the public network coarseness. The accessibility index depends on the location of the shopping centre, but also of the surrounding population and its density. The emission-based accessibility analysis can be a tool for sustainable future institution localisation.

The report shows that both housing and service facilities should be developed around railway nodes to increase accessibility. The public transport system should be further expanded from an emission accessibility point-of-view.

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Lund, December 2019
Erik Malmström

Summary

By 2030, the domestic road transportation emissions of Sweden are to decrease by 70% according to national targets, excluding aviation. Of the present emission levels, more than 60% come from car transportation. Peripheral shopping centres have been growing in numbers and retail market share since the 1970s and trips to these establishments stand for a significant part of car traffic emissions, some studies indicate up to 10%. The localisation of these shopping centres and the surrounding infrastructure can, therefore, play a role in achieving emission reductions.

Accessibility provided by the transportation system will be increasingly crucial in the future and is also a main objective in the Swedish national transport policy objectives. Accessibility improvement is an important objective in policymaking in many other regions and on different scales. Accessibility can be defined in many ways. One definition used in this study is by te Brömmelstroet et al. (2016): "*An expression of the potential number of relevant activities that are located within acceptable reach of a given place or people in acceptable reach of an activity*" (p. 1177).

To assess the accessibility of shopping centres' locations, a case study of two shopping centres in the outskirts of two cities in the south of Sweden is made. Instead of using travel cost indicators such as travel time or distance, CO_2 emissions are used to highlight the carbon footprint of the locations to link to the transportation emission objectives. The accessibility measure of choice is the contour measure, which makes visualisation and comprehensibility better. The contour measure is in line with the definition of accessibility by te Brömmelstroet et al. (2016). The accessibility index of the study is the potential number of people (customers) in acceptable reach (CO_2 emissions) of an activity (shopping centre).

The analysis is done using GIS software, a tool that is used for site location in retail. By deriving different CO_2 budgets, based on national emission levels and targets, and CO_2 per-kilometre-factors per travel mode, the assessment is based on relevant estimates. Each shopping centre is analysed in three scenarios: car, bus and bus and train combined. Each scenario has a CO_2 budget with today's emission levels and one with future emission targets.

The results of the study are that the level of accessibility decreases with emission reduction objectives, even though the future car scenario includes a more emission effective vehicle fleet. The accessibility index calculated depends on the localisation of the shopping centres, with respect to the surrounding infrastructure and the neighbouring population and its density. The shopping centre placed closely to highly populated areas and a train station has a higher accessibility index in this study.

The study shows that bus and especially train are much more carbon-accessible transport modes than the car but suffer from the coarseness of the public transport network. The train emits around 0,1% CO_2 of the car's emissions per person kilometre, which makes the maximum reach along the rail network vast.

The emission-based accessibility analysis can be a tool for sustainable future institution localisation, to show how that housing and shopping establishments (and other facilities) should be developed around railway nodes to decrease carbon emissions from transportation. The public transportation system should be further expanded from an emission accessibility point-of-view to reach more areas and people. As a tool, this type of analyses shows that our accessibility will decrease if future emission objectives were to be enforced as a *per person budget*.

Sammanfattning

År 2030 ska Sveriges utsläpp från dess transportsystem ha minskat med 70% enligt nationella mål, exklusive flyg. Av dagens utsläppsnivåer står biltrafiken för mer än 60%. Externa köpcentrum har ökat i antal och i marknadsandelar av detaljhandeln sedan 1970-talet och resor till dessa etableringar står för en betydande del av biltrafikens utsläpp, en del studier visar på upp mot 10%. Lokaliseringen av dessa köpcentrum och omkringliggande infrastruktur kan därför spela en viktig roll i att uppnå utsläppsminskningarna.

Tillgänglighet från transportsystemet kommer att vara avgörande i framtiden och är även något som ska uppnås enligt de transportpolitiska målen. Att öka tillgängligheten är även ett viktigt mål inom beslutsfattande processer i andra regioner och på olika nivåer. Tillgänglighet kan definieras på många sätt. En definition som används i denna studie är av te Brömmelstroet et al. (2016) där tillgänglighet är *”Ett uttryck för det potentiella antalet av relevanta aktiviteter som är lokaliserade inom acceptabel räckvidd för en given plats eller personer inom acceptabel räckvidd av en aktivitet”* (s. 1177).

För att undersöka tillgängligheten för köpcentrums lokalisering har en fallstudie gjorts för två köpcentrum, som ligger i utkanten av två sydsvenska städer. Istället för att använda reskostnadsindikatorer som restid eller avstånd används CO_2-utsläpp för att visa lokaliseringarnas koldioxidavtryck. Tillgänglighetsmåttet som valts för studien är konturmåttet, som gör visualisering och begriplighet enklare. Konturmåttet går i linje med den definition gjord av te Brömmelstroet et al. (2016). Tillgänglighetsindexet för studien är det potentiella antalet personer (kunder) inom en acceptabel räckvidd (CO_2-utsläpp) av en aktivitet (köpcentrum).

Analysen har med hjälp av ett GIS-program, ett verktyg som har använts för detaljhandelslokalisering tidigare. Genom att skapa olika CO_2-budgetar, härledda från nationella utsläppsnivåer och -mål, tillsammans med CO_2-per-kilometer-faktorer per transportmedel, har utvärderingen baserats på relevanta uppskattningar. Varje köpcentrum analyseras i tre scenarion: bil, buss samt buss och tåg kombinerat. Varje scenario har en CO_2-budget för dagens utsläppsnivåer och en för framtida mål.

Studiens resultat visar att nivån av tillgänglighet minskar med utsläppsmålen, trots att det framtida scenariot med bil inkluderar en mer energi- och utsläppseffektiv fordonsflotta. Tillgänglighetsindexet beror på lokaliseringen av köpcentrumen i relation till omkringliggande infrastruktur samt närliggande befolkning och dess täthet. Köpcentrumet som är placerat nära tätbefolkade områden och en tågstation har det högre tillgänglighetsindexet i denna studie.

Studien visar även att på att buss och särskilt tåg är CO_2-tillgängliga transportslag, men begränsas av glesheten av linjerna i kollektivtrafiknätet. Tåget släpper ut 0,1% CO_2 av bilens utsläpp per personkilometer, vilket gör att den maximala räckvidden längs järnvägsnätet är vidsträckt.

Den utsläppsbaserade tillgänglighetsanalysen kan vara ett verktyg för hållbara verksamhetslokaliseringar i framtiden. Bostäder och handelsetableringar (samt andra verksamheter) bör utvecklas runt järnvägsnoder för att minska utsläppen från transporter. Kollektivtrafiken bör utvecklas och byggas ut från en emissionsbaserad tillgänglighetssynpunkt för att nå fler områden och människor. Som ett verktyg kan denna typ av analys visa att vår tillgänglighet kommer att minska om framtida utsläppsmål görs skarpa som en fast budget per person.

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1 Introduction

1.1 Background

According to the Ministry of the Environment (2017), Sweden shall not have any net-emissions of greenhouse gases to the atmosphere in 2045. One of the main categories in the emission reduction is the domestic transportation system. By 2030 the greenhouse gas emissions, among these carbon dioxide (CO_2), from this sector (excluding aviation) should be decreased by 70% from 2010 levels.

In 2015, the United Nations presented 17 sustainable development goals to be met in 2030 – also known as Agenda 2030 (United Nations, 2015). Goal 11, that is Sustainable Cities and Communities, states that everybody should have access to a transportation system that is safe, affordable and *accessible*. This should be reached by mainly improving the public transport system.

Accessibility is a wide concept that can be defined in different ways (Geurs & van Eck, 2001). It is a term that is used frequently until is to be defined and measured (Gould, 1969). Depending on the research approach, different measures and indicators can be used to calculate or show accessibility (Geurs & van Eck, 2001). Some accessibility tools are used to decide on the localisation of activities (Papa, et al., 2016), e.g. retail, educational or health services, based on catchment areas.

The form of trade and retail in Sweden has changed over time. From markets and traditional town trade, supermarkets and department stores were introduced in the middle of the 20^{th} century (Ahlberger, 2010). In the 1970s came shopping centres, being placed outside of the cities, *peripherally located*. Today, shopping centres have gained almost 40% of the Swedish retail market share (Svensk Handel, 2018).

The Swedish national travel survey RES05/06 shows that 7% of all travel activity is for shopping trips (excluding groceries) with 0.16 trips on average per person and day. Some studies show that shopping trips are responsible for 10% of the transportation system emissions of CO_2 in Sweden (Trivector, 2011). The location of trade has an impact on both traffic and emissions (Trivector, 2007). Instead of making decisions regarding the localisation based on gut feeling and assumptions, actual analyses and assessments should be the foundation.

In a report from Trivector (2011), the authors recommend that the localisation of trade should increase sustainability. There are plenty of advantages that can be gained from a localisation study (Trivector, 2007). The Swedish National Board of Housing, Building and Planning recommends (among other things) that the accessibility for sustainable modes should be encouraged (Boverket, 2015). Määttä-Juntunen, et al. (2011), write that GIS (Geographic Information Systems) has been utilised for the shopping industry for finding the most accessible location for customers.

When the transportation sector needs to decrease its emissions of greenhouse gases (Banister, et al., 2011), new indicators could be utilised. In light of previous studies by Määttä-Juntunen et al. (2011) and Kinigadner (2019), a new approach to accessibility has been used to analyse establishment localisations with CO_2 emission as a base.

1.2 Scope and Research Questions

The scope of this thesis is to:

- Present accessibility measures and understand how they can influence the results of an accessibility analysis based on CO_2 emissions;
- Assess how the location of peripheral shopping centres has an impact on the result of an emission-based accessibility analysis of the facility;
- Discuss how/if emission-based accessibility analyses may have a future effect on policy-making processes.

There are some entities that are outside the scope and will not be discussed in this thesis. Regarding the concept of accessibility, the focus of this study lies on the *macro* scale. Micro and meso aspects of accessibility will not be further treated. Due to lack of coherent network and emission data, the focus of the study will be on the shopping establishments in the provinces Scania and Blekinge southern Sweden. Network data from Denmark and other Swedish provinces are excluded. The transport modes used for assessing the accessibility in the framework of this study are car and public transport (bus and train). Active modes (i.e. walking and biking) have been assumed to be zero-emission travel modes (in accord with Interreg Europe (2019)) and are not considered in this study.

1.3 Structure

The content of the thesis is organized as follows: at first, a literature review is conducted to shed light on the definition of accessibility measures and indicators, including a part where CO_2 as an accessibility indicator is in focus. The second part of the literature study gives an overview of the location of trade in Sweden, from the beginning of the 19^{th} century and onwards to the development of the present situation with peripheral and semi-peripheral shopping centres. Trends and future outlooks are also investigated.

After a theoretical basis from literature has been laid out, the methodology for the accessibility study is gone through. This covers a brief link to the accessibility literature review and a conclusion regarding the choice of an accessibility measure category.

The third main section presents the shopping centres with surrounding areas of the field study. Their geographical location and infrastructural possibilities are introduced, and some materials for the choice of trade location in the two municipalities are gone through. Further on, the section explains the hypothetical CO_2 emission *budget* calculations, based on today's emissions levels and future policy objectives. The CO_2 emission *factors* are gone through, presenting key numbers that will be the foundation of the analysis based on the properties of the national vehicle fleet. The data sources and the workflow process are also shown.

The results are presented in both tables and maps and described in the text. The final part of the thesis consists of a discussion of the results as well as the conclusions of the work, along with recommendations for further studies in the area.

1.4 Terminology

Below is a table for a number of terms used in this thesis and their definition. The definitions are mostly concerning section *2.2 Location of Trade* since many terms are only mentioned briefly in that section. In other parts of the thesis, terms and definitions for e.g. accessibility are covered more in-depth.

The definitions below have been collected from different dictionaries. The Swedish authorities' definitions have been taken from their respective websites.

Term	*Definition*
Big box store	A very large shop occupying a box-like industrial-style building, typically in an out-of-town retail park. Such stores tend to be either hypermarket offering a variety of general merchandise at discounted prices or category killers in a particular product area. (Law, 2016)
Boverket	The Swedish National Board of Housing, Building and Planning.
Handicraft	Activity involving the making of decorative domestic or other objects by hand; or decorative domestic objects made by hand. (Stevenson, 2010)
Department Store	A retail organization that carries a wide variety of product lines, typically clothing, home furnishings, personal care products, accessories, and household goods; each line is operated as a separate department managed by specialist buyers or merchandisers. (Doyle, 2016)
General Store	A shop that sells a wide variety of goods, typically one in a small town or village. (Stevenson, 2010)
GIS	Geographic Information Systems
Hypermarket	A large retail outlet combining a supermarket and a department store, typically in the range of 2,500 square metres, offering a vast range of merchandise under one roof and typically built away from the main town or city to give more space and to enable easy access and parking. (Doyle, 2016)
Outlet	A retail or trading place of business, for example, a supermarket chain store, or department store. (Doyle, 2016)
Peddling	Try to sell (something, especially small goods) by going from place to place. (Stevenson, 2010)

Retailing	The sales activities involved in selling goods or services directly to final consumers for their personal, non-business use. Retailers are powerful intermediaries that purchase goods from wholesalers, or in some cases, directly from producers and sell directly to the end customer. The retailer is the main executor of the overall marketing mix. (Doyle, 2016)
Shopping Centre	Group of retail shops, restaurants, and other businesses with a common interest in soliciting sales. The facility is developed as planned commercial location and typically offers private, off-street parking facilities or areas. (BusinessDictionary, 2019)
Shopping Mall	A large indoor or outdoor collection of many individual stores with common areas for restaurants and parking. (Doyle, 2016)
Supermarket	A medium-sized store that sells groceries and packaged goods, usually in an urban setting. (Doyle, 2016)
Trade	The activity of selling goods or services in order to make a profit. Or: to buy or sell in a market. (Law, 2016)
Trafikverket	The Swedish Transport Administration

2 Literature Review

The literature review in this thesis is conducted to firstly provide background and insights into the definition of the term accessibility and accessibility measures. Further on, the CO_2 emission accessibility approach is presented, based on previous research.

The second part of the literature study deals with the location of trade. A background with the history of trade location and trade forms is given, before briefly looking into the future trends approaching. From there, the peripheral trade location impact on the transportation system, urban and regional planning and accessibility are looked into.

At the end of the literature review, a short section of concluding remarks is included, connecting the two parts of trade location and accessibility together and introducing the accessibility measure of choice for analysing two different trade locations with CO_2 as an indicator.

2.1 Accessibility: Definitions and Measures

Accessibility provided by the transportation system will be increasingly crucial in the near future, and a sustainable system of public transport needs to be developed (European Commission, 2011a). According to the European Commission (2011a), there will be an increased gap of accessibility between central and peripheral locations in the future. An important objective in decision making in different regions and on different scales is to improve the accessibility (van Wee, et al., 2013).

Sweden adopted its current national transport policy objectives in 2009 (TRAFA, 2018). These objectives are formed by two main points, the functional and the impact objective. The functional objective states that "The design, function and use of the transport system will contribute to provide everyone with basic *accessibility* […]" (TRAFA, 2018, p. 10).

2.1.1 Defining Accessibility

Accessibility is a term that is used often until it has to be defined and measured (Gould, 1969). Geurs & van Wee (2004) write that accessibility is seldom being defined in a clear way, rather measured poorly and misunderstood as a whole. The term can have multiple definitions and meanings (Geurs & van Eck, 2001), and can be used in various fields; e.g. urban and transport planning, marketing and geography. To clarify the term, some definitions of accessibility are presented below:

> "The potential of opportunities for interaction"
>
> Hansen (1959, p. 73)

> "Accessibility is a measure of the ease of an individual to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time"
>
> Bhat, et al. (2000b, p. 1)

> "The extent to which the land use-transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s)"
>
> Geurs & van Eck (2001, p. 36)

> "Accessibility can be broadly defined as the ease with which activities at one place may be reached from another via a particular travel model"
>
> Liu & Zhu (2004, p. 105)

> "An expression of the potential number of relevant activities that are located within acceptable reach of a given place or people in acceptable reach of an activity".
>
> te Brömmelstroet, et al. (2016, p. 1177)

According to Geurs & van Eck (2001), four *components* exist in the concept of accessibility. There is a *transport component*, that indicates that there is a negative utility (cost) for people to travel with a certain mode. The cost can be time, effort or monetary value. The second component is the *land-use component*, that reflects on how many opportunities can be found within a certain area. The land-use component also indicates the properties of the activity(-ies). The *temporal component* takes time into consideration, for example when the opportunities are available to participate in. Lastly, the *individual component* is presented. Here, needs, abilities and opportunity of the individual are reflected, depending on the individual's attributes (socio-economic background, physical condition, education etc.). The connections between the components are represented in Figure 1.

