UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ETS INGENIERÍA DE CAMINOS, CANALES Y PUERTOS

# TRABAJO DE FIN DE MASTER

Diseño y estudio de viabilidad de un sistema de bicicletas compartidas en la Universidad Técnica de Dinamarca.

*Presentado por*

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*Para la obtención del*

Master Universitario en Ingeniería de Caminos, Canales y Puertos

*Curso:* *2019/2020*

*Fecha:* *Agosto 2020*

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**DTU Civil Engineering**
Department of Civil Engineering

# Design and feasibility assessment of a bike sharing system at DTU.

Master Thesis

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Master Thesis
August, 2020

By
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Cover photo: Vibeke Hempler, 2012
Published by: DTU, Department of Civil Engineering, Brovej, Building 118, 2800 Kgs. Lyngby Denmark
www.byg.dtu.dk

# Approval

This thesis has been prepared over six months at the Technical University of Denmark, DTU, in partial fulfilment for the degree Master of Science in Civil Engineering, with the specialization on Urban Planning and Construction Management.

Helena Carla Yarritu Sánchez - s182203

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*Date*

## Abstract

The aim of this thesis is to find a solution to the mobility issues suffered on campus and with colliding municipalities. The solution proposed is a Bike sharing system. Hence, throughout the project, some aspects will be studied.

First of all, it is necessary to assess whether the demand is enough for being a feasible solution. Data that has been obtained through a survey. Afterward, it is necessary to present the different scenarios that will be assessed. (i) Danish Technical University campus on Lyngby, (ii) Both the campus and the accommodations owned by the university, and (iii) The campus and the city of Lyngby.

To continue with the design phase, a mathematical model has been created to obtain the number of bikes, station size and unmet demand. This data will be used to assess the market penetration of the different scenarios.

Afterward, the final evaluation will be carried out by a sustainability assessment, that enables the inclusion of social, environmental, and economic impact. Hence, an indicator framework will be developed, which will collaborate to confirm (i) if the demand is sufficient to obtain revenues, (ii) whether there is an improvement within connectivity, and (iii) even if it helps to improve the interaction user-building.

Results obtained have shown that all scenarios are beneficial, but slightly. Moreover, all scenarios have had similar results, what can be due to the use of an equitably pondering, between other reasons.

In conclusion, a bike sharing system can help to solve mobility issues but should be studied deeper with more restrictions in order to get a solution more concrete.

## Acknowledgements

I would like to express my gratitude to my supervisors Per Sieverts Nielsen and Dario Pacino, for supporting me during the whole process and for bringing me so much valuable knowledge and guidance. Also to my supervisors from the Polytechnical University of Valencia, Francisco Javier Camacho Torregrosa, and David Llopis Castelló for their patience and support.

Thank you to the Polytechnic University of Valencia, for bringing me the opportunity to do the double MSc. within Civil Engineering, and for all the training provided during both the Bachelor and the Master.

I would like to thank my family for being by my side unconditionally, in the bad and in the good moments. And for all the support during the last years, especially during this period of change.

# Contents

## Definitions

Bike lane: a part of a road that is separated by a line from the rest of the road, for the use of people riding bicycles. [Cambridge-dictionary n.d.]

Bike path: a path or marked route that is intended for people riding bicycles [Cambridge-dictionary n.d.]

Bike sharing system: short-term bicycle rental available at unattended urban locations

Bike (Cycle) network: an interconnected set of safe and direct cycling routes covering a given area or city

## Abbreviations

DTU = Danish Technical University (Danmarks Tekniske Universistet).

BSS = Bike Sharing System.

BS = Bikeshare.

ITDP = Institute for Transport & Develpment Policy.

MaaS = Mobility as a service.

CAS = Campus Service

# 1 Introduction

Nowadays, people are pushed by society to be as productive as they can be. Working around eight hours a day and supplementing it with activities and social life. Therefore, there is a need to have a good infrastructure that allows people to move from one activity to another as quickly as possible. But this infrastructure must be complemented by public transportation systems.

Having a sustainable transportation system in a city is being one step closer to a better quality of life. It is taking care of the environment while improving citizens access to facilities and ensuring safety. One of the main goals of sustainable transportation is to reduce short trips made by motorized vehicles. This can be achieved by encouraging citizens' awareness, fostering non-motorized transportation and creating or improving existing sidewalks and bike lanes [UNESCAP and CITYNET 2012].

Many people uses private vehicles instead of public transportation due to bad connections with their destinations. Bad connections lead to long ways on foot before reaching the destination. For instance, walking around one mile from home to public transport or from the public transport to the destination. What is known as the first/last mile problem. This problem is also present on large university campuses.

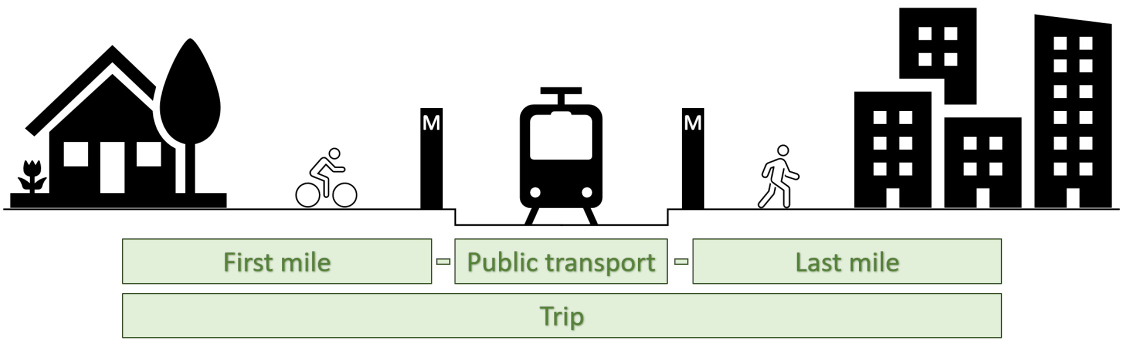



Figure 1.1: First mile - Last mile graphic scheme.

While traffic congestion increases and corporations try to find out solutions by drive-less cars and sharing car systems [Möller et al. 2019], some other focus on the potential of traditional vehicles, like the bicycle.

This ”movement” leads to the emergence of many start-ups related to bicycle sharing. Small companies that grow fast due to the current increasing demand. One popular example could be Mobike [Cox 2018], founded in 2015 in Beijing, China, and that in 2018 it was already operating over 200 cities around the world. Donkey Republic is also a popular company that started in 2015 in Copenhagen and already in 2017 had 1000 active bikes over 30 places around the world [REPUBLIC 2017].

This does not only involve cities, but universities are also jumping into this new trend. For instance, Jordan University of Science and Technology (JUST) has implemented a bike sharing system called “Darajty”, which means ”my bicycle” in arabic. It is a minute renting system that has improved the students' routines. Mohammad, a student from Jordan university, talks about the problem that existed before the bike sharing system arrived.

> I used to run a lot in order not to miss my lectures. [Freij 2018]

JUST has an area of 1.4 sq.km. which is similar to Lyngby DTU's campus area ( 1.06 sq.km.). Considering that DTU is located on the outskirts of Copenhagen, and therefore many people gets there by public transport. And that generally, students, staff and professors spend most of their day on campus. Moving from one lecture to another can mean walking up to twenty minutes. Hence, a solution must be found for this first/last mile problem encountered on campus.

Thorough this thesis is going to be designed and assessed the feasibility of a bike sharing system at DTU. This system will have the improvement of connectivity as its main objective. The study will take into account different scenarios in order to reach the most beneficial solution.

This project will have different chapters where necessary aspects to understand or develop the solution are presented.

First of all, it has two background chapters (2 & 3). The first one will present the area of study. This is the university and its location history. Moreover, since there are different scenarios, it is necessary to introduce the accommodations provided by the university and how they work. Finally, the operation of the transport network in Copenhagen and more specifically on DTU campus will be explained. This section is very important to understand the connection problem with neighbor cities.

The second background is called a theoretical background. This is because introduces all the theory necessary to understand the process followed on the project. It starts with an introduction to sustainable transportation systems. Followed by the new concept of micromobility, what it means, its typology, and benefits and drawbacks. Finally, some guidelines for designing and implementing a bike sharing system are presented.

Chapter 4 is focused on describing the problem. It also includes some sections. One focused on explaining the research questions that will help evaluate important aspects during the process. Two presenting the assumptions taken during the thesis and its limitations. And one explaining the base scenario that will be the starting point for the design. The scenario is based on the implementations planned for 2025 [Universitet 2019c]. This is new bike lanes, the arrival of the light rail and other aspects mentioned in chapter 4.4.

Afterward, there is chapter 5. Which explains the methodology followed in the thesis. It includes the process of data collection, data processing, design of the system and its evaluation. The latter includes both the framework and the normalized scale assessment. Every evaluation will be based on whether there is a positive or negative change in scenario zero.

Once the background and the methodology has been explained, it is time to introduce the scenarios in chapter 6. Followed by the analysis of the demand and the design of the system in chapters 7 & 8, respectively.

Subsequently, a sustainability assessment is going to be carried out, which will consider three main groups: Social, Environmental and Economical. The development of indicators, data collection and its evaluation will be developed in chapters 9 & 10.

Finally, there is a summary, the discussion and conclusions. The process is shown in figure 1.2.