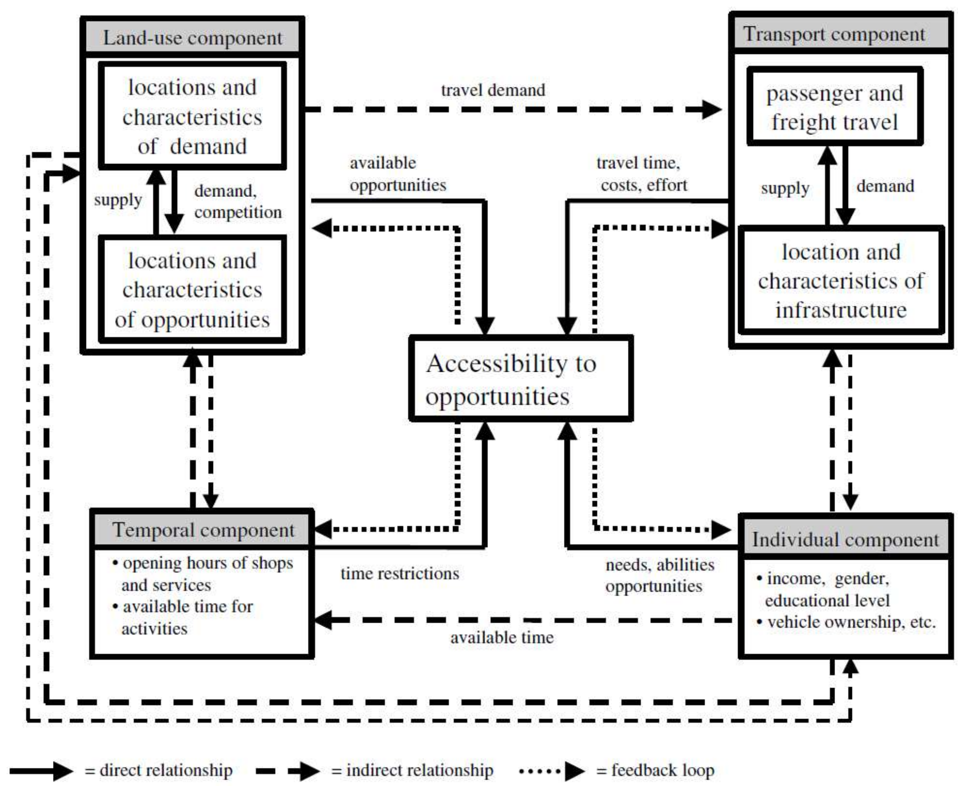

Figure 1: Relationships between accessibility components (Geurs & van Wee, 2004)

2.1.2 Accessibility Measures

According to Bhat, et al. (2000a), accessibility measure is an *equation that describes accessibility*. The form of the equation can vary depending on the type of measure. Accessibility measures usually consist of two main elements (Bhat, et al., 2000a). The first one is called the impedance factor, which is linked to the journey to the point of destination. This can e.g. be speed limit, service frequency or sidewalk continuity. The second main component of the accessibility measures is linked to the destination (and corresponding activity) itself, called the destination factor. This is e.g. opening hours, variety of shop goods or parking availability.

There are other categories used in different studies to group accessibility measures: Geurs and van Eck (2001) group the measures into infrastructure-based, activity-based and utility-based. Liu & Zhu (2004) use the following categories; opportunity-based measures, gravity-type measures, utility-based measures, and space-time measures. Geurs & van Wee (2004) use four groups when describing accessibility measures: *infrastructure-, location-, person-,* and *utility-based measures*. In this thesis, the definition from the study by Geurs & van Wee (2004) will be used, together with input from other studies.

A good accessibility measure should take all accessibility components with corresponding elements (see Figure 1), into account (Geurs & van Wee, 2004). However, in most cases, the measures only take a limited number of accessibility components into consideration. The individual component is normally covered more thorough in the person- and utility-based measures. The person-based measure is the only one where the temporal component is focused on. The land-use component is not considered in the infrastructure-based measure. The transport component is present in all measures.

Different accessibility measures can show different results regarding the level of accessibility provided (Geurs & van Eck, 2001). The authors use a scenario from the Netherlands to explain: In the western parts of the country, the majority of jobs are located in a dense form. Due to this, the road network suffers from congestion during commuting hours – leading to a low accessibility from an infrastructure-based measure perspective. However, looking at it from an activity-based accessibility measure point of view, the number of accessible jobs (opportunities) within e.g. 45 minutes, is high – indicating a high level of accessibility.

2.1.2.1 Infrastructure-based Measures

Infrastructure-based measures on accessibility are often used in transport policies in Europe and the U.S. (Geurs & van Eck, 2001; Geurs & van Wee, 2004). Traditionally, only physical distance is used as input data for these measures (Scheurer & Curtis, 2007), as they do not consider travel behaviour or value of time. According to Geurs & van Eck (2001), the lack of theoretical foundation has a negative impact on the results of this type of accessibility analysis.

The infrastructure-based measures are utilised to evaluate the performance of the transportation system in an area (Geurs & van Wee, 2004). They can, for example, indicate the level of congestion (see Figure 2) or operating speed (Geurs & van Eck, 2001). When comparing different regions' infrastructure, these measures are normally used.

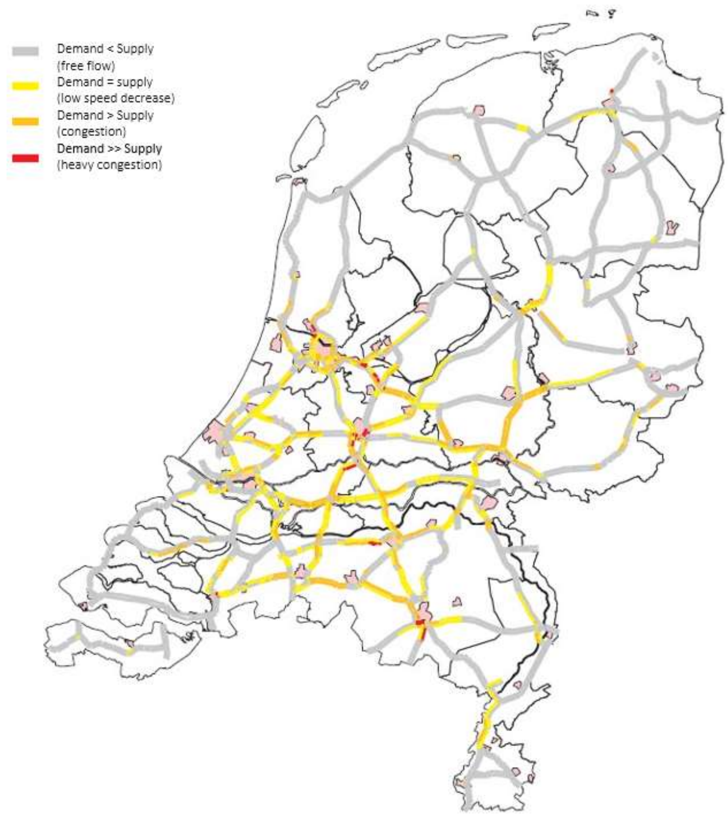

Figure 2: Example of an infrastructure-based accessibility measure analysis. Traffic level/road capacity in the Netherlands: projection for 2020 (based on 2000 policy) (AVV, 2000)

Another viable infrastructure-based measure for accessibility is travel time, expressed as a travel time ratio between public transport and car traffic (Geurs & van Eck, 2001). A key number that Trivector (2007) suggests should not be surpassed is 1,5, something that has been used in Dutch national transport policies as well (Geurs & van Eck, 2001).

2.1.2.2 Location-based Measures

Used in geographical research and urban planning, these measures focus on the accessibility at locations; for example, "number of jobs that can be reached in 30 minutes travel time from a certain location". This type of measure can also comprehend competition, e.g. capacity restrictions of a limited number of jobs at an office or maximum class size at a school. The location-based accessibility measures can be further divided into groups (Geurs & van Wee, 2004), e.g. distance, contour and potential measures.

The distance measures (or connectivity measures) are used for two points of interest and they are the simplest ones among the location-based measures. The distance measures can be used in land-use planning when looking at the maximum accepted travel time or distance from one point to another.

Another group of location-based measures is *the gravity measures* (also called potential accessibility measures). The gravity measures are continuous (Bhat, et al., 2000b). Hansen (1959) used the following formula to describe the potential:

$$A_i = \sum_j D_j \, d_{ij}^{-\alpha} \tag{1}$$

A_i = Measure of accessibility at zone i to all opportunities D at zone j

d_{ij} = distance between i and j

α = distance deterrence parameter

Here, the gravity measure has both a destination factor, the number of opportunities, as well as an impedance factor, the distance (Bhat, et al., 2000b). The formula for the potential accessibility measure has been modified to be used in different studies (Geurs & van Eck, 2001). The distance deterrence term has been changed and replaced by an impedance function that is dependent on a generalised cost term (Koenig, 1980);

$$A_i = \sum_j O_j \, f(C_{ij}) \tag{2}$$

A_i = accessibility from zone i to the relevant type of opportunities O

O_j = opportunities of that type present in zone j (employment places, shops...)

C_{ij} = generalised (or actual) time or cost for a trip from i to j

$f(C_{ij})$ = impedance function

The impedance factor can differ between models. Based on their literature review, Bhat, et al. (2000) mention euclidian distance, actual network distance, travel time, perceived distance or cost, and combined measures. Geurs and van Eck (2001) write that potential accessibility measures can be weighted or normalised and analysed from different perspectives such as travel modes (individual means of transport or multimodal) and groups of individuals (demographics and socio-economic background).

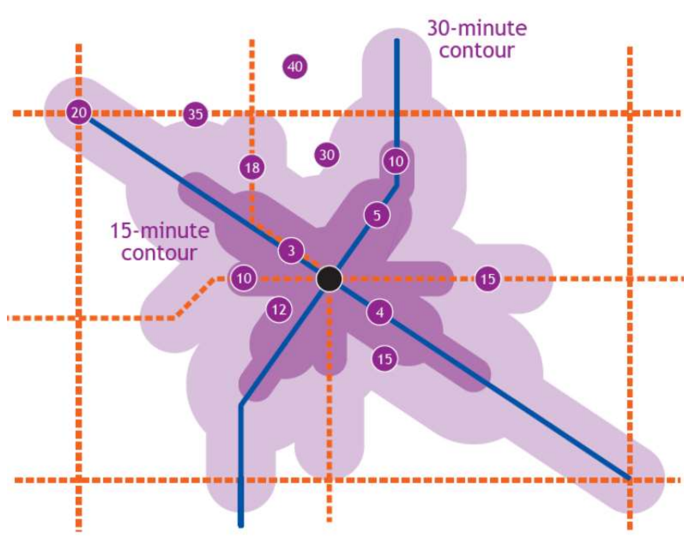

Figure 3: Gravity measure with contours. Note that the destination points (purple dots) are treated differently depending on the travel time compared to Figure 4. The origin is the black dot. (Scheurer & Curtis, 2007)

The gravity measures are not as easy to understand as e.g. the contour measure (mentioned below), according to Geurs and van Eck (2001). However, they are used frequently in many studies. These measures can be used for a location, where they indicate the accessibility in that specific point (see different destination points with corresponding travel time in Figure 3). The individual component accessibility cannot be assessed, each person that is in the same place has the same accessibility (i.e. indifferent to the individual's needs). The function of the measures is also sensitive to *self-potential*, meaning that the internal opportunities in the zone *i* could have a big impact on the weighting. To avoid this, the size of the zones should be decreased (Frost & Spence, 1995).

Another location-based accessibility measure group is the *contour measure* group (Geurs & van Wee, 2004). The measures are also called isochronic measures or cumulative opportunities (Geurs & van Eck, 2001). These are utilised when the analysed locations are more than two (Geurs & van Wee, 2004) and are frequently used in urban planning and geographical studies. The contour measure counts opportunities that are reachable within a certain threshold. The impedance can be e.g. travel time, distance or cost. The isochronic definition is another version of Equation 2, where

$$f(C_{ij}) = 1 \text{ for } C_{ij} \leq x$$

$$f(C_{ij}) = 0 \text{ for } C_{ij} > x$$

$$x = \text{a given threshold in e.g. travel time}$$

The contour measure is a measure that is easily explainable (Geurs & van Eck, 2001). A weakness with the contour measures, however, is that they are unable to make distinctions between points of interest within the same contour area (Scheurer & Curtis, 2007). As illustrated in Figure 4, all points of type A have the same amount of accessibility, even though the travel time differ within the contour. The contour measure doesn't see any difference between a destination (opportunity) one minute away from the origin and another 14 minutes away – they are both within the same area.

The contour measure is also sensitive to the threshold setting, in which the opportunities are counted. Perhaps, there are not that many opportunities within 15 minutes, but plenty within 20 minutes. These opportunities are neglected in the contour measure analysis.

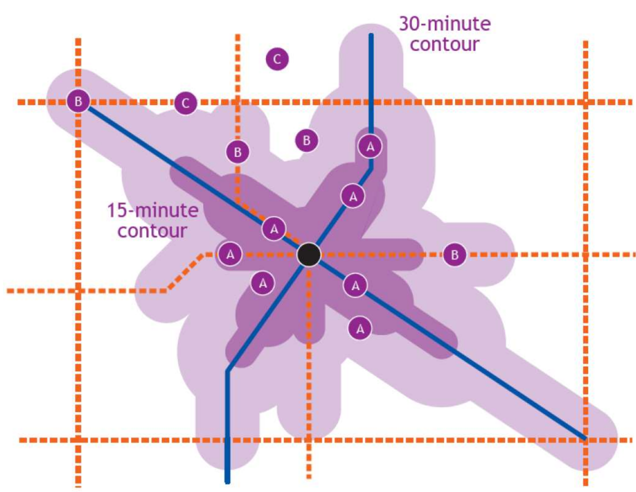

Figure 4: Contour measure with 15- and 30-minute travel time budgets from the origin (black dot). Destination points A are within the 15-minute contour and points B within the 30-minute contour. Destination points C are outside of both contours. (Scheurer & Curtis, 2007)

2.1.2.3 Person-based Measures

Focused on an individual level, this group of accessibility measures has its origin in the space-time geography defined by Hägerstrand (1970). The measures take the individual's constraints and freedom into play with mandatory activity location and duration, individual time budget and possibilities provided by the transportation system. The time-space measures take into account that an individual only can participate in activities during a certain time frame, a prism (Bhat, et al., 2000b). The prism is limited due to time constraints. As seen in Figure 5, an increase in travel time means that the time frame (and the prism of availability) decreases. A person that walks to work has a smaller prism than a worker that uses a car for transport. An example of time-space prisms in a transportation network can be found in Figure 6.

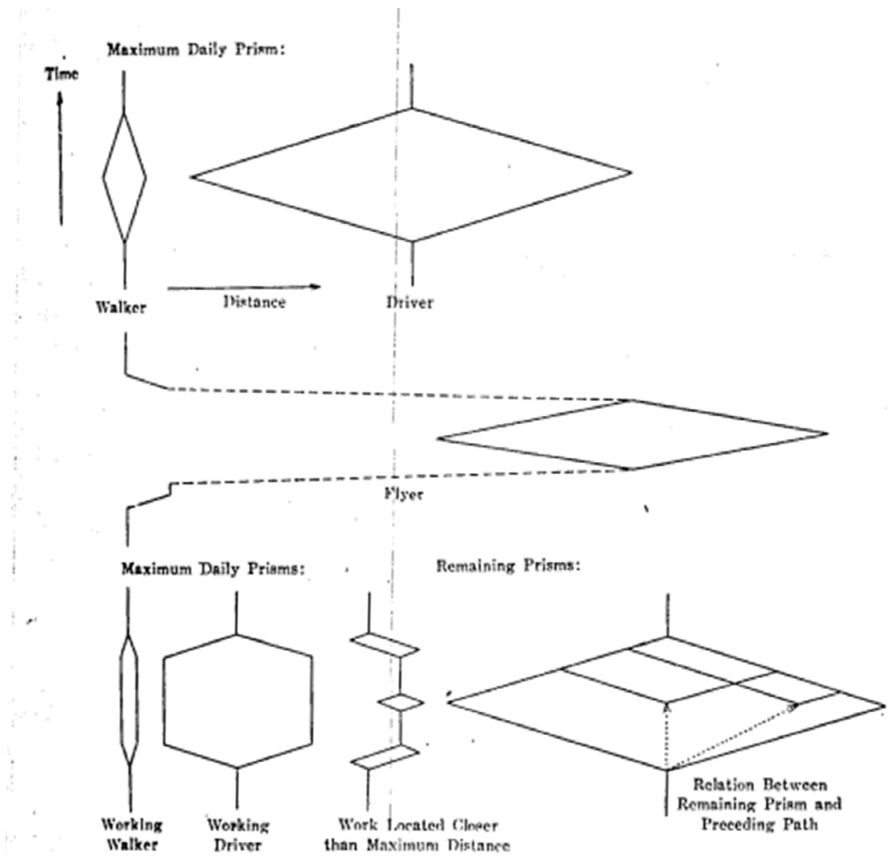

Figure 5: Daily prisms (Hägerstrand, 1970)

There are certain disadvantages with time-space measures, e.g. the difficulty of deciding on a certain time frame (limit) for persons in the same area (Bhat, et al., 2000b). Looking at accessibility with time-space geography measures is hard due to its disaggregated structure.

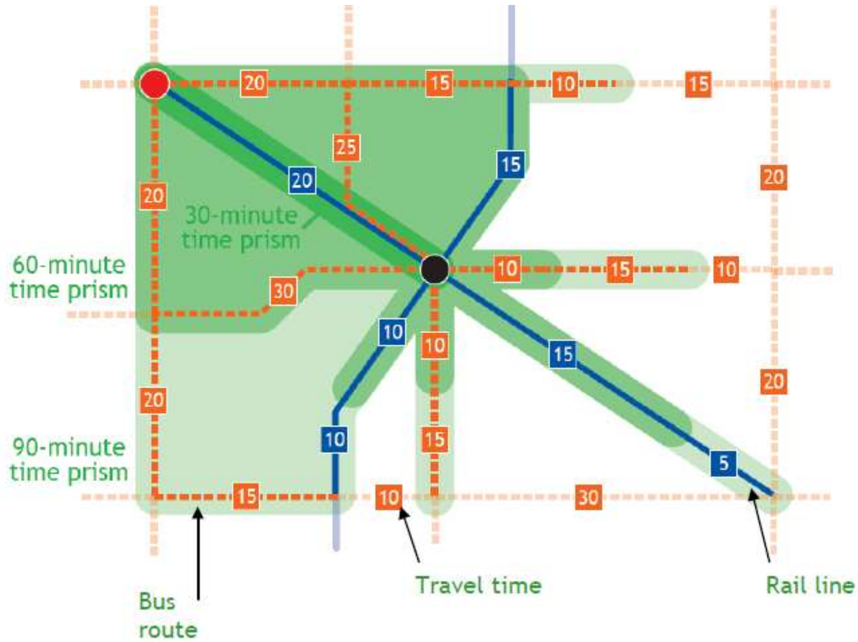

Figure 6: Time-space prisms on a transportation network. The prisms represent the area which can be covered within a certain time while getting from origin (red dot) to destination (black dot) (Scheurer & Curtis, 2007).

2.1.2.4 Utility-based Measures

The utility-based measures have their origin in economics (Geurs & van Eck, 2001) and are based on economic studies and utility functions. These measures investigate which (economical) benefits can be drawn from individuals' access to activities. The measures view accessibility as a resulting benefit of having possible transport choices (Geurs & van Wee (2004), Scheurer & Curtis (2007)). The benefit can be monetary or in the form of equity.

The likelihood that an individual will choose a certain transport choice is based on the individual's utility function, as the individual is trying to maximise his/her utility (Papa, et al., 2016).

For utility-based measures on accessibility, the *log sum* is used, which is the denominator of the multinomial logit model (Geurs & van Wee, 2004). The log sum summarises the utility for the entire set of transport choices.

As the utility-based measures have a sound basis theoretically, it has an advantage towards other measures (Geurs & van Eck, 2001). The utility-based measures also assess the accessibility for an individual at a location, compared to e.g. the gravity measures which suppose that all individuals being at the same location have the same accessibility. A disadvantage with the utility-based measures is that they are difficult to comprehend (Geurs & van Wee, 2004). Sheurer & Curtis (2007) point out that there are fields where utility-based measures are useful, such as when station areas get added value thanks to increased rail service. The economic benefits could be, for example, greenhouse gas savings, improved accessibility for individuals in unfavourable situations or economic performance.

2.1.3 CO_2 as an accessibility indicator

Indicators used for accessibility measures are e.g. travel distance, travel time or monetary values, where to two latter are the most common ones (Määttä-Juntunen, et al., 2011). To view the problems of increasing CO_2 emissions that the International Energy Agency (2018) highlights, another type of accessibility indicator could be an approach. Instead of the frequently used indicators, the impedance and threshold for the accessibility assessment could be expressed as emission levels of carbon dioxide.

Määttä-Juntunen, et al. (2011) study different shopping locations' accessibility with a CO_2 emission as the foundation in Oulu, Finland. Results are that centrally located shopping areas are beneficial to CO_2 emission levels. This study is limited to car traffic.

In Lisbon, Portugal, neighbourhood accessibility to activities such as bakeries and schools are assessed by using an accessibility function based on travel distance, but also on the estimated environmental impacts such as emissions of CO_2, PM, and NO_x (Vasconcelos & Farias, 2012).

In a recent study by Kinigadner, et al. (2019), two workplace relocations in Munich, Germany were reviewed from a CO_2 base accessibility point of view. The study takes both car and public transport (metro, subway, train and bus) into account. Concluding the article, the authors claim that having a travel impedance based on emissions, new perspectives on accessibility can be achieved. The study uses a contour measure with a fixed cost defined by CO_2 emissions.

According to Kockelman, et al. (2013), people living in accessible places can easier access activities (locations) that they desire or find attractive. With an emission perspective, this could mean that people living in accessible places easier can get to activities that are located in more *emission efficient areas*, where activities are reachable with low emissions. The individual perspective is likely not taken into consideration when using a CO_2-based accessibility measure, as everyday people are likely to not desire emission efficient ways of transport or find it attractive in contrary to decrease their travel time or cost.

When performing the accessibility study with regards to CO_2-emissions, there are certain accessibility components (from section *2.1.1 Defining Accessibility*) that are in use. The land-use component is in play, as the location of the destinations and customers have an impact on the accessibility. If the shopping location is located in a densely populated area, the number of customers that can be reached within a certain budget is larger than if the location was rural. Depending on if the street is rural or urban, the emissions per kilometre is different for a car as well. The transport component also has an impact on the CO_2-based accessibility, as the properties of the infrastructure play a role in what modes are available. With a fine network of rail infrastructure or bus lines with separate lanes, more people are likely to access emission-efficient infrastructure.

In the Munich study by Kinigadner et. al. (2019), the travel time for public transport is used as an impedance to decide the optimal route, and emissions were used as the threshold. This study does not take travel time into account and uses the emission of carbon dioxide as both travel impedance and threshold value. Using CO_2 as impedance can lower emissions used by up to 30% (Jia & Håkansson, 2016). The temporal component will not be dealt with in the analysis presented in this thesis, as e.g. the opening hours for the destinations are not considered. The individual component will not be further assessed when using CO_2 as an indicator, as every person has the same emission budget. Car ownership and demographics are not taken into consideration in this study.

As the field of the CO_2-based accessibility assessment is rather new, the supply of academic studies is scarce. This thesis aims to contribute to the topic.

2.2 Location of Trade

The location of trade has an impact on both traffic and emissions (Trivector, 2007). In the following section, different aspects of the trade location are presented. The history during the last centuries is reviewed both in Sweden and internationally, followed by future trends and how the localisation of peripheral trade impacts different areas of regional and urban planning together with the concept of accessibility and transportation

As this thesis focus on peripheral shopping centres, it seems necessary to ahead of this part of the literature review define what a peripheral shopping centre will refer to in this study. In a report by Trivector (2007), the authors use the definition:

> "All trade that is situated at a car traffic-oriented location, outside of residential areas and city centres. The term peripheral shopping centre includes outlet centres, big box stores, trade in industrial areas, hypermarkets and shopping areas"
>
> (Trivector 2007, p.4)

Additional definitions of trade and shopping terms can be found in section *1.4 Terminology*.

2.2.1 Historic perspective

The ways of trading goods in Sweden has changed over history (Ahlberger, 2010). The author (based on work by Fisk (1967)) explains that during the early parts of the 19th century, there were three main forms of trade in Sweden:

1. Buyer approaches seller (traditional town trade, handicraft farms)
2. Seller approaches buyer (peddling, mail order)
3. Buyer and seller meet at neutral locations (marketplaces)

In the early years of the 1800s, markets and peddling (as defined in *1.4 - Terminology*) were dominant as trade forms while the Swedish towns were small and unable offer a good town trade (Ahlberger, 2010). Approaching the mid-19th century, general store trading gained more freedom from the governing organizations and surpassed the marketplaces' and peddling's share. While the towns grew, the traditional town trade got more competitive and increased as well. From this point in time, the dominant form of trade in Sweden will be *buyer seeks out seller*. Tufvesson (1985) explains that modern retail has its origin in the latter parts of the 19th century when the industrialism's entry also created a change in the retail industry.

Further evolution of the forms of Swedish trade can be explained from demographic changes and the economic cycles over time (Tufvesson, 1985). From 1850 up until the 1930s, the general stores represented the primary form of trade in Sweden (Ahlberger, 2010). However, with increased urbanisation combined with improved infrastructure, the market share of the rural general stores decreased. The general stores only maintained a minor market share after the end of the Second World War.

In 1950s Swedish towns, most districts had their own local grocery store, The Swedish National Board of Housing, Building and Planning state (Boverket, 2004). With the department stores and supermarkets entry in Swedish retail, with chains as Domus and Tempo, the local grocery stores would suffer: the number of stores declined from 36,000 in the '50s to around 6,000 in the early 2000s. In the meantime, Domus, Tempo and other chains would reshape the structure of the centres of Swedish towns and cities during the '60s and '70s by building big department stores in the heart of the towns, as described in the Swedish documentary När Domus Kom Till Stan (2004). Together with the increasing motorisation, the retail development was an important cause for dramatic changes in Swedish city centres (Svensson, 1998).

The progression of shopping centres built outside of the city centre began in the United States (WSP, 2012). The U.S. had been ahead of Sweden in the development of trade forms during the 20th century (Boverket, 2004). Already in the 1930s, supermarkets in America was gaining big market shares, 20 years before the store concept had an influence on Swedish shopping (Svensson, 1998). From the '50s to the '80s, shopping centres in the U.S. increased from a couple of hundred to 22,000. At this point, hypermarkets' and shopping centres' trade turnover aggregated up to half to the total retail on a national level. In the meantime, the total trade turnover share in city centres was only 10%. In 2001, there were almost 46,000 peripheral shopping centres in the country.

After the recession of the 1970s, the Swedish department stores were being outcompeted by the peripheral shopping centres (Ahlberger, 2010). The department stores were instead rebuilt to centrally located shopping malls. For some retail industries, a central location in the city is not ideal (Boverket, 2004). The out-of-town locations tend to result in lower costs such as e.g. rent, and thus lower prices. The assortment of goods is also wider in the stores in general.

Trivector (2005) summarises that the retail development in Sweden during the 1990s has led to:

- The stores, especially grocery stores, are getting bigger;
- Chains of stores, both Swedish and international, are gaining increasing market shares;
- More goods are sold via peripheral shopping centres.

The peripheral shopping centres' turnover share of Swedish retail was 1% in the middle of the 1970s and 8% in 1992. The peripheral shopping centres showed 85% growth during the 1990s (Trivector, 2005). There has been more growth in regions of smaller cities, rather than in the big city areas. In 2001, peripheral shopping centres accounted for 30% of the turnover in Swedish retail (Boverket, 2004). HUI, the Swedish Institute of Retail, (2017) specifies that peripheral shopping areas and centres now has 37% of the Swedish retail market share.

Sweden is not the only country where the trade has gone from the inner city to other locations during the last decades. In Europe, nations such as Germany, Denmark and the United Kingdom show the same tendencies (Boverket, 2004). Where the changes have been the biggest, the impact from peripheral centres on the trade in the smaller town centres has been negative.

In the U.S., the decaying city centres led to cheaper land pricing followed by a slum-like environment with increased crime rates. Today, the U.S. is once again investing in the inner cities and downtown areas to improve the condition. Some European countries, e.g. Finland and the Netherlands, have responded with distinct policy decisions to control the development of private trade establishments on different levels of planning. Most European countries have approved some sort of policy to assess and oversee trade development. Boverket (2004) points out a number of factors that are mutual in the policies, e.g.:

- By locating service in the city centre, close to residential areas and nodes in the public transport system, car travelling can be limited;
- Maintaining a balance between different forms of trade in the city;

- Limiting the negative effects of peripheral trade locations.

However, Sweden is one of the few countries in Europe that hasn't regulated shopping at peripheral shopping locations (Trivector, 2007).

Not all shopping centres that are outside of the city centre fall under the definition of *peripherally located* though. In a report by Trivector (2003), the authors introduce *semi-peripheral* shopping centres. They have similarities with the peripherally located and are still car traffic-oriented, but are also possible to reach by public transport, bicycle and foot. The semi-peripheral centres are in the vicinity of urban areas, in connection to built-up, e.g. residential, areas. The semi-peripheral shopping centres causes lower levels of the total emissions since the driving distance are shorter (Ljungberg, et al., 1995). In the same study, however, the authors conclude that a semi-peripheral centre still causes *more emissions in the city centre* than a peripheral.

While the first category of trade form (*buyer approaches seller)* has been prominent during most part of 20th century and onwards – Ahlberger (2010) predicts that information technology innovations can change trade forms as we know them. IT can be a great influence in all forms of trade.

2.2.2 Trends in Trade

When a customer is about to buy a product, he or she wants to minimise the cost of paying and performance that is needed for the purchase (Fisk, 1967). What the cost is, depends on the individual: a person that has a low purchase power might want to save money and effort, and instead spend more time on the purchase. Someone with more purchase power perhaps will opt for saving time and effort, spending more money to do so. Fisk (1967) claims that good infrastructure saves more time, information search and benchmarking more money and postal order more effort. Today, IT and e-commerce have come to change the game (Svensk Handel, 2018). With the Internet, information and comparisons can be easily found and ordered to the person's front door.

In a report from Boverket, (2015), the trends of trade in Sweden point in several directions: shopping centres, both centrally and peripherally placed, will continue to grow. At the same time, predictions show that the traditional trade in the cities will have a revival. There are also tendencies that customer shopping habits will change in the future: the demand for service and event trade will increase. The e-commerce will increase as well, leading to lowered market shares for the traditional retail industry. The retail stores will get fewer. Reports are not completely consistent: in contrary to the Boverket report, the Swedish Trade Federation claims that sales in peripheral shopping centres will probably decrease during the next couple of years (Svensk Handel, 2018).

Recent reports from the Swedish Institute of Retail show a continuously increasing e-commerce. Since the Institute started its monitoring of Swedish e-commerce in 2011, it has increased each quarter (PostNord, Svensk Digital Handel, HUI Research, 2019). According to the same report, the authors claim that in the future, physical stores will exist to increase brand recognition and create customer relations while e-commerce will be responsible for the transactions.

The market shares of Swedish retail are shown in Figure 7. From 2005 to 2016, e-commerce's market share increased by 7%, while shopping areas grew by 8%. Shopping centres' market share did drop by 1%. The declining trade form is clearly "Other physical forms of trade", with a market share drop of 14%. This involves traditional trade in the city centres, smaller stores etc. In total, shopping areas and shopping centres claim circa 40% of Swedish retail market share. The report does however not specify to what extent the categories are peripherally or centrally placed. Other reports also show that e-commerce has around 8% of the retail market share (HUI Research, 2017), growing by almost one per cent yearly.

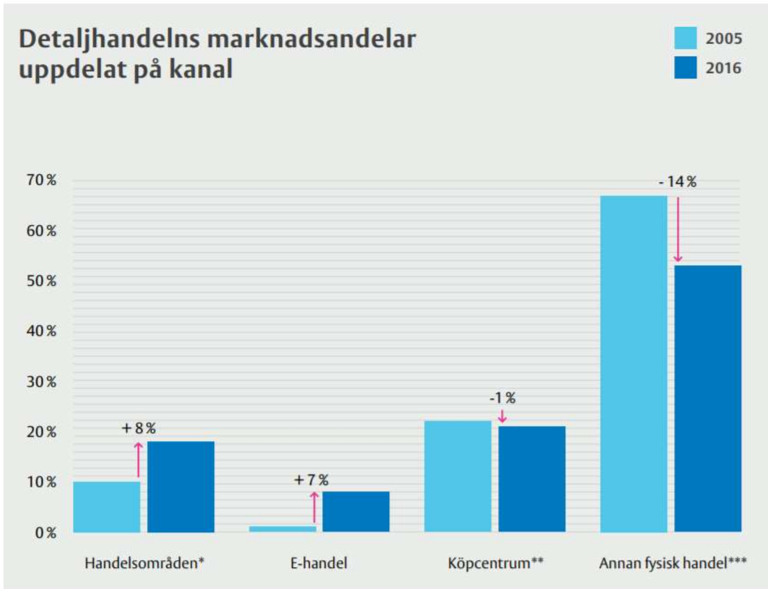

Figure 7: Retail market shares in Sweden (Svensk Handel, 2018)

E-commerce is growing and shows no signs of slowing down (Svensk Handel, 2018). To make sure that the potential of e-commerce is utilised, it needs to be not only controlled by the market but also promoted and regulated by policy decisions (Trivector, 2011).

2.2.3 Impacts of Peripheral Trade Location

A definition of peripheral shopping centres is that they are "[…] *situated at a car traffic-oriented location, outside of residential areas and city centres"* (Trivector 2007, p. 4), which means that an increase of external shopping centres is an increase of car-accessible points of interest. This will lead to more car traffic and emissions. Semi-peripheral shopping centres causes less total emission, but emissions are more concentrated in densely populated areas. Both types of establishments are somewhat peripheral, favour car traffic and are worse alternatives than city centres (Trivector, 2005). In this section, the peripheral and semi-peripheral shopping centres are viewed as having a similar impact on areas such as regional and urban, transportation and accessibility perspectives.

Land-use planning can have a reducing effect on energy use and emissions (Black, 1996). The foundation of a sustainable transportation system is to localise dwelling and shopping areas so that motorised transportation dependency can decrease (Trivector, 2011). At the same time, a good supply of public transport is a condition to make the transportation system sustainable.

2.2.3.1 Regional and Urban Perspective

Everyday life does no longer take administrative boundaries into consideration (Boverket, 2015). Instead, we travel between municipalities, living and working in different parts of bigger *regions*.

Boverket (2004) writes that an increase in peripheral shopping centres affects the surrounding cities and municipalities, not only the direct area where the complex is built. There can be a competition between municipalities in regard to the purchasing power of the region (Trivector, 2003). This competition can force municipalities to say yes to the establishment of a peripheral shopping centre. Trivector (2007) writes that both trade and traffic situation in the larger region is affected due to the big customer basis that is needed for the type of trade form.

Boverket issued a poll in 2003 to provincial architects in Sweden. Answers that came back were that regional or inter-municipal considerations in matters of urban planning, including peripheral shopping locations, almost are non-existent (Boverket, 2004). The municipals that tried cooperation had varied success. Regional planning is only apparent in the regions in and around the cities of Gothenburg and Stockholm. Trivector (2003) sent out a survey to Swedish municipalities about peripheral shopping centres. Among the answering municipalities, 92% said that they did not have any regional policies regarding the shopping establishments; 66% said that they thought that regional cooperation was needed.