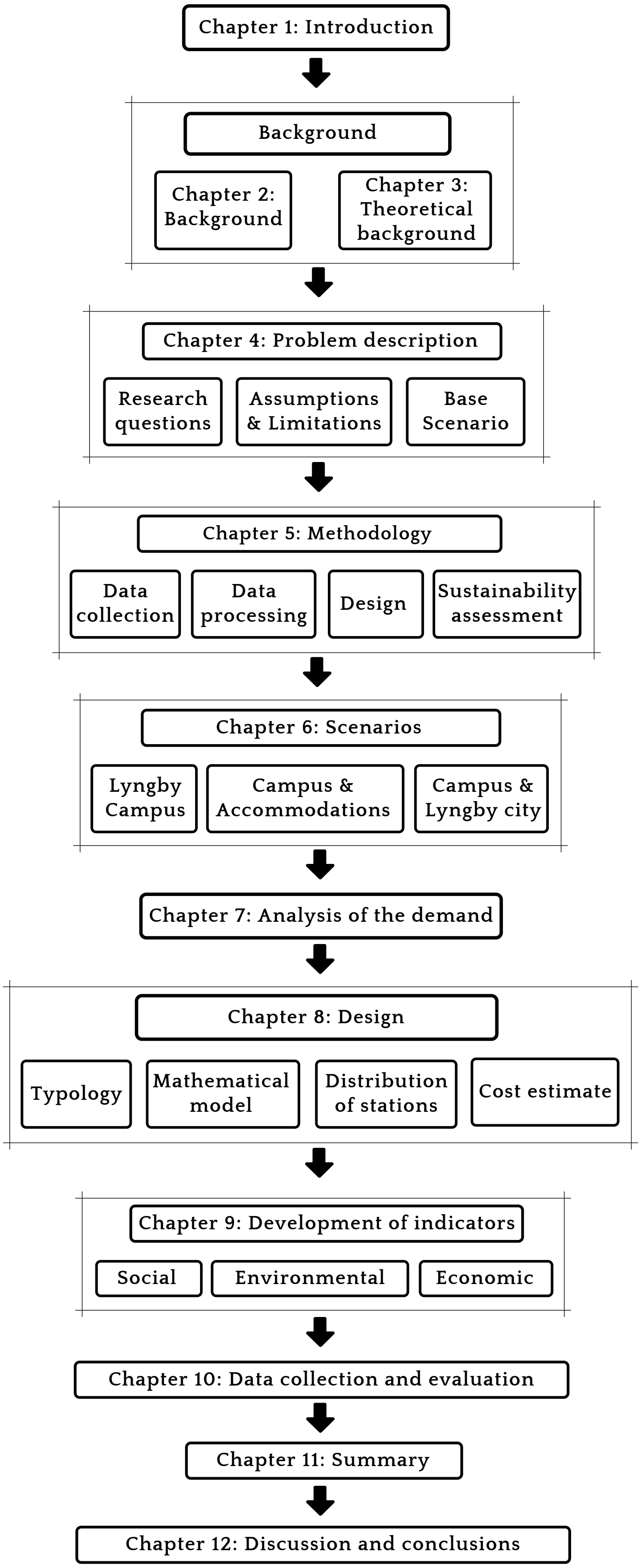



Figure 1.2: Thesis diagram

# 2 Background

The current chapter aims to introduce the environment of the project. This is the physical location and characteristics where it is taking place, as well as the main topics linked, in this case, public transportation.

The project is located at the Danish Technical University (DTU), specifically on Lyngby Campus. Therefore, DTU, its location history and development, the different campuses, facilities, and interesting agreements with organizations are explained.

Moreover, to understand the problem statement in section 4, it is necessary to understand the characteristics of public transportation in Denmark, developed in section 2.3.

## 2.1 Danish Technical University

The Danish Technical University was founded in 1829. First located in the city of Copenhagen [Universitet 2019a] and due to the fast growing number of students and the need of space for laboratories, it was moved to its current location (Lundtofte, Lyngby) between the 1960s and 70s, concurring with the movement introduced in Europe after the second world war according to Pierre Merlin:

> ”The American notion of a campus was exported to Europe after the Second World War, when rapid expansion —in the case of some universities— made it necessary to acquire land, which was only available on the urban periphery, in order to set up badly needed scientific departments. Thus the notion of campus came to be associated with sites outside, but connected to, the city, on land that allowed buildings to be spread out.” [Merlin n.d.]

The decision was not only because of the space and the multiplication of students. There were many economic aspects, like the price and availability of the land. And aspects related to the space versatility the outskirts of the city were bringing: car accessibility, availability of land, etc. [Merlin n.d.]

Nowadays, DTU is divided into three campus. Lyngby is the main campus, is 106 hectare and it has more than one hundred buildings divided into 4 sectors. This campus is mainly focused on Master studies. The second one is located in Ballerup (around 10km from Copenhagen), its focus is on Bachelor studies and the main teaching language is danish. The campus is one large building complex of $42,000m^2$ surrounded by courtyards and gardens. Finally, there is another campus in Risø, which is 40km west Copenhagen and is the biggest one with 262 hectare site. Its main function is research [Tonsberg 2020]. Throughout this thesis the focus will be on Lyngby campus due to lack of information obtained from Ballerup campus, attributable to the few means available to spread the survey, imputable to the Corona virus pandemy lock-down.

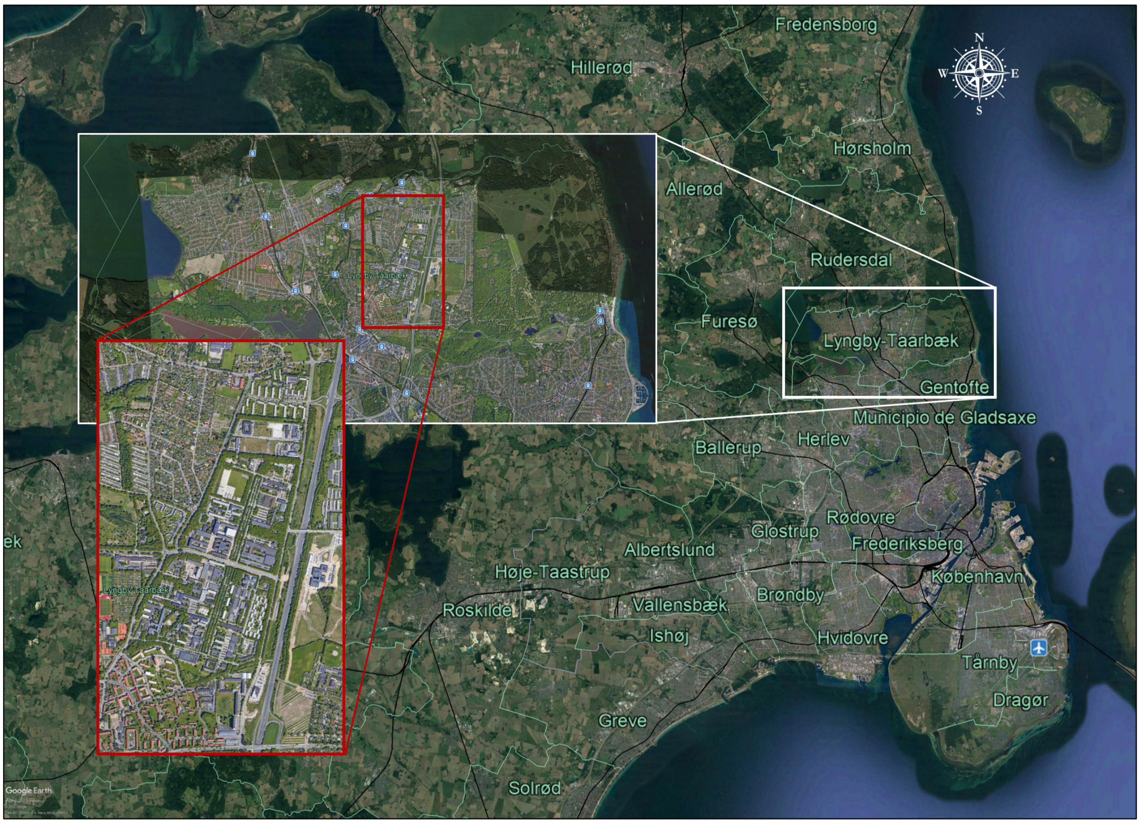



Figure 2.1: Location of Lyngby campus

In the last decade, universities are trying to recover their relationship with cities and at DTU is not different. Lyngby is 2km away from the campus and it represents a big transportation hub for the surroundings. The campus is connected with the town, almost 24h, by bus. It has also some bike lanes that are being improved [C. V. Jørgensen 2020], and the light rail will arrive soon [Skotte 2019]. Nevertheless, according with Juliana's study [Apli 2019], students do not choose to live in Lyngby, they prefer to live in Copenhagen and commute to university.

In 2012, an organization called "the city of knowledge" was created to change this. Their main goal is to *develop Lyngby into one of the leading knowledge-intensive university towns in Northern Europe (...). It has a strong focus on urban life, start-up businesses, internationalisation, mobility and sustainable solutions" [Lyngby 2012]*. And together with DTU and the big knowledge businesses, is trying to develop Lyngby towards a friendly university-town. They want to be:

- One of Europe's leading knowledge and university cities with a world-class level of research and education.
- A centre for innovation and development of knowledge-intensive business clusters
- An attractive hub for national and international talented individuals characterised by a high quality of life
- A living laboratory for sustainable urban and business development

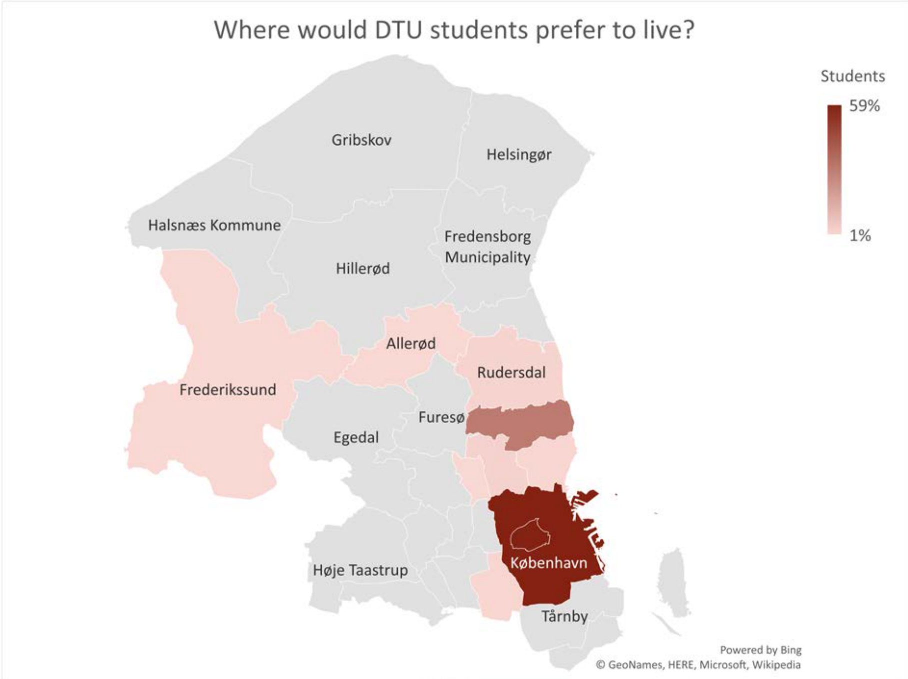



Figure 2.2: Where would DTU students prefer to live? [Apli 2019].

On the other hand, DTU's mission is to develop and utilize natural sciences and technical sciences for the benefit of society. And its values are focused on sustainability, integration and being at an elite level. In order to achieve these goals, DTU's starategy is focusing on four aspects: Landscape, architecture, utilities and mobility [Universitet 2019c]. Being the last one the core of this thesis.

DTU has made a study which shows that many students and employees go by bike to university, specifically 41 and 30% respectively. Their goal to 2023 is to increase those percentages to 50 and 40%, and they want to achieve it by implementing bicycle paths to, from and within the campus, as well as bike parking facilities [Universitet 2019b]. Network that will be used as a starting point for the design of the bike-sharing system.

More facilities are provided on DTU campus. There is a sports hall with climbing walls, basketball court and football field, a complete gym and dance lectures. Moreover, there are many study rooms around campus (silent or for group-work), a library and a bookstore on Building 101. There are also canteens in buildings 101, 358, 342 and 220; Cafés in 101, 202 and 306; And street food stalls around campus. Laboratories also abound on campus. In addition, there is a special place called DTU Skylab, which is a hub for start-up businesses and innovative entrepreneurs. Many workshops, meetings, and events are carried out in this 373 building. [Tonsberg 2020]

DTU also provides students with accommodation as far as possible. There are many reasons to do so, but the main one is the lack of available housing in Copenhagen and the large number of international students coming to DTU either for an exchange semester or for studying a two-year master. This topic is further explained in next section (2.2).

## 2.2 DTU Accommodations

Denmark, and especially Copenhagen, has a big issue with housing. There are more people who wants to live in than available houses and that is making housing costs grow fast.

> Growth in housing demand is galloping ahead of home building, causing higher-than-ever housing costs. [O'Sullivan 2016]

Consequently, DTU has a foundation called Boligfonden DTU [DTU n.d.] that owns some accommodations, and *whose purpose is to provide accommodation for international guests and students [Viborg 2019]*, ensuring they will have dwelling at least for the first year.

Due to the housing shortage, there are many terms and conditions when applying for accommodation in Boligfonden DTU:

- ”... rents out accommodations for fixed periods. When you accept the offer of accommodation, you also accept that the rental agreement is binding for the full period stated in the offer and can NOT be changed or shortened. Neither is it possible to sublet to others ...”
- ”Because of the housing shortage (...) Boligfonden DTU is able to make you one offer only. If you decline this offer, you accept that you will not automatically be offered another accommodation.”

Boligfonden has accommodations in many municipalities, but generally in Lyngby-Taarbæk, DTU campus or neighboring municipalities. Table 2.1 colors differentiate where are located:

- Green: dormitories at DTU Lyngby Campus
- Orange: located in Lyngby-Taarbæk municipality
- Black: otherwise

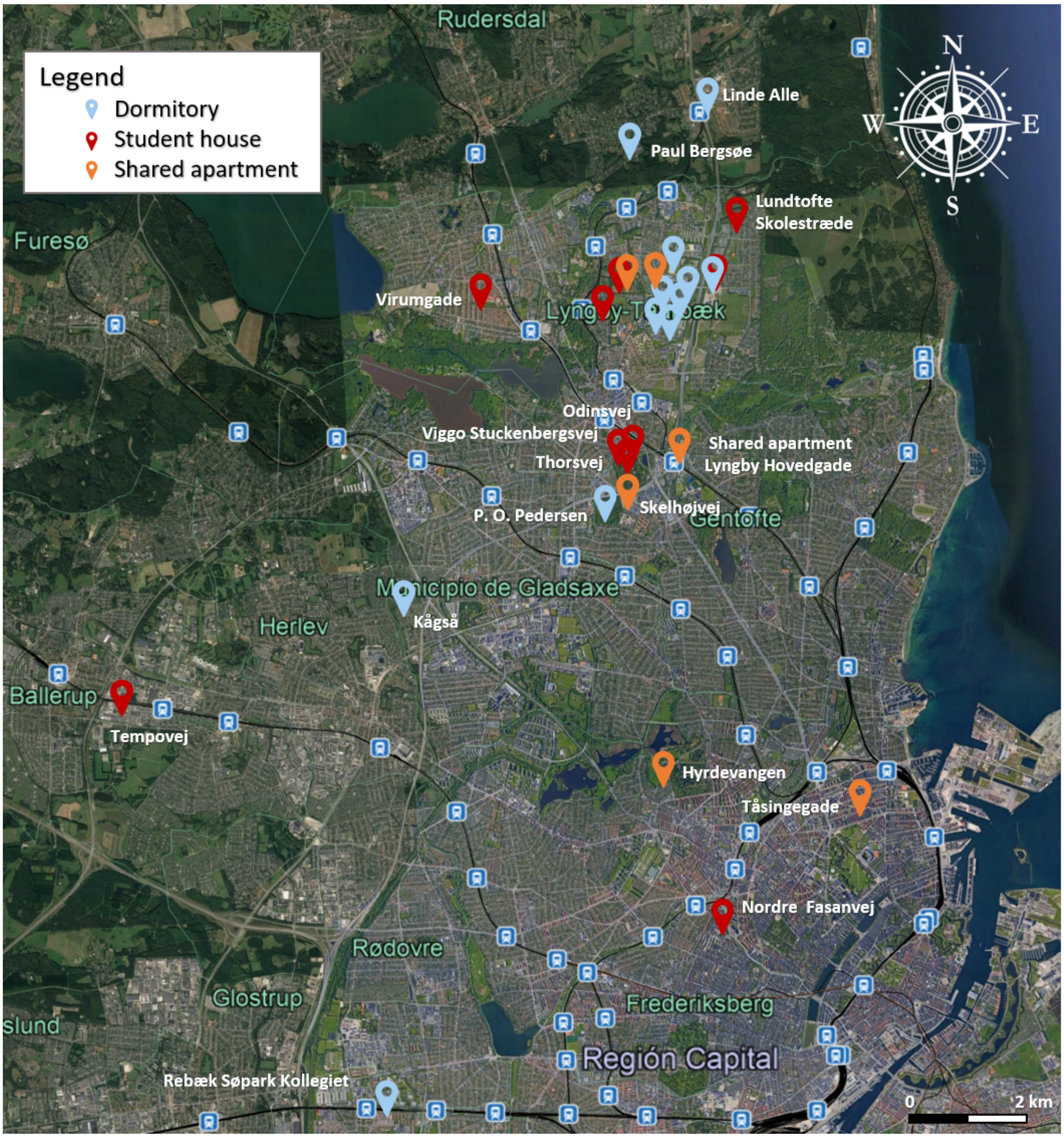



Figure 2.3: Sketch of all accommodations presented on table 2.1

| | Name | #people | For DTU | | NOTE | Built | Price |
|---|---|---|---|---|---|---|---|
| DTU | Campus Village | 160 | 160 | 100% | | 2001 | 3350 |
| DTU | Hempel Kollegiet | 200 | 200 | 100% | | 2017 | 4220 |
| Shared | Kagså Kollegiet | 309 | 16 | 5% | Accomodation Office administrates about 16 rooms | 1969 | 3400 |
| DTU | Kampsax Kollegiet | 521 | 521 | 100% | | 1969 | 3250 |
| DTU | Linde Alle Student Residence | 300 | 300 | 100% | | | 4200 |
| DTU | Nordvej Student Residence | 312 | 312 | 100% | | 2019 | 4225 |
| Shared | P.O.Pedersen Kollegiet | 274 | 27 | 10% | LIMITED | 1964 | 2794 |
| Shared | Paul Bergsøe Kollegiet | 383 | 35 | 9% | 352 single rooms, 31 apartments; LIMITED single rooms | 1967 | 2888 |
| Shared | Professor Ostenfeld Kollegiet | 288 | 28 | 10% | 276 single rooms, 12 apartments; LIMITED amount for DTU | 1968 | 3213 |
| Shared | Rebæk Søpark Kollegiet | 361 | 15 | 4% | 15 rooms for DTU | 1977 | 2772 |
| DTU | Shared apartment - Lyngby Hovedgade | 3 | 3 | 100% | in Lyngby | | 5000 |
| DTU | Shared apartment - Lystoftevej | 3 | 3 | 100% | 1 single, 1 double room in Lundtofte | | 2850 |
| DTU | Student house - Caroline Amalievej | 6 | 6 | 100% | 4 single, 1 double room in Lundtofte | | 2500 |
| DTU | Student house - Lundtofte Skolestræde | 12 | 12 | 100% | 3 single, 3 double, 1 triple room in Lundtofte | | 2500 |
| DTU | Student house - Lundtoftevej | 6 | 6 | 100% | 4 single, 1 double room in Lundtofte | | 3150 |
| DTU | Student house - Lystofteve | 9 | 9 | 100% | | | 2950 |
| DTU | Student house - Nordre Fasanvej | 8 | 8 | 100% | | | 4950 |
| DTU | Student house - Odinsvej | 4 | 4 | 100% | | | 3400 |
| DTU | Student house - Prof. Ostenfeld Kollegiet | 6 | 6 | 100% | ala: The Inspector house | | 3263 |
| DTU | Student house - Tempovej | 10 | 10 | 100% | | | |
| DTU | Student house - Thorsvej | 8 | 8 | 100% | 4 single, 2 double rooms | | 2750 |
| DTU | Student house - Viggo Stuckenbergsvej | 9 | 9 | 100% | 5 single, 2 double rooms | | 3150 |
| DTU | Student house - Virumgade 3 | 4 | 4 | 100% | | | 3250 |
| DTU | Student house - Virumgade 3A | 8 | 8 | 100% | | | 3150 |
| DTU | Student house - Virumgade 3B | 4 | 4 | 100% | | | |
| DTU | Student house - Virumgade 3C | 11 | 11 | 100% | | | 3150 |
| DTU | Studio apartment - Skelhøjvej | 2 | 2 | 100% | | | 7500 |
| DTU | Studio apartments - Egedalsvænge | 45 | 45 | 100% | DTU register 45 rooms in the complex | | 2850 |
| DTU | Studio apartments - Hyrdevangen | 40 | 40 | 100% | | | 4300 |
| Shared | Studio apartments - Tåsingegade | 44 | 22 | 50% | DTU has 22 rooms for international students | | 3250 |
| DTU | Villum Kann Rasmussen Kollegiet | 84 | 84 | 100% | 42 double rooms | | 3787 |
| Shared | William Demant Kollegiet | 100 | 10 | 10% | 100 rooms, LIMITED amount for DTU | | 4262 |