In a report by the Institute of Transport Economics in Norway (TOI, 2009), they point out that the location of trade should be one of the main element in regional plans. An analysis should be conducted for future trade development and for the already existing.

Boverket (2004) points out that the competition between the peripheral and city trade needs to be balanced. In Swedish cities where the peripheral shopping centres have been too dominant and allowed to outcompete the city centre, the cities have suffered and have had a hard time, almost impossible, recovering.

2.2.3.2 Transportation Perspective

Over the course of the next decade, the emissions from the Swedish transportation system needs to decrease by 70% (Ministry of the Environment, 2017). Main elements that influence the transport emissions are fuel types, vehicle energy efficiency and total vehicle mileage (Naturvårdsverket, 2018a). While more sustainable fuels and more efficient vehicles have been increasing in share, total vehicle mileage has continued to grow nationwide. This has led to that the decrease in traffic emissions has not been as big as it potentially could.

Both peripheral and semi-peripheral shopping centres generate car traffic (Trivector, 2005). From that perspective, the establishment of new peripheral shopping centres is counterproductive against the Swedish national transport objectives. According to the national travel survey done in 2005, the shopping trips in Sweden represent 7% of the total number of trips (excluding grocery shopping). In a report by Trivector (2011), the CO_2 emitted by the shopping trips (including grocery shopping) stands for 10% of the Swedish transportation system emissions.

The localisation of the shopping area has an impact on the traffic levels and emissions that it generates (Trivector, 2005). However, it is not certain that a more central location equals lower environmental impact. A central establishment is usually more attractive, hence is the potential customer catchment area larger – leading to more traffic and emissions.

Using GPS data in the Swedish city Borlänge, a study find that an establishment of a peripheral shopping centre would increase the CO_2 emission of customer trips by almost 60% (Carling, et al., 2013), compared to if the shopping took place in the city centre or in the fringe of the city. The authors add that a peripheral shopping centre also would cause additional emissions due to store logistics. In another study from Shenyang, China, results are that the localisation of a shopping establishment has a big influence on CO_2 emissions caused by transportation (Li, et al., 2016). Peripherally located shopping centres having 7-25% higher emissions than centrally located ones.

A potential reason for a peripheral location from an entrepreneur's point of view is that through the situation by big infrastructure nodes and links, freight can be more effective and cheaper (Fisk, 1967). A peripheral location most often also equals a lower price of land and rent (Trivector, 2005). From a customer point of view, peripheral shopping centres have gained increased popularity because of an increase in car accessibility and car ownership.

The location of shopping establishments with sustainable modes of transport, such as bike and public transport, generate fewer emissions (Trivector, 2007). Public transport users also combine their shopping trip with other errands to a higher degree than car users (Trivector, 2005). Even though semi-peripheral centres are more accessible by public transport and bicycle than peripheral centres by definition, they are still car-oriented and cause emissions.

According to a report by Trivector (2003), the emissions of CO_2 from road transportation could be lowered by 20% in the long term through good location and urban planning. There is a great potential to increase sustainability in transportation to and from peripheral shopping centres (Trivector, 2011). In the report from Trivector (2011), the authors recommend the localisation of trade to increase sustainability. By situating retail close to areas with high residential concentration, more customers will choose active modes (biking or walking) for their trips to the centre. Through placing trade close to public transport nodes and links, sustainable modes' shares can increase as well.

2.2.3.3 Accessibility Perspective

In his book from 1967, Fisk explains that goods will be easily *accessible* for many individuals if they are centrally located: "The localisation in the core of the physical distribution's problem" (Fisk, 1967, p. 344).

From an accessibility point of view, peripheral trade location development has caused exclusion (Boverket, 2004). While peripheral shopping centres in some cases have made shopping for families easier, the centres are not ideal for individuals without a car. Trivector (2007) writes that peripheral shopping centres have caused decreased accessibility for individuals that do not have access to a car. Trivector (2011) states that even if car available shopping centres in the peripheral parts of our city regions have made mobility easier, the total accessibility has decreased, especially for groups without car ownership. 25% of Swedish households, mainly single mothers, elderly or boys and girls under 25 years of age, lack car access (Boverket, 2004).

Trivector (2007) recommends that an accessibility analysis should be conducted if *"the accessibility to trade for different groups in society is affected in different ways, in the short or long term. Pay particular attention to vulnerable groups like the disabled, elderly, adolescents and households without a car."* (p. 13).

For future trade, Trivector (2007) and Boverket (2015) recommend that the accessibility for sustainable modes should be encouraged. Trivector (2007) expands onwards that the municipality's planning can have a great influence on decreasing the environmental impact and increase the accessibility provided by the transportation system. Through a localisation study in early planning stages, site selections that can:

- Decrease the dependency of motorised transportation;
- Have a high degree of accessibility for public transportation;
- Have a traffic design that focuses on public transport and active modes.

Interviews with entrepreneurs, conducted by Trivector (2007), show an attitude where some believe that a high accessibility with public transport and active modes is not relevant when it comes to peripheral shopping centres due to the range of goods. Even though many stores sell big volume products such as furniture and appliances – almost no store has an explicit range of bulky goods. When buying smaller products, PT and active modes are useful for transportation for the customers. Therefore, according to Trivector (2007), an accessibility analysis is always needed. In a study by Trivector (2011), customers from four peripheral shopping centres in southern Sweden are observed. Results are that only 12% have so many products that a car was necessary for transportation. The other 88% can use other, more sustainable, modes of transport. In another report by Trivector (2005), 70-90% of customers that have used public transport to get to a shopping centre say that they would *not* shop more if they were using a car.

While this study focuses on accessibility from a macro perspective, it is worth noting that improvements in micro-accessibility can influence the usage of public transport. According to Boverket (2015), safety measures on the path to and from a bus stop can result in more people taking the bus. Even if the location of the shopping centre is fixed, there are still actions such as good detail planning and design that can serve a sustainable transportation system (Trivector, 2007). The actions Trivector points to is not certain, but the planners should aim to achieve higher accessibility by making transportation via walking, biking and public transport better and more competitive versus the car. Accessibility by the alternative modes is not solely that they are available, they also need to be competitive and attractive.

The location of a proposed shopping centre is, in the end, a political decision (Trivector, 2007). By comparing different possible locations and showing the results for the stakeholders, a bigger impact in policymaking can be obtained. Instead of making decisions based on gut feeling and assumptions, actual analyses and assessments can be the foundation.

2.3 Literature review conclusions

In this literature review, an overview is given on how trade forms and locations in Sweden have gone from the traditional peddling, town trade and marketplaces to today's peripherally located shopping centres and trending e-commerce. The changes in trade and the cities' and the transport system's structure have influenced each other historically. According to the literature reviewed, trade locations can have a big impact on sustainability in the transportation system.

It is evident that e-commerce's entrance in retail has had an impact on the way people shop. At the same time as e-commerce has increased, traditional ways of shopping have seen a decline. However, it is relevant to point out that the physical forms of shopping hold the majority of the market share, where shopping centres and shopping areas stands for 40%.

Over the course of the next decade, the emissions from the Swedish transportation system needs to decrease by 70% (Ministry of the Environment, 2017). From a case study in Borlänge, Sweden, conclusions were that there is a potential to decrease CO_2 emissions from shopping trips by over 50% by the relocation of the stores (Jia & Håkansson, 2016). As shopping trips are responsible for 10% of the transportation system emissions of CO_2 in Sweden according to some studies (Trivector, 2011), this can have a significant effect. According to a report by

Trivector (2003), the emissions of CO_2 from the road transportation sector could be lowered by a total of 20% in the long term through good location- and urban planning.

Peripherally located shopping centres increase the accessibility for car users but decrease the accessibility for users of other modes. National transportation objectives state that the transport system should contribute to providing everyone with basic accessibility. Through a localisation study in early planning stages, site selections can increase accessibility for public transport, create prerequisites for infrastructure that favour sustainable transportation modes and decrease car dependency.

By highlighting the trade locations' impact on emissions, this thesis will attempt to provide further contributions to the CO_2-based accessibility modelling. Carbon dioxide is the indicator of choice and substitutes more frequently used indicators such as travel time and travel distance. As mentioned in section *2.1.3 CO2 as an accessibility indicator,* this will mean that this study does not consider the temporal or individual accessibility component in the model. The temporal component is neglected by not considering opening hours of the shopping locations. By not taking the individual person's needs into account, the individual component is not included when using the new indicator.

Regardless of the indicator, there are many ways of measuring accessibility. Some measures lack a theoretical basis but are easy to understand for decision-makers while others show results that are based on proved hypothesises show a lack of transparency. With a CO_2-based accessibility model, the environmental benefits of using public transports can be shown. Also, the localisation of the trade can be viewed from an emission point-of-view.

Location-based accessibility measures are normally used for analysing accessibility on a macro scale (Geurs & van Wee, 2004). The contour measures' is a group within the location-based accessibility measures described in section *2.1.2 Accessibility Measures*. The contour measures' results are easy to interpret and communicate. In a study Bertolini, et al. (2005), authors conclude that a contour measure has its greatest strength in that it is easy to understand. The contour accessibility measure should, however, be used with knowledge of its theoretical flaws, such as not making distinctions between points within the same contour and not taking competition into account.

Going back to one of the definitions of accessibility introduced in *2.1.1 Defining Accessibility*, by te Brömmelstroet, et al. (2016, p. 1177):

> "An expression of the potential number of relevant activities that are located within acceptable reach of a given place or people in acceptable reach of an activity".
>
> te Brömmelstroet, et al. (2016, p. 1177)

A contour measure with CO_2 emission as threshold value would mean that the *acceptable reach* is the emissions. The *potential number of relevant activities* in this study's case means the number of potential customers, as seen from the location perspective on accessibility in Figure 8. The *given place* is the respective shopping centre of the case study, introduced below in *3.1 Case Study Areas*.

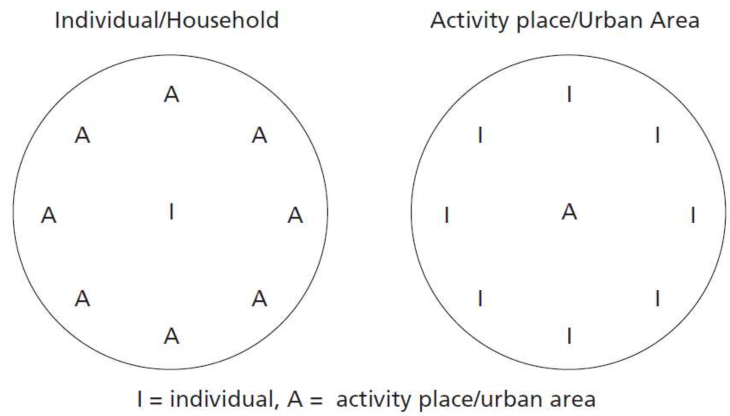

Figure 8: Individual/Household perspective (left) and location perspective (right) on accessibility (Dijst, et al., 2002)

The location of a proposed shopping centre is a political decision in the end. The contour measures are easily explainable (Geurs & van Eck, 2001) – enabling policy decision making to be based on actual analyses and assessment. Geurs & van Wee (2004) state that accessibility is an important input in policymaking. The contour measures are also frequently used in urban planning.

For the study, a location-based accessibility measure (that is, a contour measure) will be used to assess the points of interest in the field study. The accessibility indicator of choice is CO_2 emissions: by using a contour measure with a fixed emission cost, a CO_2 catchment area for the studied locations can be generated. The different emission cutoffs for the contours will be specified in section *3.2.1 Emission Budget*.

3 Methodology

Through this section, the two shopping centres that are subject of the case study are introduced, including surrounding areas and infrastructure. The CO_2 emission budgets and factors for the modelling are derived, followed by a brief description of data sources used for the study. At the end of the section, the workflow of the modelling is explained.

3.1 Case Study Areas

The objects and corresponding areas in the case study are chosen as they are located in different parts of the Scania region, near cities of different sizes and the infrastructure connecting the shopping areas to their customers differ. Below is a short introduction of both shopping centres and the enclosing areas. If the shopping locations are in fact peripherally located is looked into as well.

> "All trade that is situated at a car traffic-oriented location, outside of residential areas and city centres. The term *peripheral shopping* centre includes outlet centres, big box stores, trade in industrial areas, hypermarkets and shopping areas"
>
> (Trivector 2007, p.4)

Both locations of the case study are situated in the very south of Sweden (Figure 9), in the county of Scania. As introduced in section *2.2.1 Historic perspective*, both of the shopping centres introduced below can be seen as a consequence of the development of peripheral trade location starting in the 1970's.

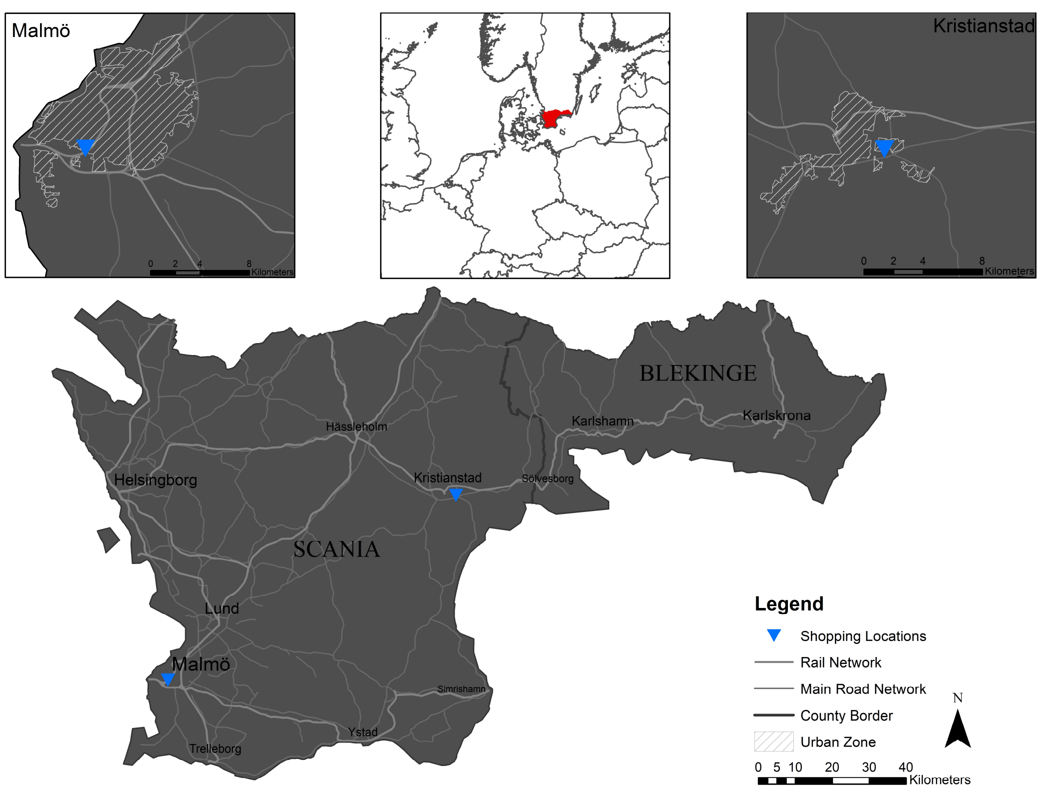

Figure 9: Overview of the study region with both shopping locations and the main road and rail network.

3.1.1 C4 Shopping – Kristianstad

Kristianstad is situated in the north-eastern part of Scania in the south of Sweden. The municipality has 85,000 inhabitants, with around 40,000 living in the city (Kristianstad Kommun, 2019). In Kristianstad, the transportation sector accounts for 61% of the total CO_2 emissions of the municipality (Kristianstad Kommun, 2018). Of this, 95% is from road traffic.

C4 Shopping opened in 2018, with a total area of 50,000 m2, both with a shopping centre (around 30,000 m2) and hypermarkets (Kristianstadsbladet, 2016). The establishment is located to the east of Kristianstad city centre in the suburb of Hammar, that also has a residential function and an industrial area.

An overview of the surrounding infrastructure is given in Figure 10. The highway E22 runs right next to the shopping establishment, connecting it with the southwestern parts of Scania and Blekinge in the northeast. The road numbered 118 connects the bigger towns of the municipality and surroundings. The public transport around C4 Shopping consists of four bus lines. One city bus (green line in Figure 10) connects the centre with Kristianstad city centre as well as a few suburbs. The three regional buses (yellow lines) go from the city centre and out to surrounding towns and areas. The railway network is connected to the city centre.