Table 2.1: Details of the accommodations that Boligfonden manages. [Apli 2019]

## 2.3 Public Transport

Copenhagen's public transportation is very efficient. Different bus, train, light rail, metro and ferry lines, integrate the transport network. All well interconnected by bike lanes complemented with a wide variety of micromobility systems in the city center, for example bike-sharing systems or e-scooters (See section 3.2 for further explanation of this concept).

Copenhagen municipality seeks sustainable mobility for its city, as it is shown in its Action Plan for Green Mobility and the CPH 2025 Climate Plan.

> Copenhagen prioritises mobility, and has a target that 75% of all movement will be on foot, by bike or by public transport. (...) To facilitate this, the City of Copenhagen is putting considerable effort into providing an integrated, efficient and green transport network. [Technical and Administration n.d.]

The municipality believes that the more cyclists, pedestrians, and public transport the more space will be on roads for those who really need to use motorized vehicles. For instance, commercial traffic or people who really need these means in their commutes.

Public transportation is not cheap, but it gives you a wide range of options when traveling. To use public transport it is needed a card called "rejsekort". This card is for checking in every time you get into a mean of transport and for checking out only when the trip has been finished. In case check out is not done, after 2 hours the card charges the most expensive journey possible (70 dkk). It exists the possibility of purchasing one-way or round-trip ticket, but it is usually more expensive. There are different ”rejsekort”, the general one is impersonal and allows to travel anywhere within Sjælland, including Malmö station in Sweeden.

Concerning the price of the journey, it depends on how many sectors do you cross from origin to destination (Figure 2.7). The higher the distance (and therefore the number of sectors) the more expensive. But, if the time of the journey does not correspond with the one estimated by the system, the price may increase. This is because the system understands that more lines than the usual to get to that destination have been used from the starting point. For example, checking-in near your home, picking up a friend from a station in the countryside and then check out in the city center. Maybe the estimated time was 10 minutes and you have spent 30 minutes in total, therefore an extra percentage cost is applied to your journey.

Regarding the service, depending on the mean of transport, the frequency and working hours change [Mcomish 2019]:

- Metro: It works 24/7[1] with a high frequency, 2-4 minutes in rush hour and 3-6 minutes otherwise. In total there are 39 stations shared between 3 lines: M1, M2 and M3. Being the last one the circular line, which was opened in September 2019. The municipality is planning a fourth line to connect with Nordhavn.

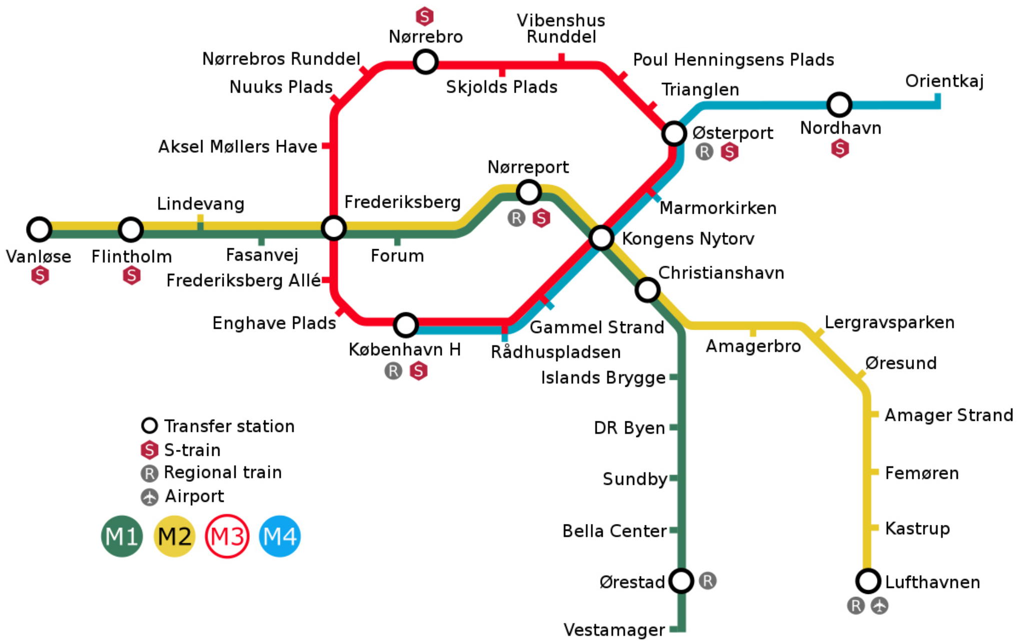



Figure 2.4: Copenhagen metro lines map.

- Train: There are two types of train, the S-tog which runs in the city and in some of the neighbour municipalities, and the fast train that travels all around the country. The most usual in commutes is the S-tog, which is a light rail. It runs from 05:00 to 00:30. Depending on the line the frequency goes from 4 to 10 or even 20 minutes. On weekends, these trains run at night (from 01:00 to 05:00) every hour, except line F that does it every half an hour.

[1] 24 hours 7 days a week

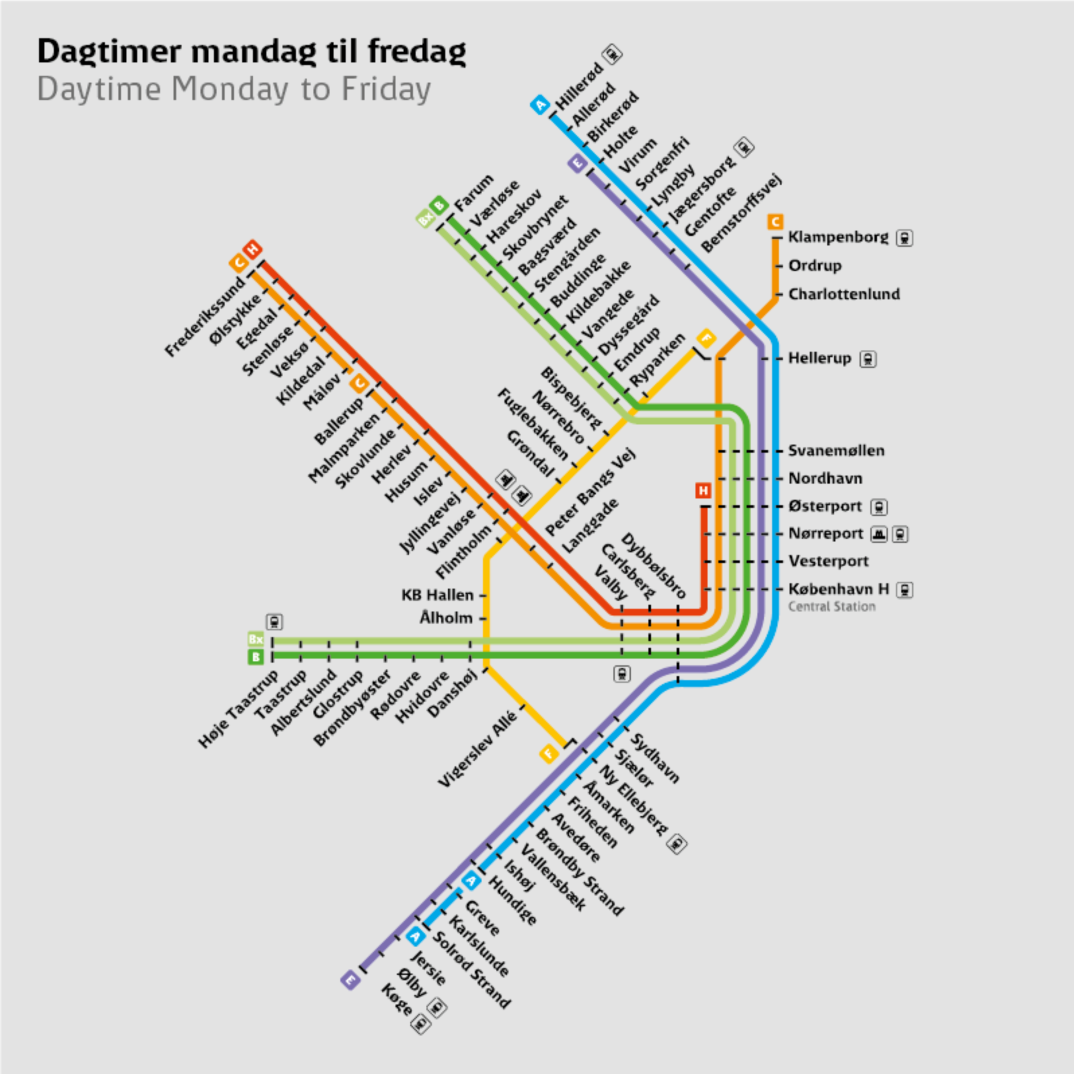



Figure 2.5: Copenhagen S-tog lines map.