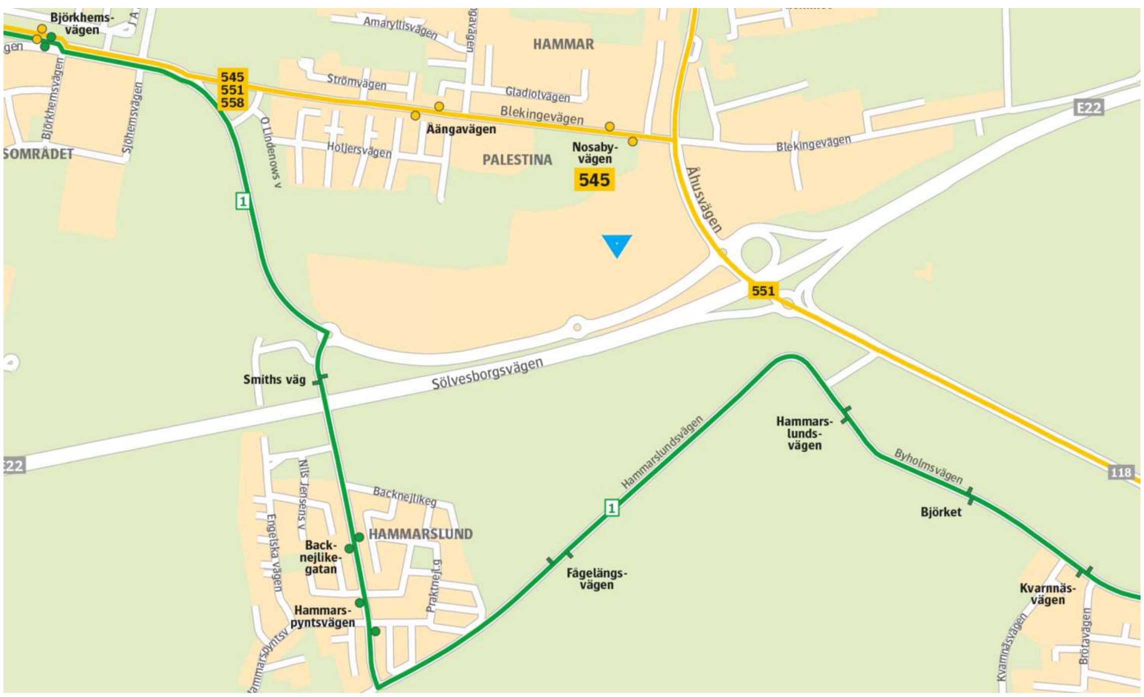

Figure 10: Infrastructural overview of the area surrounding C4 Shopping (blue triangle) (Skånetrafiken, 2019)

According to the retail strategy of Kristianstad municipality (Sweco, 2013), some main points of localisation of new shopping areas exist, where two are:

- No new peripheral trade locations;
- New establishments will be located within areas with good public transport and in connection to the main pedestrian and bicycle network.

Looking at the definition of peripherally located shopping centres, C4 Shopping does not fall completely under category, as it is located close to residential areas. However, it is arguably a car traffic-oriented location – indicating that the centre is of *semi-peripheral* character. On the shopping centre's website, they market themselves with being right next to the highway E22 (C4 Shopping, 2019).

3.1.2 Emporia – Malmö

Malmö is the third biggest city of Sweden, with a population of 340,000 people (Malmö stad, 2019a). It is situated in the south-west parts of Scania and is connected to Denmark and Europe by the Öresund Bridge. Between Malmö city centre and the bridge lies Hyllie, a newly developed urban area that has housing, offices, an arena and the shopping centre Emporia. In 2018, road traffic stood for 88% of the CO_2 emissions from the transportation sector (Malmö stad, 2019b).

Emporia opened in 2012 and has an area of 77,700 m2 (Steen&Strom, 2019). According to their website, over half a million people can reach the shopping mall within 30 minutes by car. The establishment is focused on retail but also has a grocery store on the bottom floor.

An overview of the public transport situation and traffic infrastructure is given in Figure 11 below. The shopping mall of Emporia is surrounded by residential areas but is outside of Malmö city centre. The mall is located close to highways (E6 and E20) connecting Scania and Denmark to Emporia. Other, more local, roads that are located close-by are both the inner and outer ring road of Malmö. Public transport makes it possible to travel by both bus and train to the shopping centre. The trains depart frequently from the closely located Hyllie Station to both Denmark and Malmö (and onwards to other Swedish cities). Four city buses and three regional buses connect Emporia and Hyllie to different parts of Malmö and its surrounding areas.

Figure 11: Infrastructural overview of the area surrounding Emporia (blue triangle) (Skånetrafiken, 2019)

In the planning programme for Hyllie by the City of Malmö (Malmö stad, 2003), it is stated that from an environmental perspective, the number of car trips should be minimised. This is considered in the infrastructure planning to not create an optimal solution for car traffic but find a good mixture between all modes. The programme recognises the car traffic generated by a shopping centre, followed by increased pollutions and emissions. From the traffic investigation, done by the City of Malmö in 2004, the estimated mode share for car traffic to the shopping centre was 70%.

Hyllie stands as a mixed business and residential area, on the fringe of Malmö but also closely connected to Copenhagen. While there are plenty of ways to travel to and from the centre with public transport, big highway runs next to the area. With this mix, the *semi-peripheral* definition is also applied on Emporia rather than a completely peripheral definition.

3.2 CO_2 Emissions

3.2.1 Emission Budget

In 2016, the transportation sector accounted for 25% of the global CO_2 emissions (IEA, 2018), emitting a total of 74% more than in 1990. Among the transportation sector emissions of CO_2, road transport stands for 74%. This means that road transportation emits almost a fifth of all emissions of CO_2 in the world.

Emissions from domestic transportation stands for 32% of Sweden's total emissions (Naturvårdsverket, 2018a). From this, 61% is from car transportation (Naturvårdsverket, 2018b). In Sweden, car transportation emitted 10,386 thousand tonnes of CO_2 equivalents in 2017, as seen in Figure 12.

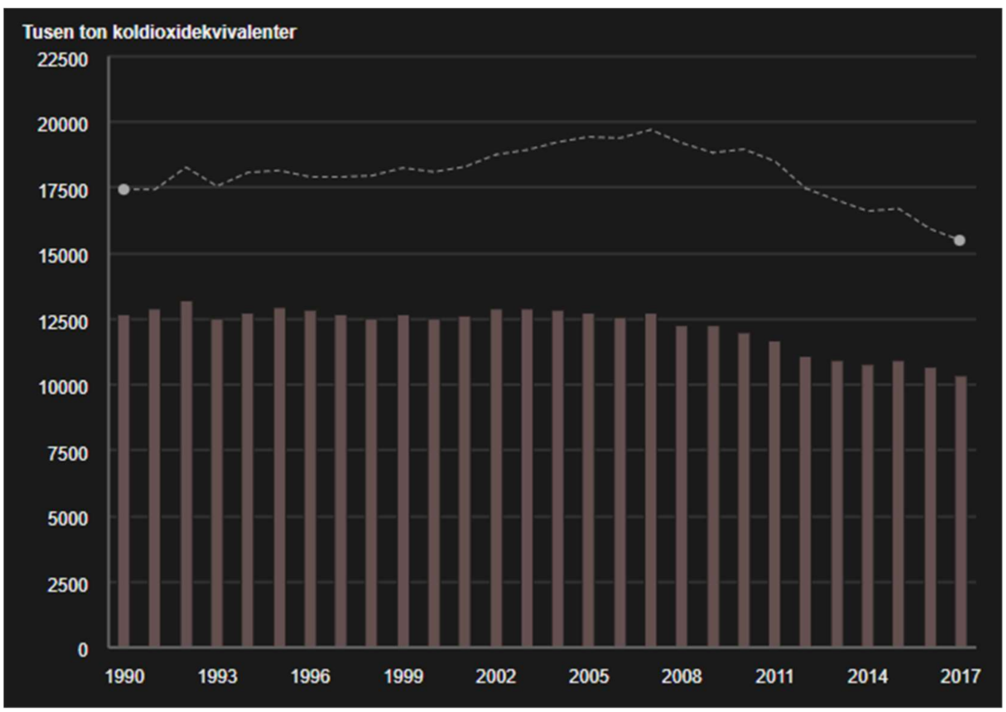

Figure 12: CO_2 emissions from the Swedish domestic car traffic 1990-2017 (columns). Dotted line represents the total CO_2 emissions from domestic transportation sector (Naturvårdsverket, 2018c)

In 2045, Sweden should not have any net-emissions of greenhouse gases to the atmosphere, according to the country's climate policy framework taken into effect in 2018 (Ministry of the Environment, 2017). One of the main categories of emission reduction is the domestic transportation system: by 2030 the emissions from the sector (excluding aviation) should be decreased by 70% from 2010 levels, which were at 12,035 thousand tonnes CO_2.

The contour measure counts opportunities that are reachable within specified thresholds (Geurs & van Wee, 2004). In this section, certain thresholds are calculated based on present and target emission levels from the transportation sector. The CO_2 budget indicates how much a trip to or from the field study destinations can *cost* in emissions of carbon dioxide. For the base of this study, the 2017 values from the Swedish car traffic emissions are compared with the 2030 target.

$$CO_{2_{2010}} = 12{,}035{,}000 \text{ tonnes}$$

$$CO_{2_{2017}} = 10{,}386{,}000 \text{ tonnes}$$

$$CO_{2_{2030}} = CO_{2_{2010}} \cdot 0.3 = 3{,}610{,}500 \text{ tonnes}$$

According to the national travel survey RES05/06, the share of travel activity (share of all kilometres travelled in Sweden per person) by car to shopping trips (not including grocery shopping) was 7%. This is used as the shopping centres are mainly focused on retail, per definition in section *1.4 Terminology*. The average number of trips per person and day of this kind is 0.16 in Sweden. The present population of Sweden is used (SCB, 2019).

$$\text{Travel Activity Share} = TA_{\text{shopping}} = 0.07$$

$$CO_{2_{\text{car, shop}}} = CO_{2_{\text{car}}} \cdot TA_{\text{shopping}}$$

$$\text{trip}_{\text{avg}_{\text{shop}}} = 0.16 \text{ trips/(person}\cdot\text{day)}$$

$$\text{population} = 10{,}305{,}517$$

$$\text{days} = 365$$

$$CO_{2_{\text{budget,2017}}} = \frac{CO_{2_{\text{car, 2017}}} \cdot TA_{\text{shopping}}}{\text{trip}_{\text{avg}_{\text{shop}}} \cdot \text{population} \cdot \text{days}} = 1.21 \text{ kg } CO_2$$

For the 2030 budget, the target emission value is used. Apart from this, the other components stay constant to create an understandable comparison.

$$CO_{2_{\text{budget,2030}}} = \frac{CO_{2_{\text{car, 2030}}} \cdot TA_{\text{shopping}}}{\text{trip}_{\text{avg}_{\text{shop}}} \cdot \text{population} \cdot \text{days}} = 0.42\ CO_2$$

3.2.2 Emission Factors

For the car modelling, the emission factors have been extracted from the emission manual for Swedish road traffic, published by the Swedish Transport Administration, Trafikverket. The factors are based on average vehicle data for the 2018 Swedish car fleet, including hot engine driving, cold starts and engine deterioration due to ageing (Trafikverket, 2019). The factors are based on the entire life cycle of the fuel types, from well to wheel, which take the production of the fuels into account. This means, that biofuels and electricity also cause emissions of CO_2. The factors also include both data for petrol cars with and without catalyst.

In the emission manual from Trafikverket (2019), there are two emission factors – depending on the road type (urban and rural). In the cities, carbon dioxide emissions are higher per kilometre than in rural areas. Reasons for a higher emission level in urban areas are e.g. that the traffic flow is less steady, lower average speed and more traffic jams (De Vlieger, et al., 2000).

According to the travel survey RES05/06, the average occupancy rate for shopping trips in Sweden is 1.77, which means that the emission factors per person kilometre are

$$CO_{2_{\text{car, urban,2017}}} = 0.21 \text{ kg/km} = 0.119 \text{ kg/pkm}$$

$$CO_{2_{\text{car, rural,2017}}} = 0.17 \text{ kg/km} = 0.096 \text{ kg/pkm}$$

In the report by Trafikverket (2019), there are projected emission factors for 2030. As the case study involves key objectives of transport emissions for 2030, these factors are relevant to the study. The occupancy rate for shopping trips is assumed to be at the same levels as for the 2017 scenario:

$$CO_{2_{\text{car,urban,2030}}} = 0.14 \text{ kg/km} \Rightarrow 0.079 \text{ kg/pkm}$$

$$CO_{2_{\text{car,rural,2030}}} = 0.11 \text{ kg/km} \Rightarrow 0.062 \text{ kg/pkm}$$

The emission factors for the public transport vehicles are provided by email conversation on 17^{th} September 2019 with Iris Rehnström, Environmental and Sustainability Strategist for the local public transport operator Skånetrafiken. The numbers are based on the vehicle emissions divided by average occupancy rates and trip lengths. The emissions are based on a well-to-wheel perspective (Skånetrafiken, 2018). The numbers used are from two types of trains, the Öresundståg (regional character, fewer stops) and the Pågatåg (more local character, stops more frequently). For the bus factors, the regional buses traffic lines between urban areas while the city buses run inside the city areas with surroundings.

$$CO_{2_{\text{train,O}}} = 0.034 \text{ kg/km} \Rightarrow 0.00041 \text{ kg/pkm}$$

$$CO_{2_{\text{train,P}}} = 0.034 \text{ kg/km} \Rightarrow 0.00068 \text{ kg/pkm}$$

$$CO_{2_{\text{bus,city}}} = 0.253 \text{ kg/km} \Rightarrow 0.028 \text{ kg/pkm}$$

$$CO_{2_{\text{bus,regional}}} = 0.289 \text{kg/km} \Rightarrow 0.029 \text{ kg/pkm}$$

The public transport network data used does not specify what type of vehicle that uses which transit line. Both train types often traffic the same railway lines, making it difficult to include and differ the emission factors depending on the trip. The higher emission train type stop on all stops eligible for person traffic along the railway network, and its emission factor is used. The bus emission factors are very similar to each other, and a simplification is made using the higher value.

$$CO_{2_{\text{train}}} = 0.00068 \text{ kg/pkm}$$

$$CO_{2_{\text{bus}}} = 0.029 \text{ kg/pkm}$$

No projections for emissions from future public transport vehicles could be obtained from the operator, meaning that the emission factor for bus and train stayed constant when modelling the 2030 situation. The public transport emission factors are still lower than the projected car numbers for 2030. A comparison between each emission factor per mode can be found below in Figure 13.

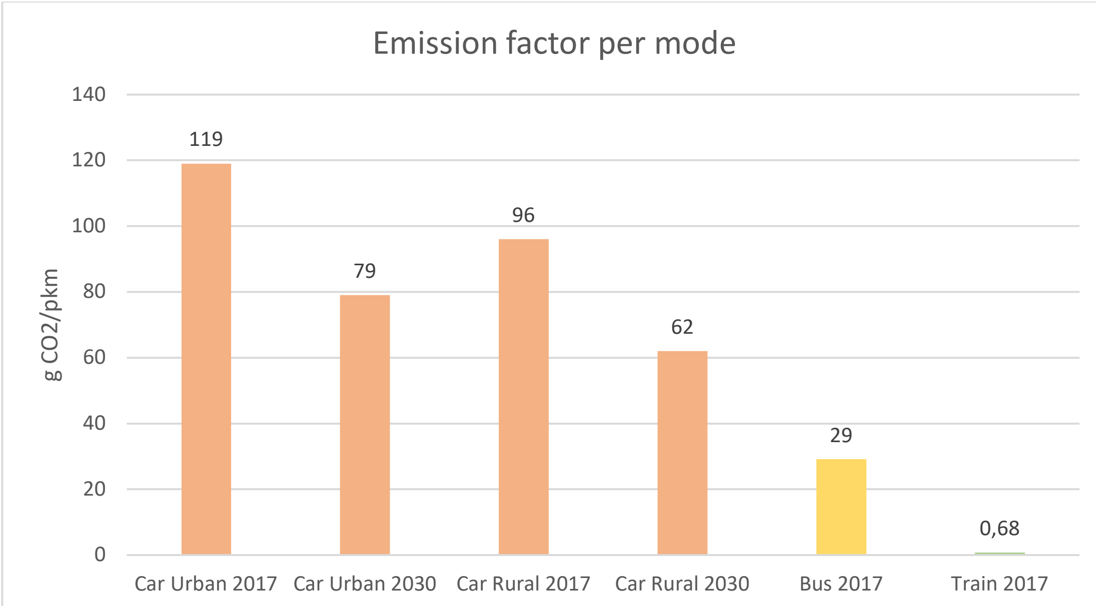

Figure 13: Emission factor per mode

The Munich study conducted by Kinigadner et al. (2019) had significantly higher emission factors in public transport modelling. This is because of Sweden's electricity emits less carbon dioxide per energy unit than the German, giving an impact on the train emission factor. The Munich buses are run on diesel, which emits more than the Swedish buses which run on biofuels or electricity.

3.3 Modelling

In this study, the focus lies on the accessibility of the shopping centres' perspective. Instead of viewing accessibility from an individual's point of view and seeing what type of activities that can be reached for each person, the activity is in focus. As seen in Figure 8, the viewpoint is instead on how many individuals that can be reached from the activity, this indicating the accessibility that each shopping centre has.

The accessibility in this model is a contour measure.

$$A_i = \sum_j O_j \, f(C_{ij}) \tag{2}$$

$$O_j = \text{Individuals in zone j}$$

$$C_{ij} = CO_2 \text{ emission of the trip between point i and j}$$

$$f(c_{ij}) = 1 \text{ for all } C_{ij} < CO_{2_{budget}}$$

$$f(c_{ij}) = 0 \text{ for all } C_{ij} > CO_{2_{budget}}$$

Where point i is the current shopping destination and j is each 100×100 meter population grid cell (see Figure 14). Each population square specifies the number of people living there, specifying O_j as each individual is considered a potential customer. $CO_{2_{budget}}$ is the cutoff value for the contour that changes between each scenario.