- Bus: Even at night you can easily find different lines operative. Every bus has a letter that shows which hours or in what area operate.
  - Buses with the **letter A** are city buses. their frequency is very good, 3-7 minutes in peak hours and 10 minutes otherwise. They also operate at night, but with a lower frequency.
  - The **letter S** indicates suburban buses. It has fewer stops and operates from 06:00 to 01:00. Their frequency goes from 5 minutes in rush hours to 20 minutes outside.
  - Buses with **letter E** are express buses. They only work during peak hours in the suburban areas, having less stops than S buses.
  - Other letter that can be found on buses is **P**. This type of bus operates locally, at daytime and has a circular route, starting and ending on the same stop.
  - There are buses that only work at night-time. This is the case of buses with **letter N**. Their frequency is 10 minutes Fridays and Saturdays, and 20 minutes during the week.

  - Finally, there are buses **without letter**. Those run during daylight hours and finish their route around 19:00.
- Ferry: The ferry operates during daytime, from 07:00 to 20:00 on weekdays and 10:00 to 20:00 on weekends. Only have 6 stops ans works in zone 2.

An important aspect to know of the public transportation in Denmark is whether you can or cannot travel with your bike. Which actually depends on the mean of transport you are taking. Bikes can be carried for free only when traveling in S-togs, where there is an area enabled (Figure 2.6). On fast trains, the metro and the bus it is possible to travel, but you have to pay a fare. In the case of the buses, it will only be possible if the bus has enough space. Hence, hardly anyone travels with the bicycle on buses.

Figure 2.6: S-tog internal bike parking.

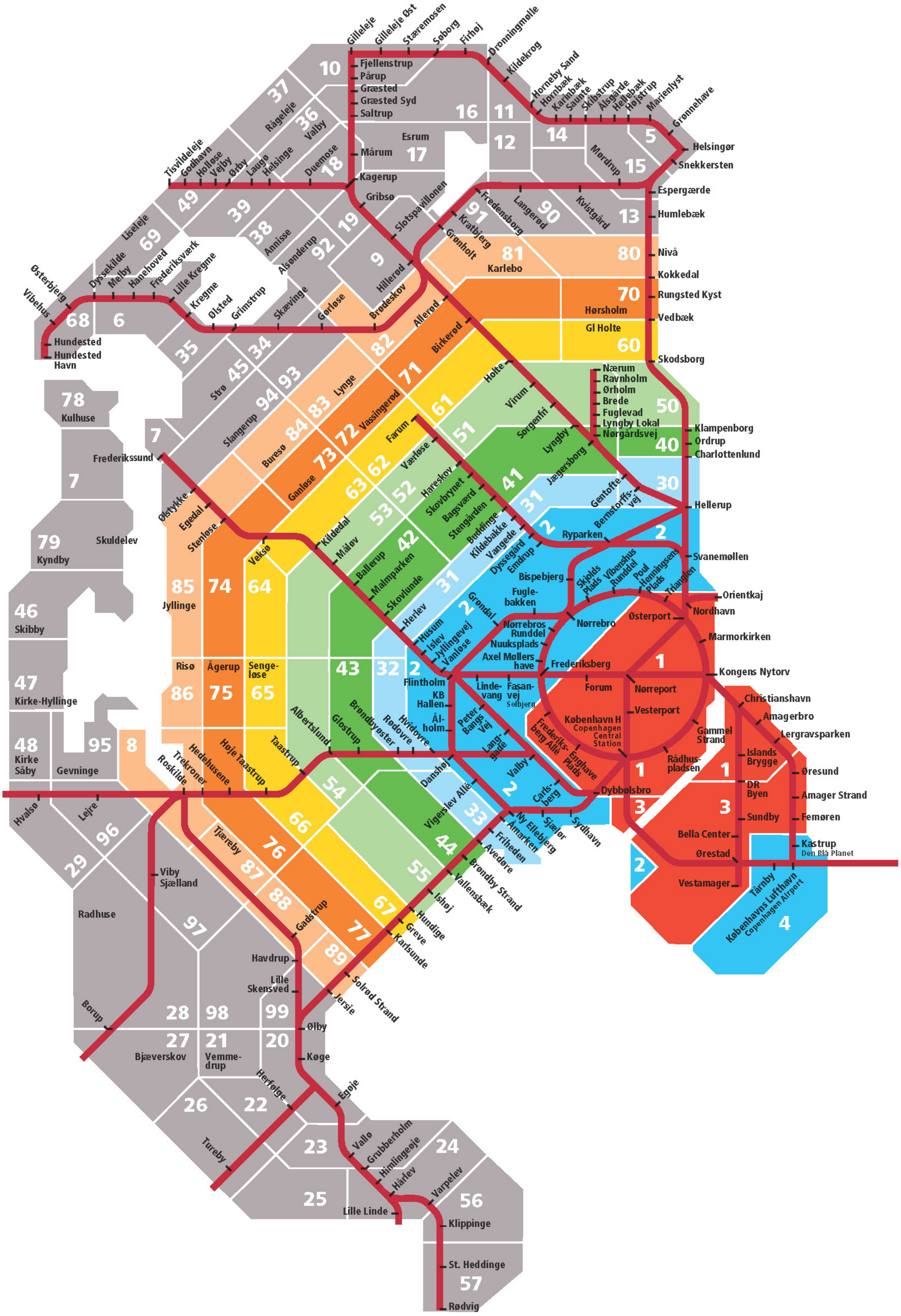



Figure 2.7: Public transportation map of the Greater Copenhagen area.

### 2.3.1 Public transportation service on DTU Lyngby campus

On DTU Lyngby campus there are fifteen bus stops, two along the highway and the rest spread around the main arteries. The lines operating are 150S and 15E along the highway, which destination is Copenhagen. And 30E, 40E, 300S, 180, 181 and 190 lines around campus, which have Lyngby Station among their main stops. In 2025, three stops will be added with the implementation of the first phase of the Greater Copenhagen Light Rail, called ”ring 3”, that will cross DTU campus [Skotte 2019]. Moreover, this year a driverless bus will be tested on campus. In case it is approved it will connect the 29 light rail stations with its surroundings. During the test period it will give service from Netto to somewhere in between sector 4xx and 3xx [].

Looking into the quality of campus connection by public transport, it can be said that is adequate depending on the time of the day and the destination.

Travel time by bus from Anker Engelunds Vej to Lyngby St. ranges from 16 to 17 minutes. On foot is 35 minutes (2.8 km) and by bike 10 minutes. After 19:00, the frequencies of buses with this travel time drop from 10 minutes to 30 minutes. Being half an hour the alternatives offered. Moreover, according to the explanation in section 2.3 and after checking the app ”Rejseplanen” [Rejseplanen n.d.], it has been proved that after 00:30 there is no proper connection with Lyngby Station. At least not with a travel time smaller than one hour, which includes walking 1.6km to the bus stop. It comes back to usual frequencies at 6:30 in the morning, when daytime buses start operating again.

On the other hand, Copenhagen’s connection does not stop at night, but the frequency increases to one hour.

With the arrival of the light rail in 2025, some lines will be eliminated or cut at some areas (See figure D.4. At DTU, the bus line 300S will be competing with the light rail in some areas, and therefore it will be cut in those departures only running between Gladsaxe Trafikplads and Lyngby station and between Lyngby station and Naerum station [Andersen, Landex, and Nielsen 2006].

The light rail will increase by three the number of nodal connections on campus (Akademivej DTU, Anker Engelunds Vej DTU and Rævehøjvej). It will have 29 stops throughout the first phase route, from Ishøj to v/Lundtofte, what will improve DTU connections with the southern part of the campus.

The timetable of the light rail will start, from Monday to Saturday, at 05:10 and it will give the last service at 00:30. On Sundays it will start one hour later. Extra service will be given from 06:04 to 18:44 (Monday to Friday) and 07:04 to 15:44 on Saturdays (See Figure C.1). This extra service will be a fast line variant that will only stop at the most important stops based on transfer possibilities and expected passenger loads [Andersen, Landex, and Nielsen 2006]. Frequency on both lines will be 20 minutes and the estimated travelling time of the normal line is shown in Table 2.2.

| Station | Travelling time (estimated) |
|---|---|
| Lundtofte | 0 |
| Rævehøjvej | 1 |
| Anker Engelunds Vej | 3 |
| Akademivej | 5 |
| Fortunbyen | 7 |
| Lyngby Centrum (Nærum Line) | 10 |
| Lyngby station (S-tog) | 11 |

Table 2.2: Estimated travelling time between the light rail stops in Lyngby municipality.

Driverless vehicles are allowed in Denmark but must pass an evaluation process before going into service. It is a 15 step approval process [Pernestal 2020]:

1. Vehicle approval application sent to Danish Road Traffic Authority
2. Processing of vehicle approval application
3. Vehicle approval
4. Prepare site assessment report for test site
5. Send site assessment report to project's assessor
6. Processing of site assessment report
7. Approval of site assessment report by assessor
8. Send approved site assessment report to Danish Road Directorate
9. Processing of site assessment report
10. Consolidation act sent to public hearing
11. Consolidation act approved by the Transport Committee
12. Final approval of consolidation act by Minister for Transport
13. Prepare and initiate site acceptance test
14. Site acceptance test approved by project's assessor/Danish Road Directorate
15. Test start with passengers

DTU's driverless bus is on the last stage. The test was supposed to start on March 2020, but due to the coronavirus lockdown it has been postponed, hopefully, to September 2020 []. The test will give service from Netto to somewhere between sector 4xx and 3xx. Moreover, an App is being developed and it will be tested together with the driverless bus. The app seeks to find the fastest route to passengers' destination, modifying the route depending on which passengers are on the bus [Simonsen n.d.].