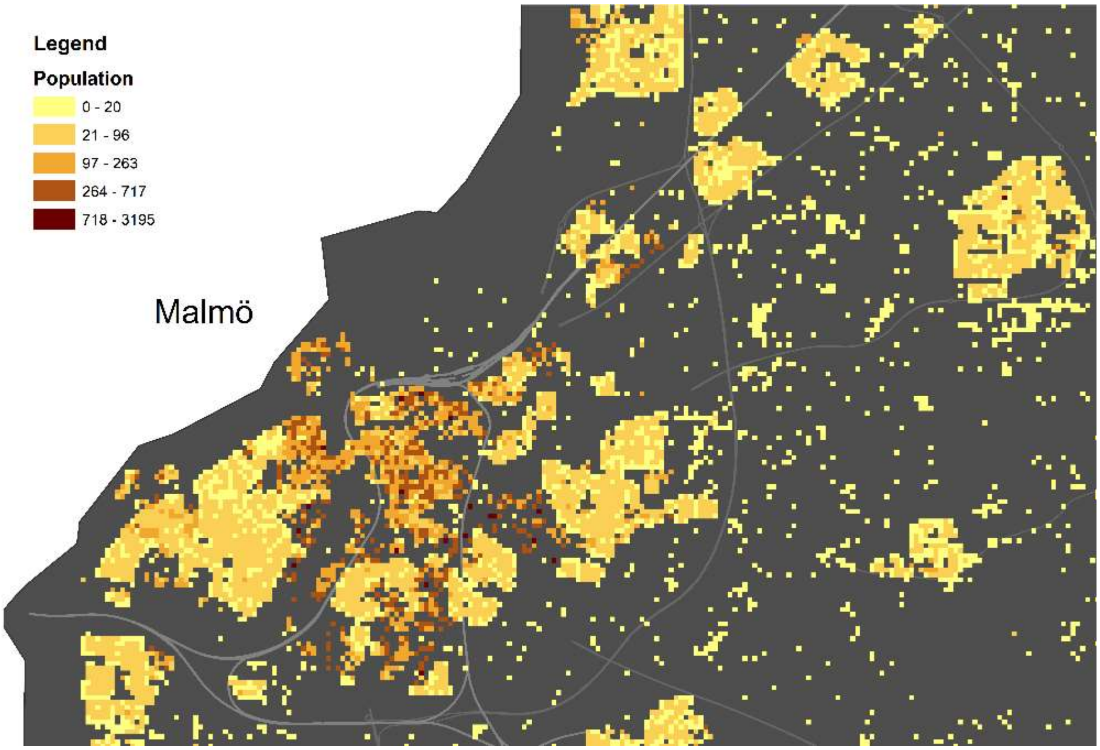

Figure 14: Population by 100x100 m^2 squares in Malmö

The software ArcGIS is used for the analysis. ArcGIS is a GIS system, where GIS stands for Geographic Information System and was first mentioned in a publication in 1968 by Roger Tomlinson (ESRI, 2012). One definition of GIS is:

> "A powerful set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world."
> (Burrough 1968, p.6)

GIS data can be organised and viewed so that policy decisions can be facilitated (Heywood, et al., 2011). There is a wide range of areas of use for GIS, for example, transport planning, mineral mapping potential, natural hazard assessment, and retail site location. Määttä-Juntunen, et al. (2011), mention that GIS has been utilised for the shopping industry for finding the most accessible location for customers.

3.3.1 Data Sources

The data used for the modelling in ArcGIS have been gathered from various open data sources. Being geodata, all data have a spatial reference that is utilised in the GIS software. Road and rail data have been downloaded from the Swedish Transportation Administration's platform – Lastkajen. The transportation network was merged and completed with a pedestrian and bicycle network from Lantmäteriet (Vägkartan). To get the public transport data (stops and transit lines), GTFS data from Trafiklab was used. Data about population and urban areas were collected from Statistics Sweden (SCB) which is the official statistics agency in the country.

3.3.2 Workflow

The geodata described in section *3.3.1 Data Sources* was imported into ArcGIS. The rail network only includes railways that are trafficked with passenger services. The region that is used for the analysis consists of the two Swedish counties Scania and Blekinge. Blekinge is included as it is closely integrated with the public transport system of Scania, and C4 Shopping (one of the studied shopping centres) is outspoken about having customers from the area (Kristianstadsbladet, 2019). Street and railway links that are outside of Scania and Blekinge are excluded from the dataset.

The analysis is divided into three scenarios. The first scenario analyses the accessibility provided by each shopping centre when travelling by car. The second scenario uses the bus as the only available mode of transport, and the third assesses accessibility supplied from the entire public transport network (both bus and train). The scenarios are used to view the differences in accessibility in regard to travel modes because of the network design and emission factors. A train-only scenario has not been analysed, as the rail network is very coarse and are not directly connected to both of the analysed establishments

For the car-based analysis, the first step consists of assigning the emission factors for both 2017 and 2030 (as described in section *3.2.2 Emission Factors*) to the street links in the network. To do this, the street links that are inside the urban areas are assigned the urban factor while the others are assigned the rural emission factor. Both shopping destinations are added to the map. The built-in function *Network Analyst* is used in ArcGIS to calculate a catchment area from each shopping location respectively within the emission budgets calculated in *3.2.1 Emission Budget*. The indicator CO_2 is chosen as impedance for the catchment area generation. For one route, the total emission is equal to the sum of every included link's emission. Each link's emission is the length of the link times the specific emission factor. The destination points are connected to the network by snapping to the closest network link. Each respective area shows how far out in the transportation network a passenger can travel within a specific emission budget.

For the second and third scenario, focusing on public transport accessibility, the workflow is different. The ArcGIS tool *Add GTFS to Network Dataset* is used to import GTFS data. The GTFS data adds public transport lines and stops. The public transport lines are straight lines (called *transit lines*) between each respective stop and do not completely resemble the real network shapes of streets and railway. For bus transit lines, the stops were placed frequent enough to align the lines with the street network in a sufficient way. Using the bus transit lines in the network analysis is a simplification (effectively making the bus routes' geometries shorter). However, it makes the modelling easier. The bus transit line network is used as the transportation network, with each line assigned with the bus emission factor. From there, the *Network Analyst* tool is once again used with carbon dioxide as an indicator.

In scenarios 2 and 3, a certain number of public transport stops are reached within the specific emission budget. From there, a new catchment area is generated around each stop. The new catchment areas are not based on CO_2 emissions as a cut-off value. Instead, they are based on an accepted maximum travel time (by foot), which is considered to be 5 minutes (Nielsen, et al., 2005). Using a bee line-shaped buffer around each stop, 5 minutes is represented by a 400 m circle. This does not cover barriers and the pedestrian network, as shown by Figure 15. An average walking speed of 100 meters per minute means that a 5-minute travel time is instead represented by a 500 m catchment area *along the network*. As the network data was available in this study, a catchment area using the network was used rather than a 400 m buffer. By using distance as a cut-off value in the transportation network, each stop gets an area assigned to it. The sum of all the stops' catchment areas can be viewed as the total catchment area of accessibility provided by the second and third scenarios.

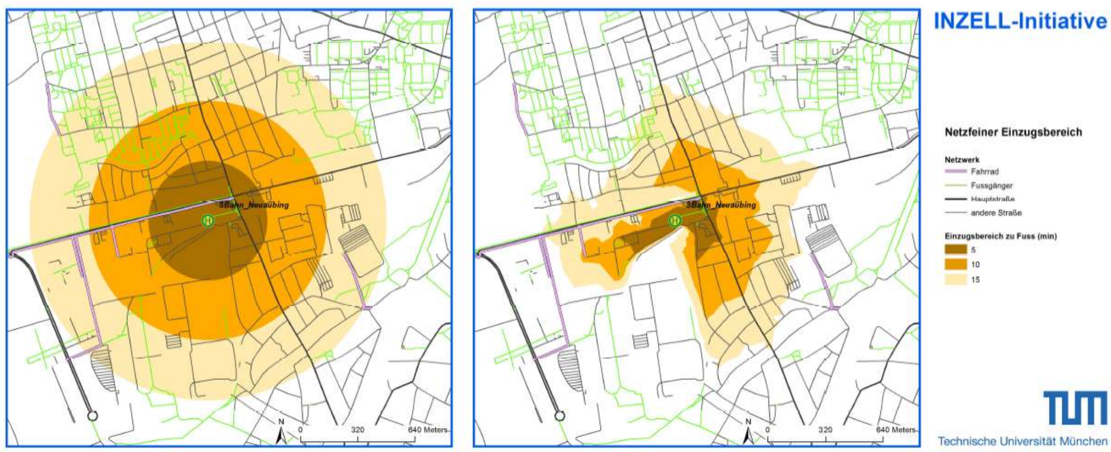

Figure 15: Catchment areas for pedestrians within 5, 10 and 15 minutes. Notice the difference between using the beeline (left) versus the actual network distance (right) (Wulfhorst, 2019)

In the third scenario, both bus and train transit lines are used. For the train transit lines, the stops are much further apart, meaning that the difference between the transit line distance and the real transportation distance in the network is significantly bigger than for the bus transit lines. To solve this error, the train transit lines are removed, and the real railway network (open for passenger transport) is merged with the bus transit lines, together forming a public transport network. This is rather simple operation due to that the railway network consists of few links and is delivered in a separate data file.

In some instances, the bus stop and the train stop were not always located at the exact same place even if they belonged to the same station area (e.g. one train station and a local bus node some 100 meters away). These were connected manually in the network to represent that an interchange in a trip can happen using both stops. The public transport network links are assigned with respective emission factors calculated in section *3.2.2 Emission Factors*, and the *Network Analyst* is run with the same cut-off values as in scenarios 1 and 2.

When the catchment areas for the car-based and public transport-based analysis for each shopping destination is generated, the accessibility index is calculated according to Equation 2 described in section *3.3 Modelling*. If a population square is intersected or covered by the scenario catchment area, the individual square population is added to the accessibility sum. Results are generated for each of three scenarios, with both emission budgets. This results in a total of 12 accessibility indexes, shown in Figure 17.

4 Results

In this section, the results for each of the analysis scenarios are presented. The results consist of visualisations in the form of maps, but also the accessibility index and how it changes depending on the mode of transport and emission budget.

4.1 Car Accessibility

In the first scenario, car accessibility is assessed from both locations. The results are displayed in Figure 16. Both catchment areas for the car are decreased from the 2017 levels to the 2030 target.

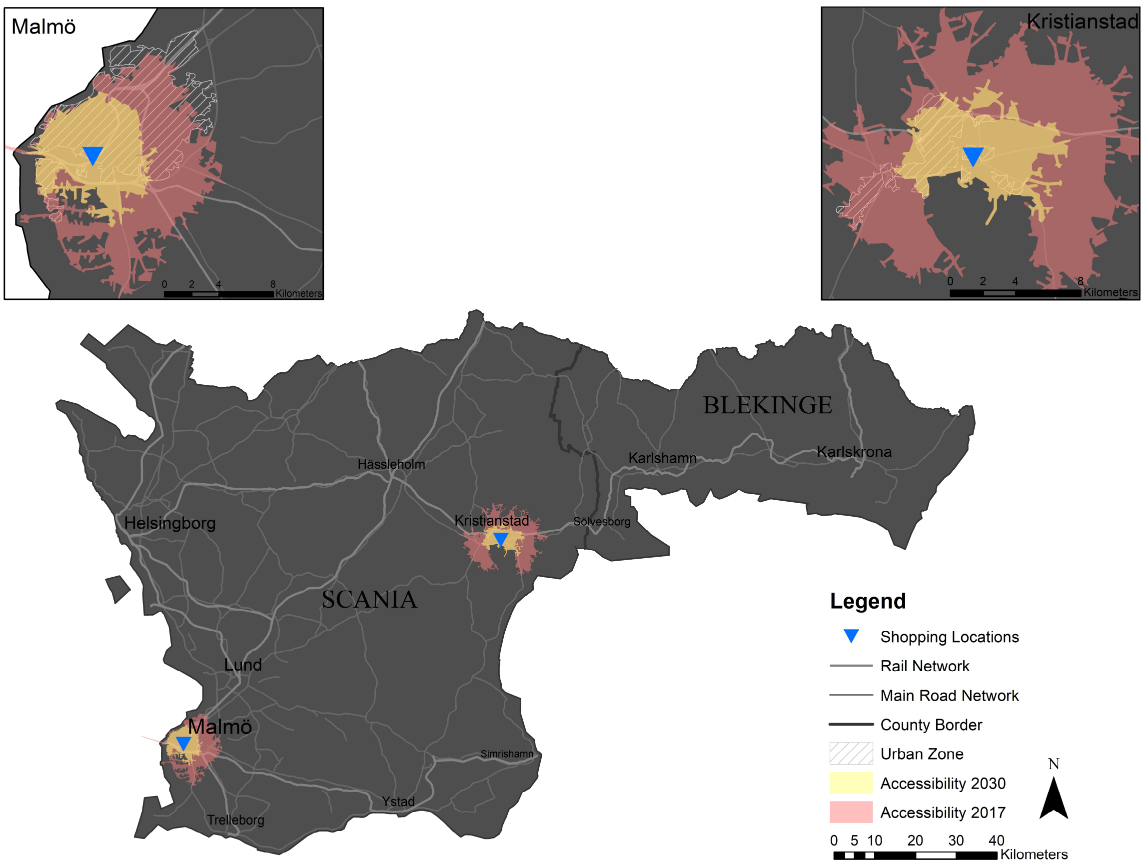

Figure 16: Accessibility by car

According to the generated maps, the 2017 emission level with a car makes it possible to reach almost the entire urban zone of Malmö city from Emporia, and south of it. For C4 Shopping, the main urban area is reached both with 2017 and 2030 budgets.

With the reduced emission budget, the catchment area decreases for both areas. In Malmö, Emporia now only reaches half of the main urban zone. The western urban area of Kristianstad is not as densely populated as the city centre but is not reached with the 2030 level.

The street networks surrounding the respective shopping centres are both fine, with the exception of a lake south of C4 Shopping. This is a strength of the car accessibility perspective, as the street network can reach every person in the area as long as the emission budget is not exceeded. It is unlikely that there are people living in residential building without access to streets just nearby, compared to public transport, where everyone is not within 500 meters of a bus stop or train station.

The population of Scania and Blekinge reached within the emission budgets, which is the index of accessibility in this study, is presented in Figure 17. A relative measure of the accessibility index is the *share* of the counties' population reached, presented in Figure 18.

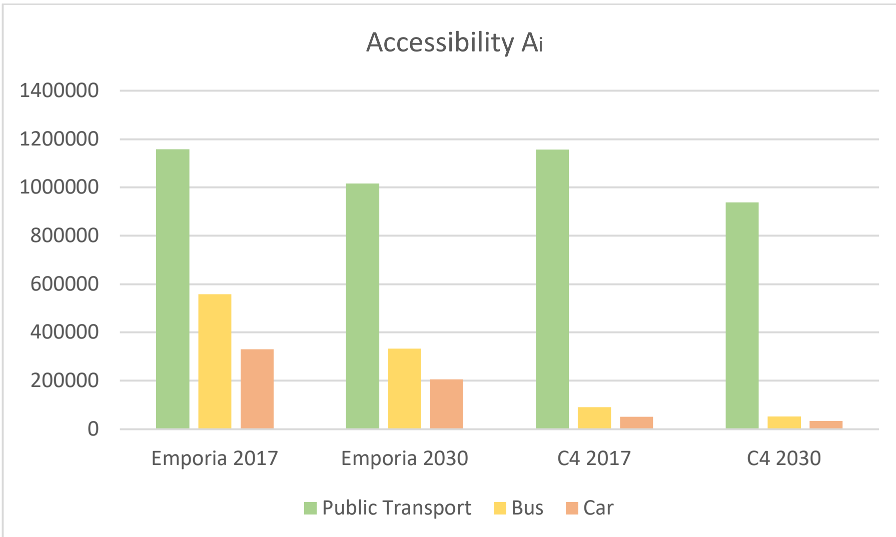

Figure 17: Accessibility Ai

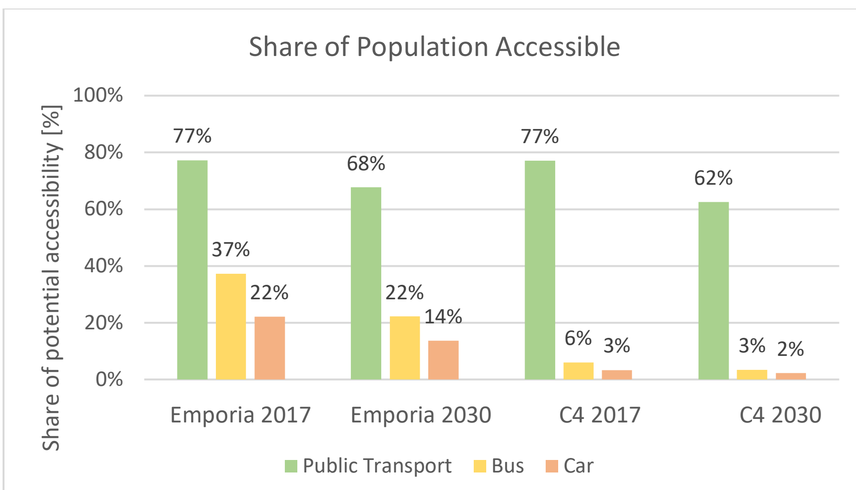

Figure 18: Share of the studied region's available population per mode and emission levels/targets

For Emporia, the shopping centre is accessible by car for 22% of the population with the 2017 levels. With the 2030 target, that number is 14% – a relative difference of -38% (shown in Figure 19). The share is lower for C4 Shopping with 3% to 2%, a relative difference of -33%. The results are likely due to the differences in the demographics of Malmö and Kristianstad. In Malmö, the population is larger (the third biggest city of Sweden) and it is more densely populated than the Kristianstad population. This results in more people reached within the same budget because there are simply more people close-by. As seen in Figure 16, the accessible part of the Malmö urban area is roughly seen to be cut in half between 2017 and 2030, but the relative difference is only -38%. This could be because the area that is still covered within the

2030 area is the more densely populated part of Malmö. In the smaller city of Kristianstad, the relative difference (Figure 19) is not as big as for Emporia, and the absolute difference (Figure 20) is much smaller.