> ”The light rail and the driverless buses will, in general, help ensure that we also have smart, green and flexible ways to transport us collectively in the future. The upcoming light rail is a decisive step, but the driverless buses can create better connections when the light rail is finished and thus ensure that even more people will choose green and collective transport.”
>
> Steen Christiansen, Mayor, City of Albertslund [Pernestal 2020]

# 3 Theoretical background

## 3.1 Sustainable transportation systems

Sustainable transportation is crucial for having a livable city with high quality of life. Sustainable transportation is defined based on the definition of sustainable development given by the World Commission on Environment and Development, Which according to CAI-Asia, the definition is as follows

> ...set of transport activities together with relevant infrastructure that collectively does not leave problems or costs for future generations to solve or bear present builders and users of the system should pay such costs today. These costs are not limited to environmental externalities, but also include social and other economic impacts caused by transportation. [UNESCAP and CITYNET 2012]

A key aspect of sustainable transport lies in the organization of urban space, with an adequate distribution of goods and services people do not need to travel long distances or use transport, but can reach their destination on foot. This objective seeks to reduce environmental and economic impact by reducing the demand of transport. [UNESCAP and CITYNET 2012]

Moreover, connectivity is very important. It is necessary to have a proper transport network to avoid "transportation gaps". *"For instance, there are places that people travel to, but are too far to walk or too close to drive."*[UNESCAP and CITYNET 2012]. In order to avoid the use of personal motorized vehicles or walk long distances, systems like bike-sharing or e-scooters could be the solution in these cases. This is promoting green vehicles, car sharing and non-motorized vehicles.

> By promoting public transportation and non motorized transportation the transportation system is made more efficient to both the providers and the users. As less people uses personal vehicles, the lower is the level of traffic congestion and demand for new roadways. [UNESCAP and CITYNET 2012]

Public transportation must be integrated and balanced to reach as many groups of the population as possible. And has to provide proper connections with the main areas of activity, like the city center, malls, sports facilities, etc.

Transportation does also includes the movement of goods, which is between 10 to 18% of trips in urban areas and represents 40% of pollution caused by the transport sector. Moreover, freight transport causes part of the traffic congestion in urban areas due to the time needed for the loading and unloading process. Since this service cannot be banned on cities, the creation of freight hubs and Intelligent Transport Systems should be implemented to reduce as far as possible its impacts. [UNESCAP and CITYNET 2012]

On the other hand, accessibility and affordability of transportation are crucial for the development of the city since ensures access to work and essential services.

> ...the benefits of having a sustainable transportation system is not limited to mitigating traffic congestion and improving air quality only but it also helps to reduce poverty and brings economic prosperity to the city. [UNESCAP and CITYNET 2012]

Therefore, the main objectives of sustainable transportation systems according to UN-ESCAP and CITYNET 2012 are the following:

1. Reduce the travel demand, particularly by motorized modes by reducing the number of trips and trip lengths
2. Greater use of truly sustainable modes (i.e. walking and other non-motorized transport)
3. Efficient use of existing systems and reducing the use of all resources – natural, physical and financial
4. Increasing energy efficiency and emission standards of motorized vehicles.

And the measures proposed to reach these goals are five.

1. Organization of urban space – land use planning and finding better solution to meet the needs through action in other areas
2. Making services and opportunities accessible by walking and non-motorized transport
3. Development of a balanced integrated transport system that ensures efficient travel using multiple modes
4. Technological standards (vehicle, fuel, emission etc.) and
5. Improvement in efficiency of urban freight logistics through organization of freight distribution and delivery facilities and services.

To achieve a sustainable transportation system is important to have a strong methodology which with measure the progress towards sustainability. Thorough this project, objective (2) and part of (1) are followed. And for achieving them, a solution based on measures (2), (3) and (4) somehow, will be sought. The methodology followed will be based on social, environmental, and economic indicators.

## 3.2 Micromobility

Before going into the concept of micromobility, it is important to understand what MaaS means.

> Mobility as a Service (MaaS) is the integration of various forms of transport services into a single mobility service accessible on demand. To meet a customer's request, a MaaS operator facilitates a diverse menu of transport options, be they public transport, ride-, car- or bike-sharing, taxi or car rental/lease, or a combination thereof. For the user, MaaS can offer added value through use of a single application to provide access to mobility, with a single payment channel instead of multiple ticketing and payment operations...
>
> ...The aim of MaaS is to provide an alternative to the use of the private car that may be as convenient, more sustainable, help to reduce congestion and constraints in transport capacity, and can be even cheaper. [Alliance n.d.]

**Micromobility definition**
Micromobility is a trendy new concept that officially appeared in 2017 when business and technology analyst Horace Dediu was giving an speech, although can be found earlier as a technical term in computer science [Granath 2020]. *The idea behind micromobility is to have an efficient and environmentally-friendly way of getting around cities*. [Dictionary 2019]

Because of its novelty, there are many definitions but none official. However, they all have similarities, as shown below.

Analyzing the root of the word ”micromobility”, a definition can be obtained. Two primitive words can be found: ”micro” and ”mobility”. Meaning ”micro” minimal or small, and ”mobility” the ability to move or be moved freely and easily. Therefore, micromobility could be simply defined as *the ability of movement through minimalistic means*. [Dediu 2019]

A more technical definition could be: personal transportation using *any vehicles whose gross weight is less than 500 kg* as stated by Granath 2020.

Other organizations like the Institute for Transportation & Development Policy (ITDP), defines micromobility as *a range of small, lightweight devices operating at speeds typically below 25 km/h and is ideal for trips up to 10 km*. [ITDP n.d.]

If all these definitions are combined into one, a general and complete definition can be obtained. Hereby, micromobility is the ability of movement through minimalistic means, whose gross weight is less than 500 kg, operates at speeds typically below 25 km/h and is ideal for trips up to 10 km.

One of the objectives of micromobility is to solve the first-last mile issue that most cities are struggling with (Figure 1.1).This problem can appear even in cities with a great public transportation system and is referred to the *space between the station and home, or the transfer between buses or any distance that is too close to drive, but too far to walk* [Granath 2020].

> Not everybody can possibly live or work within easy walking distance of a transit station or bus stop. Thus, cities still suffer from traffic congestion, parking problems, and excessive auto emissions.[Witzel 2018]

On the other hand, to solve this problem, more transportation routes cannot be simply added because of the high cost. And meanwhile, people refuses using MaaS because of this first/last mile issue.

> If people lack a convenient, affordable way to get on a bus or train, they are far more likely to opt for a personal vehicle(...). Or, perhaps worse, they may opt to not travel, forgoing job opportunities, access to healthy food, preventative medical care, and more. The first-mile/last-mile problem (...) can create “transit deserts”—areas with transit-dependent populations that lack adequate public transit service. [Zarif, Pankratz, and Kelman 2019]

Micromobility is demonstrating in many cities that can be the solution for the first/last mile problem. In China, Mobike has doubled accessibility with a dockless bike sharing system. This has been reached by including their bikes in areas located further than meters from public transport. Achieving that half of the trips made by bike sharing are part of commutes. [Zarif, Pankratz, and Kelman 2019]

> An integrated transportation system that includes public transportation and such flexible alternatives as micro-mobility vehicles can help fill in the gaps. (...) city planners, micro-mobility companies, and the public need to work out the best and safest ways to implement these new solutions. [Witzel 2018]

**Vehicles and systems**
Micromobility includes a wide range of vehicles, but the most popular ones are e-scooters and bikes (human- or pedal-assisted). Moreover, there are different working systems, usually grouped into station-based and dockless systems. The first ones have specific

spots where bikes can be parked, and the second one defines a limited area, usually the limit of the city where vehicles can move freely. It is very important to know their differences in order to choose the most adequate for each situation.

> The benefit for MaaS players of station-based micromobility is the predictability and clarity around where the vehicles can be parked. Dockless of course bring in more unpredictability about where they will be at given times and where they can be parked. [B. Cohen 2020a]

**Benefits and challenges**
There are many benefits it can be obtained from micromobility, but there are three that bright over the others according to Consulting 2020.

1. Environmental footprint. Urban air is improved by reducing the CO2 emmissions, and therefore increasing the quallity of air and reducing climate change.
2. Get people out of their cars. Thanks of the improvement of connectivity towards public transportation, people is more open to use multi-modal transport.
3. Efficient mobility. Convenient and flexible transportation help people moving towards green mobility and MaaS.

As mentioned in section 3.1, one of the main challenges to achieving sustainable transportation and hereby, quality of life, is to reduce pollution and congestion in cities. According to Consulting 2020, smart policies and infrastructures will not be enough to transform European cities into car-free hubs, without noise and pollution. Rather, *”a fundamental shift in mobility habits and behavior”* would be needed. At this point is where bike sharing and e-scooters play a role. *By making alternative and public transit systems more accessible and convenient, (...) can serve as a catalyst toward shared and low-carbon mobility.* [Consulting 2020]

> ”Shared mobility is part of the bigger plan of creating a livable, sustainable and accessible city with places that are pleasant to stay in. MaaS and micromobility are key in our plans,” say Eindhoven MaaS experts, Astrid Zwegers and Jan Willem van der Pas. [Consulting 2020]

But these systems also faced challenges, which have a more or less impact depending on the city and its culture.

- **Regulations**

  Due to the fast growing path of this technology, there was a lack of regulations and authorities have had to quickly create them.

  > local authorities are unavoidably going through a stage of trial and error, where they experience that some regulatory approaches or specific rules may work better than others.

  Other cities have had conflicts with some companies which have followed the approach *“better to beg forgiveness than ask permission”*. This lead to the spread of e-sooters and dockless bikes around the city without authorization to local officials. Therefore, many cities have created severe regulations when not totally banned this type of mobility. One example is San Francisco’s scooter war. [Zarif, Pankratz, and Kelman 2019]

  Hereby, while some are happy to include this new means into their mobility, others are prohibiting the operation because of the impact they cause on the streets and sidewalks. [Insigths 2019]

> To unlock their potential, it's vital that governments and cities implement policies while addressing the challenges. That includes making clear regulations that foster responsible and sustainable behavior and enabling access to micromobility infrastructure, such as parking and lanes. [Consulting 2020]

Hence, regulations need to be flexible to embrace rapid changes and *enable more pro-active interventions*. [Bidasca et al. 2020] Which will avoid overwhelming of local governments when new services flood into a city, like it already happened with Uber, Cabify, etc. and it is now happening with micromobility companies. [Zarif, Pankratz, and Kelman 2019]

- **City infrastructure**

Cities are trying to come back to their origins, when with their infrastructure they supported people's well being and not motorized vehicles. But even now, many cities still do not have specific parking spots, bike lanes or separate paths for the safe use of micromobility devices. According to B. Cohen 2020b,

> ... we need to see dedicated pedestrian areas, dedicated non-motorized micromobility lanes (e.g. pedal-powered bikes, skateboards, etc) and dedicated motorized micromobility lanes. If we really want to improve safety of our cities and of e-scooter use, the best way to achieve this, in my opinion, is reduce the availability of public infrastructure for private cars and turn over that space to more people-friendly and environmentally friendly infrastructure for movement.