Overall, the car accessibility from an emission perspective is low as the mode cannot reach any other cities or urban areas than the city the shopping centre is connected to, due to the high emissions that the car produce. The emission factor in 2030 for the urban area is 34% lower for the urban streets and 36% for the rural roads than the 2017 factors. This does not compensate for the 70% decrease in CO_2 budget between 2017 and 2030, and the catchment area is therefore decreased.

From the modelling, the accessibility (calculated by Equation 2) shows that Emporia is more accessible due to that more people can be reached within the emission budgets than for C4 Shopping. However, it should be noted that the Emporia advantage for car accessibility largely comes from being close to Malmö.

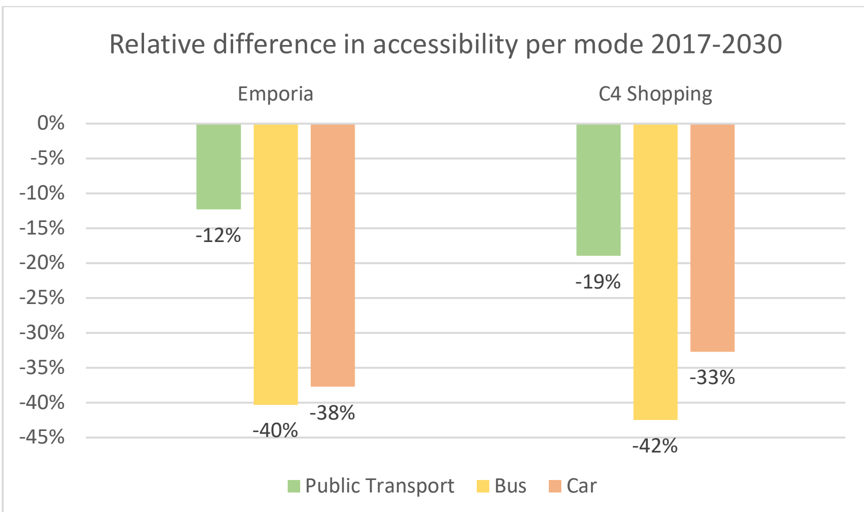

Figure 19: Relative difference of accessibility reached per mode between 2017 levels and 2030 targets

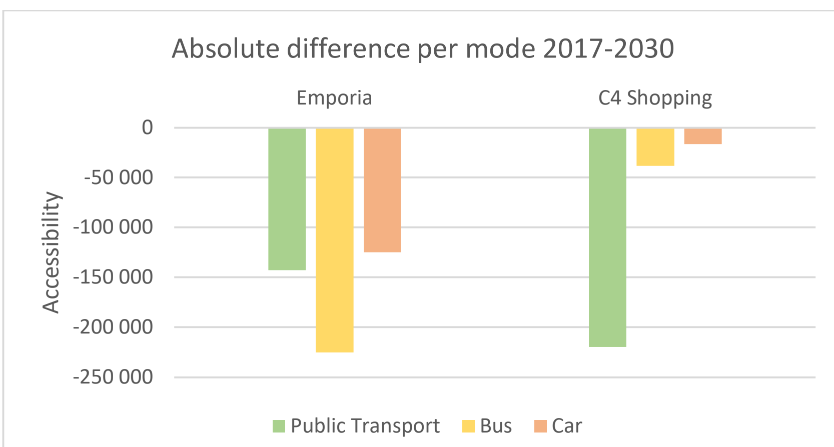

Figure 20: Absolute difference of accessibility per mode between 2017 levels and 2030 targets

4.2 Bus Accessibility

Looking at the result of the bus-only accessibility analysis in Figure 21, it is evident that the bus network is coarser than the car street network. As the catchment areas are generated in two steps, as described in *3.3.2 Workflow*, it looks quite different. Comparing the regions, the Kristianstad zone has a coarser network of bus lines but is also less densely populated in the urban areas in the city surroundings. Thanks to the lower emission factor of the bus in comparison to the car, the maximum distance range of the bus with an emission budget is longer than a car. This compensates for the coarser network that the bus traffic operates on and gives a higher index of accessibility than the car in all cases, as seen in Figure 17.

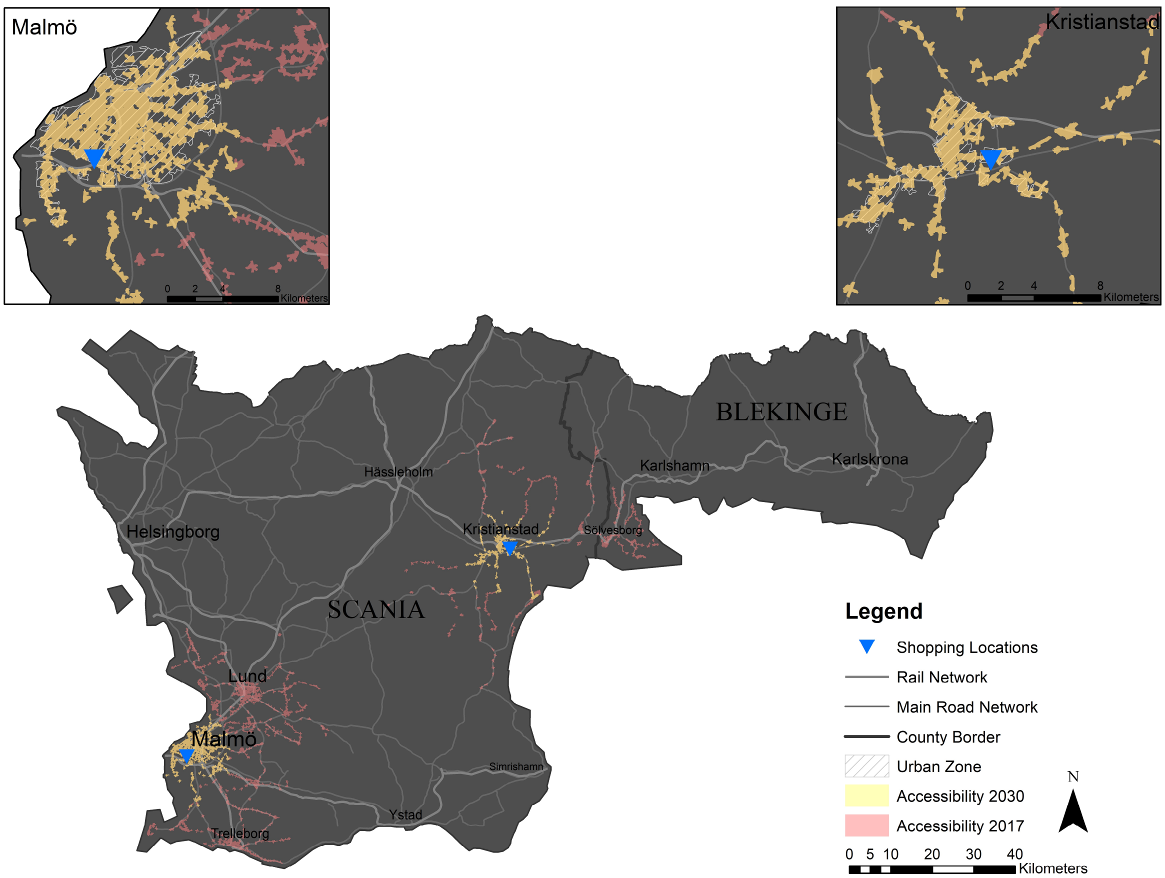

Figure 21: Accessibility by bus

Using the 2017 budget, the Emporia catchment area reaches the cities of Lund and Trelleborg and the surrounding areas. The C4 Shopping area extends to minor urban centres and to more populated areas such as Sölvesborg. For both C4 Shopping and Emporia, the accessibility catchment areas with the 2030 target budget is smaller, but enough to cover the whole urban areas of Kristianstad and Malmö, respectively, but also a bit further out in the network.

According to Figure 19, Emporia's accessibility provided by the bus scenario has a 40% relative decrease from 2017 to 2030. As shown in Figure 20, it is the largest loss of absolute accessibility of the scenarios and is due to the loss of coverage of Lund and Trelleborg, which are cities with large populations. For C4 Shopping, the relative accessibility numbers go from 6% in 2017 to

3% in 2030 (rounded numbers). The relative difference for this scenario is -42%, the biggest relative loss of coverage of all scenarios.

In the bus scenario, Emporia is more accessible than C4 Shopping in both 2017 and 2030 scenarios. The reasons are the demographic differences. Scania also has more cities in the southwest, which are reached by bus in the 2017 scenario and leads to a higher index of accessibility. As the bus networks coarseness vary between the northeast and southwest parts of Scania, this also plays a role. The Malmö region has more bus lines trafficking the area with more stops, resulting in a larger total catchment area.

4.3 Public Transport Accessibility

The third scenario is using the entire public transport network, in the studied region meaning both train and bus. As seen by the maps for Emporia (Figure 22) and C4 Shopping (Figure 23), the catchment areas for the 2017 emission budget cover almost the entire area of Scania and Blekinge from both shopping locations. There are a few stops that are not reached in any of the scenarios, but according to the maps, the maximum coverage for Emporia is higher than for C4 Shopping as there are fewer red dots in the Emporia map (Figure 22). The areas around these stops do not have that big of an impact, as according to Figure 18 the share of population reached is equal in both cases with 77% of the population, meaning almost 1,2 million people can reach both shopping centres within 1,21 kg of CO_2 by public transport.

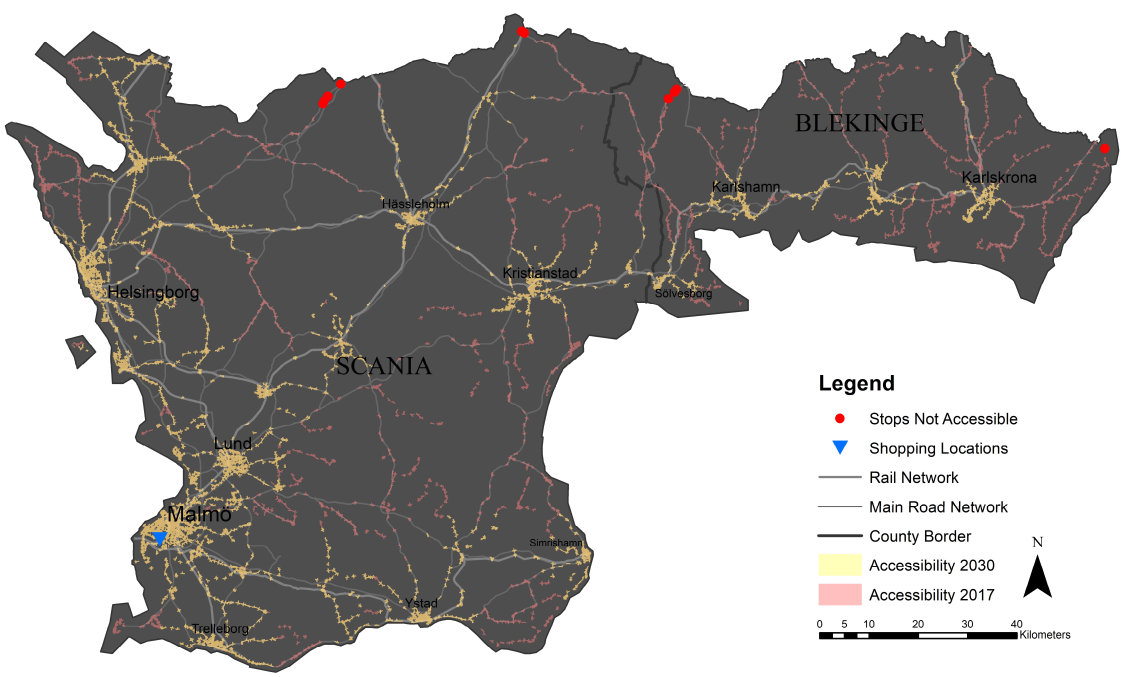

Figure 22: Accessibility by Public Transport (bus and train) from Emporia

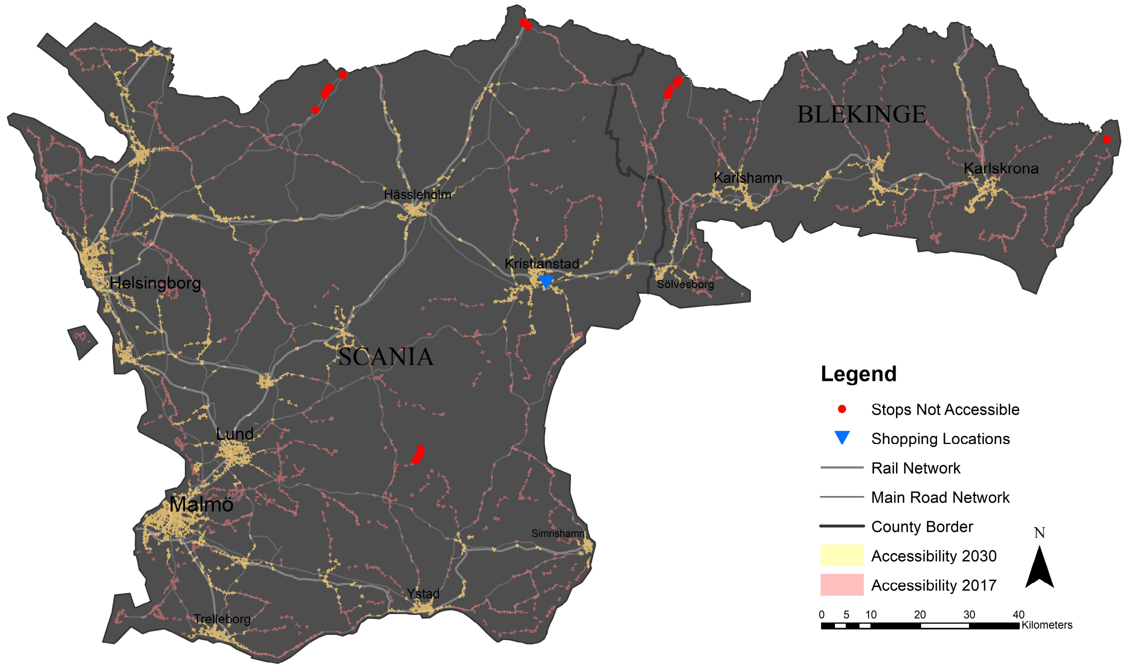

Figure 23: Accessibility by Public Transport (bus and train) from C4 Shopping

The difference between the locations instead becomes visible when analysing the 2030 scenario. From the numbers in Figure 18, Emporia can cover 68% of the population while C4 Shopping can cover 62%. As seen by the respective maps, both C4 and Emporia has a catchment area that stretches to all urban areas that has a train station. This is because of the very low emission factor of the train, as seen in Figure 13. The train-connected cities are the most populated areas of the study region, which is why the share of the population reached remain high. Where the locations' accessibility differ is the accessible region around each train node. As Emporia is in the direct vicinity of a train station, no CO_2 is emitted going to from the shopping centre to the railway. For C4 Shopping, the bus network must be used first before arriving at the carbon-efficient railway in the centre of Kristianstad. When arriving at another train station, there is simply more from the CO_2 budget left to use to travel further out in the network with bus for the Emporia scenario rather than the C4 Shopping scenario. Comparing Figure 22 and Figure 23, this is visualised by the yellow colour (accessible areas within the 2030 emission budget), reaching further out in the transportation system from the railway nodes in Figure 22.

The changes in accessibility between 2017 and 2030 are the biggest for C4 Shopping when looking at both absolute and relative numbers. Emporia has a higher index of accessibility from a CO_2 point-of-view when analysing the public transport scenario, as seen in Figure 17.

5 Discussion and Conclusions

This section discusses the results of the previous section. Further on, the methodology of the study and the potential areas of impact of the type of study are also assessed. Finally, the conclusions of this thesis are done followed by recommendations for further studies on the topic.

5.1 Result Discussion

Trivector (2007) says that peripheral shopping centres have caused decreased accessibility for individuals that do not have access to a car. From an emission perspective, however, this is quite the opposite according to Figure 17. The least accessibility is provided by the car, meaning that peripheral shopping centres actually causes decreased accessibility for individuals *with access to a car*. According to the index, the mixed public transport scenario has the highest amount of accessibility, followed by the bus-only scenario. This is in accord with Boverket (2004), which recommends locating service close to nodes in the public transport system to limit car travelling, which rings true also from a CO_2 perspective on accessibility.

In section *2.2.3.1 Regional and Urban Perspective*, the influence that a shopping centre has on a whole region was stated to be significant. Cities and towns in the surrounding of the shopping centre has to compete for customers, so does also other, nearby, shopping centres. Interestingly enough, the catchment areas of peripheral or semi-peripheral centres are rather small in the car-scenario, even though the centres are car-favoured. From a CO_2 perspective on accessibility, the regional influence of trade is only relevant for the bus and the public transport scenarios. This is, however, only a hypothetical scenario and does not represent the actual regional travelling patterns.