Nowadays, due to the COVID pandemic, the lack of cars on the streets has shown the benefits that green mobility can bring to the planet. *Now is the time to take action and make temporary cycling infrastructure permanent, plus add policies to maintain the modal shift that we have observed back to cycling and walking.* [Sutton 2020]

According to Tom Nutley, an expert in artificial intelligence of BICO AI,

> It is in our hands to make the small changes to create a large ongoing effect for the benefit of our planet. It is much less about size vs available space and more to do about repurposing, change of infrastructure, sustainable option availability and knowledge. [Sutton 2020]

- **Safety feeling**

The feeling of safety comes together with the availability of proper infrastructures. Available data has shown that users rather use sidewalks or bike lanes (when existent) than share the street with high-speed vehicles. [Zarif, Pankratz, and Kelman 2019]

> some pedestrians, suddenly sharing space with motorized vehicles, have understandable safety concerns. [Zarif, Pankratz, and Kelman 2019]

Moreover, as policy expert Emily Warren stated, *dockless bikes and scooters that users can conveniently drop off anywhere can create unkempt public spaces and even safety issues*. [Zarif, Pankratz, and Kelman 2019]

This problem is being approached in some places by painting on the streets of the city some areas where dockless systems can be parked or implementing station-based systems, which are not as flexible but, in the long term, with higher initial investments can be as productive as a dockless system.

- **Profitability**

  Micromobility systems have low profits when they start and, if they are small, usually are subsidized by the local government. Therefore,

  > While some companies may fail along the way, the companies that do survive will likely thrive in this multi-billion-dollar market, as they provide urbanites with a viable solution to their transportation woes and offer a greener alternative to cars. Covid-19 has accelerated the potential consolidation of the space, but also driven demand in a time where one-rider, open-air transportation solutions are highly desirable. [Insigths 2019]

  Differences are focus on the type of system. Station-based systems have a higher implementation cost due to the cost of the station, but dockless have huge cost because of the relocating and charging process. One solution that some companies have adopted for avoiding relocating, is flooding the market with bikes. [Zarif, Pankratz, and Kelman 2019]

  Companies that succeed, grow fast. For instance,

  > Bird hit 10 million scooter rides within 12 months of first appearing on Southern California streets and sidewalks,6 while Lime users took 34 million trips across the company's platform of vehicles—including e-scooters, electric and pedal-assist bikes, and carsharing—in that company's first year. [Zarif, Pankratz, and Kelman 2019]

  Europe is one of the opportunity places some investors interested in micromobility are looking at. It has dense populations and in the past decade, bike lanes have increase exponentially. [Insigths 2019]

  For a micromobility system grow fast, two aspects are necessary

  1. Start in a conductive environment where users have already test this kind of mobility solutions, and
  2. Being economically profitable for the users (Although when they are private operators, fares can be pretty expensive) .

     > It's in many ways easier for companies to scale up micromobility assets compared with car-based sharing solutions. While thousands of dollars are often required to purchase a car, the current acquisition cost of an electric scooter is about $400. [Granath 2020]

- **Vandalism**

  This is the main problem of micromobility, the bike sharing system Velib in Paris is a station based system and has suffered from theft or damage in 80% of their bikes. [Granath 2020]

  Many start-ups have been ejected from the bussiness due to theft, vandalism and damage. Even though it is a strong hit to every company.

  In order to solve this issue, companies are continuously changing their designs to make it difficult for thieves removing wheels, batteries, etc.

- **Equipment's lifetime**

  The resilience of the different devices is an important aspect when designing these systems. The longer they endure, the cheaper for the company.

  Some important companies, like Bird ans Lime, have reported that their scooters last around two months. [Granath 2020]

  > In an effort to increase their lifespan, Bird upgraded to a more durable "Bird Zero" model in 2018, featuring solid-core tires. [Insigths 2019]

  As mentioned before, companies are always *looking at new prototypes, tweaking shapes, sizes, and wheel arrangements for vehicles to serve different transportation needs and comfort levels. (...) Ultimately, models that prove to be sustainable, more durable, and safer for riders will likely win out.* [Insigths 2019]

- **Weather and geographic conditions**

  Rain, snow and wind can be tricky, if not dangerous when riding. The northern countries of Europe usually have this weather conditions, but they are also used to them, being countries with a strong bicycle culture. Even though, it is very typical to see e-bikes to save geographic obstacles like hills.

  Some micromobility companies offer to its users gloves and hats, but reality shows that usually companies are forced to take off the street their devices. [Insigths 2019]

Regarding the contribution of micromobility in the transition to low-carbon cities, they do contribute, but they still have room for improvement. Oliver Bruce, stated that

> as durability of the scooter hardware increases, coupled with continually improving efficiency of their batteries we are likely to see even further improvements in e-scooter's contribution to lower carbon cities. [B. Cohen 2020b]
>
> Together, investment toward micromobility infrastructure, effective policies, innovation and responsible business practices can help cities reach their climate goals, reclaim space for citizens and improve their quality of life. [Consulting 2020]

According to Zarif, Pankratz, and Kelman 2019, the way we travel today is changing fast. MaaS is evolving towards individual mobility and is creating a new ecosystem. We are just at the beginning, and we should expect to see new and diverse designs in a near future (shape, size and capability), together with the development of up-to-date information technology. Moreover, it is important in this process to consider aspects like unifying platforms, since it has been proved that people hates to download new apps [B. Cohen 2020a].

## 3.3 Bike Sharing System. Guidelines for designing and implementing

Bike Sharing Systems are one type of Micromobility that is being implemented all around the world. However, planning a BSS is not easy, many variables must be taken into account.

> ... the city's density, topography, and weather; its commitment to investing in infrastructure; and its political will to support active transportation, for example. [A. Cohen et al. 2018]

Governments with long-term plans for cycling should take into account the BS as an opportunity to raise the number of cyclists. Bikeshare accelerates the implementation of infrastructure and it is usually employed as a tool to reduce vehicle trips.

> For example, in California, Santa Monica adopted a Bike Action Plan in 2011, which designated bikeshare as a high priority project toward the city's goal to reduce vehicle trips. [A. Cohen et al. 2018]

There are many steps when planning and implementing a Bike Sharing System. According to the Institute of Transportation and Development Policy, seven phases are needed with their respective processes. All guidelines are going to be explained but emphasizing those points that are going to be developed throughout the thesis. Hereby, points from one to three will be further explained than others.

1. **Getting started** First of all, there is a need of political will. This means that without interest on the system it is very difficult to move along and arrive to the implementation phase. Hence, benefits of BSS must be shown and studied for each specific location. Moreover, the system must be equitable and accessible to everyone. For example, allowing different methods of payment for including those without a bank account (e.g. exchange students). However, equity can lead to higher cost for the operator.

   The purpose of bikeshare cannot be forgotten at any step, which is

   > enabling any user to pick up a bike in one place and return it to another, removing the complications of having to own or maintain a personal bike, yet still providing a convenient, environmentally-friendly mode for short trips. [A. Cohen et al. 2018]

2. **Goal Setting and Initial planning** Four steps must be taken into account on this phase.

   - Identify goals of BS, for instance reduce CO2 emissions, improve mobility, solve first/last mile issue, generate employment, etc.
   - A Request for Expression of Interest (RFEI)
   - Examine feasibility and choose a system type.

     The feasibility study includes from basic system metrics (defining service area: number of bikes, stations and docks; User types: Casual, per trip and long-term; define system size and market penetration with parameters: bikes per 1000 residents(10-30), bike density, station density (10-16 per $km^2$), docks per bike(2-2.5), trips per bike per day(4-8)...) to evaluate potential investment and revenue resources. It is also recommended to create a contracting model.

     Regarding the system type, there are three types:

     - **Station-based:** which require to pick up and return bikes to specific points.
     - **Dockless:** Does not need specific point to be locked, it is usually unlocked by an app using a QR or a code. It has an operational area predefined where bikes can be used. Two sub-types can be found:

       (a) Lock-to: bikes must be locked to a fixed object.

       (b) Wheel lock: bikes are self locked by a locker usually located on the back wheel.

– **Hybrid:** Is a mixed system that allow users to decide whether locate a bike on a station or leave it within geofenced hubs. Different choices for users are:

(a) Pick up and return a bike to a station (station-based model)

(b) Pick up on a station and lock it anywhere

(c) Pick up anywhere and return it to a station

(d) Pick up and return from and to anywhere (Dockless model)

All systems have their strengths and weaknesses. From the point of view of cities, station-based have high capital and operating costs but are more longevity and have better public space management. On the other hand, dockless have lower capital costs but has a big public space impact and inconsistent availability. Looking into the user's perspective, station-based are more affordable and reliable while being less accessible and it has the risk of not availability of bike or docks. regarding dockless systems, it is more flexible and convenient but it is more expensive and sometimes not accessible depending on the fleet's size. Hybrid systems have the strengths from both types, while still having part of the weaknesses: public space impacts, inconsistent availability, additional usage fees, and a new one, user confusion. The latter is because the system has too many possibilities and sometimes users have not clear where cannot end their trip and end up paying some extra usage fees.