Looking at Figure 17 and Figure 20 that use absolute values for the accessibility, Emporia will be more sensitive to changes in emission budgets or sustainable transportation alternatives. Absolute accessibility and absolute difference will have a bigger impact on Malmö, as the population in the area is bigger and denser. If the catchment area is of equal size, Emporia's accessibility will be higher. But if a decrease of the accessibility catchment area is of equal size in Malmö and Kristianstad, the absolute decrease of accessibility will be higher for Emporia as well. The relative difference, presented in Figure 19, adds a nuance to the analysis, as the 2030 value is put into perspective with the 2017 value of accessibility. However, this measure is still sensitive to *which* areas that are lost with a decrease in the emission budget. For example, if an emission budget is 0.50 kg CO_2, a bigger city where it takes 0.49 kg CO_2 to travel to or 0.51 kg CO_2 can make a very big difference in the result. This is a problem with the contour measure, as discussed in *2.1.2.2 Location-based Measures*.

As the accessibility is based on the catchment areas of public transport stops in two of the scenarios. The more frequent the public transport stops are located, the bigger the total catchment areas are in these scenarios. This will lead to more people within the total catchment area, indicating higher accessibility. Since the Malmö region has a higher density of bus lines and bus stops (which can be seen in Figure 21), more population squares are reached with more 500m catchment areas. This means that the Emporia accessibility in the bus and public transport scenario gains an advantage in this way.

As the public transport scenario cover almost the entire region, apart from a few stops, this can be further used for the analysis: using a 500 m catchment area around *every stop in the region*, it is evident that roughly 23% of the population in Scania and Blekinge do not have public transport available to them. The question if the public transport modes have the means to satisfy the population's needs, arises, especially the rural area population. This is in line with the European Commission (2011a) projections, that there will be an increased gap of accessibility between central and peripheral (in this case rural) locations in the future.

In the thesis, it is clear that the case study locations do not fall within the field of a completely peripheral shopping centre, rather the semi-peripheral definition. The destinations were chosen because of the disparity of their location in regard to surrounding infrastructure: Emporia being very close to a railway station and C4 Shopping near a highway. However, in relation to urban areas (not considering the size), both centres are situated on the fringe of the urban zones. Comparisons between the absolute values of accessibility of the two case study locations show that cities have different prerequisites for carbon-based accessibility, as it heavily depends on the population available in the nearby area.

As an addition to this study, the results of an analysis of one peripheral, one semi-peripheral and one centrally located shopping facility in the same area would be interesting to view. The tendencies would most probably be to favour the centre that is closest to a railway station in the public transport scenario. However, as the concept of peripheral centres is defined by its' car-favoured situation, it is unlikely that a peripheral shopping centre is placed close to a train station. In a bus-only scenario (as in section *4.2 Bus Accessibility*), a higher density of bus lines likely increases the accessibility with the catchment area of the emission budget, as more lines likely would mean more stops. The car has different emission factors depending on the properties of the road (urban or rural), but as can be seen in Figure 13, the relative difference is not that big. The accessibility catchment area of the car is roughly the same size no matter the location. This means that as long as the distance to the urban centre from the shopping location is the same, the accessibility from a car scenario depends heavily on the size of the city. The car accessibility would be the highest for the centrally located shopping facility, as it then would reach the most densely located parts of the city. A very peripheral shopping centre, far from residential areas, would have a very low accessibility index. A key to having a high index of accessibility is to reach densely populated areas in all mode scenarios.

Comparing the case studies' results, the land-use component of the accessibility measure should be taken into account. As mentioned already in section *3.1* Case Study, the regions differ in population density. This means that within the same budget, the number of potential customers differ partly because of the land use structure. It can be argued that the most accessible way of locating a shopping centre is to place it close, or inside, a densely populated area. The region that has been included in the study consists of Scania and Blekinge. With the scenario of using both bus and train, it is evident that other, densely populated, areas outside of the region can be reached within the 2017 emission budget. Especially Denmark with Copenhagen could be included, introducing a capital city with a large population. The accessibility for Emporia is higher in the current study, even though a big market in the Copenhagen area is neglected. The introduction of Copenhagen would also mean a new mode of transport, a metro. This, together with the risk of a non-coherent network lead to that the Danish network was excluded. Further north, along the west coast of Sweden, is the second biggest city of Sweden, Gothenburg. Connected to Scania by rail, there is a chance that the city's central parts could be reached thanks to emission-efficient train traffic.

As the number of studies in the field of CO_2-based accessibility is small, there is not much room for comparisons between this thesis' analysis and previous studies. There are similarities with the CO_2 based study of Kinigadner, et al. (2019): the catchment areas with public transport are much bigger than the car catchment areas. The number of accessible people from the eligible part of the population is also significantly larger by public transport than for car. The relative decrease in accessibility because of the reduced CO_2 emission budget is smaller with public transport than with car in all cases but one of the Munich scenarios.

The factors of the electric part of the vehicle fleet are depending on the source of the electricity and its generation. In Sweden, the electricity sector causes low carbon dioxide emissions compared to other countries. Using the model in other countries with their respective electricity generation can have other results. Electrification of the car fleet can have a positive impact on the CO_2 accessibility in this study. The issue with this is once again the production of electricity and its emissions. In Sweden, electrification would mean a lower emission factor as the factors for buses and train indicate. A carbon-heavy way of production, as a coal-powered generation, would still create high levels of CO_2 emissions in a well-to-wheel analysis. In countries with this type of energy production, the results would probably mean that the local emissions in the cities would decrease, but on a bigger scale, there are still emissions from electricity production. However, there are other issues with the car traffic as congestion, barrier effects etc, that will remain with an electrified car fleet and are not discussed further in this thesis.

5.2 Methodology Discussion

For all modes used in the analysis, the emission factors factor is based on well-to-wheel emissions. This takes all emissions from the production to the usage of the fuels, but the production of the infrastructure (roads and railroads) are not considered. As the emissions of the production of railroads are substantially higher than road production, this favours the rail traffic.

In most of the region that have been studied, there are two types of trains that are trafficking the railway system. However, on some train lines, there is another type of train, between Karlskrona and Holmsjö as well as between Osby and Hässleholm. These trains' emission factors are unknown but represent only a small fraction of the total rail traffic. If the Öresundståg factor would be used for the railway lines where it is in traffic, the emissions from the trains would be even lower on average. With using the Pågatåg, a simplification was made to create a less complicated model. However, it creates a deficit for the train stations where the Öresundståg go to as these stations should be reached with an even smaller amount of emission.

The public transport network is also affected by the mix of buses. In section *3.2.2 Emission Factors*, two factors for buses are introduced. These are averages of the lines and vehicles for city and regional buses. Today, some bus lines in the bus fleet are being electrified instead of being driven by internal combustion engines with biofuels (Skånetrafiken, 2018), leading to even less emissions on those lines. A more detailed model would consider each individual bus line's emission factor, hence favouring the electrified lines and penalising the others.

Using ArcGIS for the analysis makes the generation of accessibility catchment areas based on emissions possible. As in most data-heavy operations, the result is not better than the data used for the analysis. The bus lines do not follow the street network, creating some flaws in the analysis. A more precise method would be to isolate the roads used by the buses from the street network, creating a network similar to the railways. This would be very time-consuming.

In the scenarios of public transport and bus-only, the accessibility is based on the catchment area of 500 m in walking distance from each stop. The catchment area is based on how long a person is prepared to walk for, which can be thought of as being an individual parameter. Perhaps a person living in a rural area consider walking further than a person in an urban area, even using a bicycle to get to the public transport stop. In some areas, people could travel by car to their local public transport stop. This form of mixing modes, other than bus and train together, has not been considered in this study. The catchment area of bicycle, as discussed in section *1.2 Scope and Research Questions*, would be non-emissive. It would likely also be larger than the pedestrian catchment area because of higher speeds. The catchment area of walking distance is also based on network data. Even if the data used contain pedestrian (and bicycle) streets, it cannot take shortcuts and smaller paths into account.

With more stops for public transport come more accessibility. However, the total travel time for the public transport line would increase, hence making the trip alternative less attractive. Drawing a line to section *3.2.2 Emission Factors* and the urban versus rural emission factor for car, a bus or train would also face more frequent acceleration (resulting in higher emission factors) with more frequently placed stops.

The travel time of the trips is not considered in the analysis. While the catchment area in which the accessibility index is calculated is based on a level of emission, there is no limit of a maximum travel time of any mode. In the car-based analysis, it is probable that the cut-off of carbon dioxide is not further away than what a maximum acceptable travel time could be for a shopping trip. The difficulties arise with the modelling of public transport, both with bus-only and by bus and train combined. As the analysis does not take timetables into account, it is not possible to see if a route would have a reasonable travel time (making the trip viable), or if there would be long waiting times. In other public transport models, using travel time as impedance, the waiting time (before trip start or between public transport lines) would not be favoured. However, as the waiting time does not cause any emissions of CO_2, the waiting is "free", which is not a representation of real-life travel behaviour.

> "An expression of the potential number of relevant activities
> that are located within acceptable reach of a given place or peo-
> ple in acceptable reach of an activity".
>
> te Brömmelstroet, et al. (2016, p. 1177)

Even if there would be minimum waiting time, some routes along the complete public transport lines would be very long, for example going from Emporia to a suburb outside of Karlskrona. According to Google Maps, that could be around 3.5 hours of travel time. No matter the emission budget, it is likely that not many people would consider that a viable trip alternative, hence meaning that a shopping location could be outside of an acceptable reach (as in the definition above by te Brömmelstroet (2016) above). This is perhaps not the case in other countries with other energy generation mixes, where the emissions from public transport would be the smaller catchment area compared to the travel time. Incorporation of timetables could enhance the model, making the analysis only taking viable (or acceptable) trips into account.

With the time component of the study, another point to bring up is the peak hour of commuting and its impact on the CO_2 based accessibility analysis. The peak hour in the morning is normally between 7-9, and in the afternoon around 15-17, as seen in Figure 24. With peak hour comes traffic queues and idling, worsening the conditions (and increasing emission factor) of urban driving as described in section *3.2.2 Emission Factors*. This aspect needs additional knowledge of when shopping trips to the studied location take place. As the shopping centres normally open after the morning peak hour (both C4 Shopping and Emporia opens at 10:00), it is in the afternoon that this effect can have an impact on emissions.

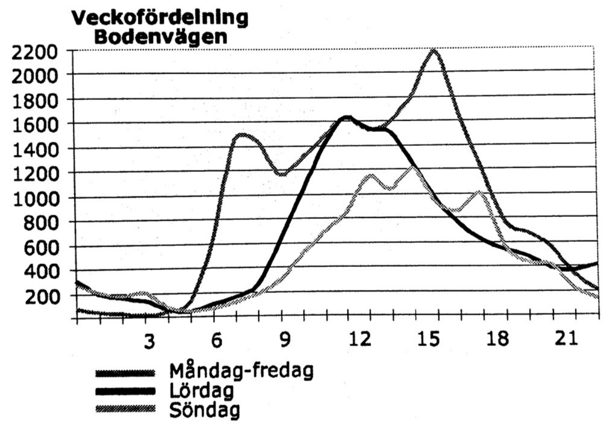

Figure 24: Example of car traffic flow over the day during the working days, Saturday and Sunday. Note the high peaks of traffic flow in the morning and afternoon during weekdays, indicating peak hour (Luleå Kommun, 2004)

Another land-use related matter is connected to the emission factor for cars, where the urban driving conditions result in a higher factor than rural road driving. A shopping centre (or any analysed location) can indicate a high level of accessibility when close to populated areas. As the areas grow more populated, it is likely to think that a more urban environment is developed, with a traffic state that could contribute to even higher emission factors. The development of densely populated and urban areas should be done with the development of an efficient transportation system.

> "Accessibility is a measure of the ease of an individual to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time"
>
> Bhat, et al. (2000b, p. 1)

Bhat, et al (2000b) use the individual's *desire* for a specific type of activity to define accessibility. This can be thought of as the individual component of the accessibility concept used in section *2.1.1 Defining Accessibility*, meaning that each person has preferences, needs and abilities of his/her own. With a CO_2 -based accessibility, it is likely to believe that the perspective does not reflect the actual behaviour of the individual. Taking the result of the car-based scenario in Figure 16 as an example, it is unlikely that customers from outside of the catchment area(s) would choose not to go shopping if the emissions were too high. Also, if an emission catchment area was generated for each shopping facility in Sweden, it is likely that a big part of the population would face non-accessible shopping by car. This would probably not mean that this part of the population would accept to never go shopping at a peripheral centre. A factor that would rather be considered by individuals is travel time. The accessibility from a CO_2 perspective does not take change of travel behaviour into account. The trends of trade, presented in section *2.2.2 Trends in Trade*, can have an impact on how many and how long shopping trips will be in the future.

Even though the individual preferences are not necessarily represented by the CO_2-based accessibility, it can be argued that change is coming, thanks to environmental and emission awareness. Emerging from the impact of climate activist Greta Thunberg, a word called *"flygskam"*, in English *"flying shame"*, has entered the Swedish language. This word means that people avoid flying to reduce their carbon emissions (Institutet för språk och folkminnen (2019) and The New York Times (2019)). With further behaviour changes in this direction, CO_2 emissions can decrease in road transportation, either with choosing modes more efficient (emission-wise) than car or choosing a route that is ideal from an emission point-of-view. In another case study, the authors state that intra-urban shopping trips' CO_2 emissions can be decreased by around 30% if the CO_2 optimal route is used (Jia & Håkansson, 2016). As the model in this study uses carbon dioxide as the travel impedance, the model already chooses the most emission efficient route between each point. However, in a CO_2 emission study by Jia, et al. (2013), most trips observed are almost completely optimal from a CO_2 emission perspective, even though the individuals making the trips choose the shortest path from a travel time perspective. This means the shortest path for route choice is an acceptable method when modelling cars routing and emissions.

For trips for shopping at peripheral centres, a report by Trivector (2005) show that roundtrips are most common during weekends – on average 60% of the trips do go from home to the centre and back. During the week, the share is 41%. In this thesis, the trip statistics for the emission budget assume that every trip is going from home to the shopping centre. In the travel survey, some trips could originate from other locations. Depending on where these other locations are, the actual budget should be changed. The budget is also affected by the share of person mileage not taking grocery shopping into account. There are grocery stores in both Emporia and next to C4 Shopping, which could mean that some trips that are made can have the sole or combined purpose of grocery shopping. This possibility has not been considered in the analysis.

In the literature review made in section *2 Literature Review,* there are several different sources but a lot of references to Trivector. Trivector is a Swedish company that, among other things, does consulting and research in traffic and transport, and has done plenty of reports within peripheral shopping centres, especially in the region of Scania. While there can be risks with looking too much at one source of information, their research covers the scope of this study well.

5.3 Potential Impact Discussion

With the arising urgency of the climate change threat, it is important to highlight and show the emissions that different activities and operations cause. To achieve ambitious targets on greenhouse gases on all levels of policymaking, it is probable that drastic changes can come into play. As emission budgets in this study are completely hypothetical, they can still give an indication of how the accessibility by different modes to different destinations can be affected if fixed emission-per-capita targets were to be implemented.

From a planning perspective, an emission accessibility analysis can help to visualise and show the importance of locating services in strategic ways to decrease the carbon footprint the facility causes. The contour measure has advantages in that it is easy to understand. This could affect decision-makers, as accessibility is an important policymaking input, to make the "right" choice regarding where and if to establish a shopping centre (or other facilities). If the shopping centre, or another facility, is already in use in a (semi-)peripheral location, a CO_2-based accessibility study can help to show where to further develop public transport in the region around the facility. However, one can argue that to achieve carbon-efficient travelling potential provided by the public transportation system, other efforts need to be made for people to use it over the car.

The understandable contour measure can also contribute to further raise awareness of individual choices of travel mode and which destinations to travel to. In a study by Girod, et al. (2013), calculations show that changes in travel behaviour could decrease carbon dioxide emissions by 50% at the end of the current century. More studies and awareness-raising actions could have an impact on this behaviour adaption.

5.4 Conclusions

This thesis has used emission of CO_2 as an indicator for an accessibility analysis of two semi-peripheral shopping centres' location. The literature review explains that the contour accessibility measure is easy to interpret and communicate to decision-makers.

The study shows that the accessibility decreases with a smaller CO_2 emission budget to travel with. The results also demonstrate that the location of a shopping centre have an impact on accessibility when using carbon dioxide as an indicator. The location is relevant in two regards: First, the location in relation to existing infrastructure, where the railway nodes and trains are highly beneficial followed by bus. Secondly, the closer to a highly-populated area, the higher the degree of accessibility. The study highlights the importance of developing both housing, activities and service in the vicinity of public transport, especially the railway network.

Even though the literature review show that peripheral and semi-peripheral shopping centres' location are car-oriented by definition, this is the mode of travel that provides the least amount of accessibility when using a CO_2-based analysis.

Using emission-based accessibility studies that are comprehendible can visualise the carbon footprint of facilities' location and travel modes and influence decision-makers. This can lead to a more direct course in land-use and transportation planning to reach ambitious and imminent emission reduction targets. By looking at the result of the study, it is clear that a future emission budget cap would decrease our accessibility and where we can shop or do other activities.

5.5 Suggestions for Further Research

As discussed in *5.2 Methodology Discussion*, there are aspects that this thesis is not directing. There could be ways of using the structure of the methodology in this study, but at the same time incorporating other elements of the concept of accessibility – especially *travel time*. To combine the emission modelling of public transport (and car) with a maximum time budget for shopping trips, this would create a more realistic scenario for a future model.

With the emerging e-commerce, the shopping trips of tomorrow may be somewhat exchanged for delivery logistics from retail companies and services such as Amazon and Alibaba. To create a CO_2-based accessibility model to assess goods transport from factory to customer could be a way to identify potential hubs for the logistic companies. The emission factors could be in grams of CO_2 per tonne-kilometre, instead of per person-kilometre.

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