All these systems can be implemented with human- or electric-powered bikes changing some of the characteristics like the type of stations. There are two types of electric powered bikes, throttle (works like a motorbike) or pedal assisted (the electric motor helps when pedaling, having three options: low, medium and high assistance, being the latter for cycling faster without sweating and the first for workout). [Pete 2013]

- Draft financial planning estimates Once the size of the system and the typology are chosen, a rough financial analysis can be obtained. The analysis aims to assess if the system is economically sustainable. Usually includes an estimated capital outlay, the projected revenue and operational costs.

  The draft has to consider different aspects depending on whether the operator is private, or it is public (or has public-funded).

  – **Public funded:**

  Capital and Operating costs per Bike:

  > For station-based systems, an estimation of capital costs and operating costs can be calculated by multiplying the number of bikes, docks, and stations against an average cost for each type of asset. Capital and operating costs are a function of system technology and are straightforward to determine, but revenue depends on usage levels and can only be fully estimated in the infrastructure planning stage. Usually the revenue scenarios are based on expectations of demand using both a conservative estimate (...) and an optimistic scenario (...). [A. Cohen et al. 2018]

$$Capital \quad costs = \frac{Total \quad cost \quad of \quad the \quad system}{Total \quad number \quad of \quad bikes \quad in \quad the \quad system}$$

Operating costs vary depending on the system and the city. Estimates range them between $900 - 3,500\$$ annually per bike.

| CAPITAL COSTS | OPERATIONAL COSTS |
|---|---|
| Bikes | Rebalancing |
| Stations | Maintenance and rebalancing staff |
| Rebalancing vehicles/equipment | Call center staff |
| Control center | IT system fees ans servicing |

Table 3.1: Aspects considered in capital and operational costs. [A. Cohen et al. 2018]

Operating costs per Trip:

> The cost-per-bike estimate may be useful in the planning stage to size the system financially, but to analyze system performance after the system launches, a per-bike analysis is not recommended because bike fleet size varies from day to day. Some have used the per-dock metric for analyzing annual operating costs as a more stable, and therefore, more comparable basis. However, this guide recommends evaluating the cost efficiency of a system after it opens by looking at operating costs per trip. [A. Cohen et al. 2018]

Estimating revenue:

Incomes can be estimated through three parameters: uptake rate, farebox recovery and trips by type of user. The first parameter aims to calculate revenue by multiplying the estimated demand and the proposed revenue structure. There are three scenarios: conservative, middle and optimistic (3%, 6% and 9% of population respectively) For instance, Mexico uses 10% due to the high commuters in the area. This parameter is used to estimate the demand of the system.

The farebox is used to calculate the financial health of the system which is meassured by *the percentage of operating costs that are covered by membership, security deposit and user fees.[A. Cohen et al. 2018]*.Measuring if it is self-sustaining or other sources like advertising will be needed to cover these costs.

Finally, the latter parameter is defining the number of casual or permanent users. This is because normally casual users are charged with higher fares. Generally, the percentage of casuals declines as the system grows and long-term members increase.

– **Privately funded:**

  Both capital costs and revenues are obtained in the same way as for public-funded, but for operational costs some extras may be included, as annual permits fee, permit review fee, administrative fee, performance bond, non-compliance fee and In-lieu fee.

3. **System planning and design**

   This section has differences depending on the type of system. Station-based will be focused on siting and designing stations, while dockless will draft the requirements for managing operations by private companies. A common aspect to both systems will be the identification of potential infrastructure improvements and bike models.

When implementing a BSS, having a proper cycling infrastructure is important but not absolutely necessary. Nevertheless,

> pairing the construction of new bike lanes with the opening of a bikeshare system can add to public acceptance and improve safety for users of the new system, as well as personal bike riders. (...)
>
> Additionally, data generated from bikeshare trips can provide evidence of the impact of bicycle network improvements, whereas it can be difficult to gather this data from private bike users. [A. Cohen et al. 2018]

IT is very important in BSS because it is the link between all components. Therefore, it has to support the front end which includes:

- Registration of new users,
- payment and subscriptions,
- general information about the system and customer data management,
- website portal or apps,
- station and bike location monitoring,
- rebalancing of bikes,
- defect and maintenance issues,
- biling,
- customer data, and
- use of card technology for permanent users to unlock faster.

But it also has to serve casual users and tourists. Hence sometimes bikes are implemented with keypads.

Regarding the type of bikes, some characteristics are valuable when designing. Normally there is only one size and style of bike, but the seat must be adjustable without allowing to remove it (to avoid vandalism). It is recommended to use a step through frame with long seat post because it adjusts to a wide range of height and allow riders to wear skirts or dresses. Moreover, bikes must be robust because its greater use in comparison with personal bikes. It is recommended to have bikes with an average life-span from 3 to 5 years. Another characteristic is their low-maintenance, but being careful of not loosing ride quality. The docking system must be well designed to be easily lock and unlock to discourage theft. At the same time, the bike must be equipped with safety components like reflectors, bells, brakes and lights. Each bike must have an identification code and include storage (front basket or similar).

Bikes maintenance is an important factor, being the tires, brakes, drivetrains and lightning the most typical issues.

> Modern bikeshare systems are typically based on a standardized bicycle with specially designed or proprietary components built solely for the

system. This ensures durability and security so that the parts cannot be easily stolen and/or resold. [A. Cohen et al. 2018]


(a) Traditional.


(b) Pedal-assisted.

Figure 3.2: Traditional bikeshare bikes. [Divvy n.d.]


(a) Lock-to.[Sawers 2018]

(b) Wheel lock.[Lime n.d.]

Figure 3.3: Dockless bikeshare bikes.

Nowadays some dockless systems are implementing stations for charging e-bikes, like JUMP in figure 3.3a.

4. **Encouraging Ridership through community engagement**

   Once phase 3 is finished and the design is clear, a marketing strategy needs to be developed.

   > A bikeshare system needs a clear, consistent identity—a strong brand—that presents a professional, modern image and distinguishes it from other urban transport options.
   >
   > Ridership must be encouraged through a strategic combination of branding, marketing and education campaigns, community engagement, and reducing barriers to entry. [A. Cohen et al. 2018]

5. **System operations**

   Bikeshare systems can be public, private or a combination of both. Moreover, it can have one or multiple operators as it can be observed in Appendix A, table A.1.

This phase must focus on defining an organizational structure for system operations, expectations for quality of service delivery and enforcement of regulations.

Different responsibilities must be assigned in the organizational structure phase. The implementing agency will be in charge of supervising the planning, implementation and operations of the system. The operators, public or private, is responsible of planning, expanding the system and day-to-day operations like rebalancing. It is also important to define the ownership of the asset. There are different ways of doing it, but usually the operator owns, supplies and operates the infrastructure of the BSS and the city provides the space needed (in case of station-based systems) [A. Cohen et al. 2018]

Regarding the contracting structure, it will depend on the systems procurement. For publicly procured, more than one contract can be done for achieving all components. Nevertheless, for privately procured is the operator who must provide all the equipment. Systems can be Public-Private Partnership (PPP) or Privately-Operated. The latter has three differences, publicly owned and operated, publicly owned and privately operated, and privately owned and operated.

Finally, the quality of service must be defined and mechanisms for enforcement should be established. Moreover, it is important the exchange of information between operator and city government in order to improve public transportation and infrastructure.

> Contracts and permits with bikeshare operators should require them to share real-time data with the city (...) that will better inform system-level operation, infrastructure, and integration with public transit. [A. Cohen et al. 2018]

6. **Financial model**

A complete financial model will include expenses and incomes. Expenses are generally capital and operational costs and revenues are from users payments, government fundings or sponsorships.

Capital costs:

- Bycicles: in station-based systems are a small part of the capital cost compared with stations. Cost can range from $100 - 2,000\$$ depending on its technical specifications. Portland's BIKETOWN bikes cost around $1,500\$$ because of its solar-powred LCD screen, automatic lights and chainless shaft.[A. Cohen et al. 2018] In dockless systems bikes are the major component of the capital cost.
- Stations: are the main cost for station-based systems, non-existing in dockless. It ranges from $40,000 - 50,000\$$
- Software:

> ...software can be purchased outright, developed, or licensed, and each option will have a different impact on the capital costs and the longer-term operational costs. Developing software is the most expensive option (...). Buying (...) is initially more expensive, it is a one-time cost, with perhaps an annual service cost. (...) Licensing software can be a good initial solution to help offset capital costs, but can be a cost burden on the system down the line.

- Control center, Depot, Maintenance and redistribution units:

  > The control center is where the central management of the bikeshare system is housed, the depot is where bikes are held while being serviced or stored, and the mobile maintenance unit is the unit responsible for responding to requests for repairs.

  Many cities have depots and maintenance areas that can be beneficial for the system and help reducing costs. However, depots must be secure to avoid loosing equipment. When repositioning, it is important to find a non-emission vehicle to reduce CO2 emmissions of the system. Other cost to consider is the flatbed trucks or trailers behind vans, which can be pretty expensive.

Operating costs:

- Rebalancing: Is by far the most expensive component of operational costs.

  > ...is broadly defined as the relocating of bicycles from stations that are near or at capacity to stations that are close to empty. Successful rebalancing is critical to the viability of the system from the customer's perspective, and is one of the greatest logistical challenges of operating a bikeshare system. Rebalancing can account for anywhere from 30% to over 50% of operating costs. If an operator has an adequate IT system, rebalancing becomes predictive, and is better thought of as pre-distribution—the movement of bicycles to areas where users will need them and away from areas where users will be dropping them off. [A. Cohen et al. 2018]

- Staffing: Cost depend on local regulations and employment cost of the city. Staff need to include administration, management, rebalancing, mechanical and customer service.

- Maintenance: Together with rebalancing is one of the most expensive parts of operational costs. It is usually repairing docks, removing graffiti, fixing punctures, chains and brakes.

  Maintenance is an important aspect to achieve high levels of safety, reliability and image.

- Marketing is another initial cost that has to be taken into account. It can be printed posters or more elaborated campaigns in media.

- Insurance: It is really important to have a good insurance that covers all security aspects as well as theft.

  > Some operators estimate a 10% annual theft rate, and integrate the costs of replacement bikes into their financial models. [A. Cohen et al. 2018]

Revenues: User fees are the stable part of revenues, even though usually are not enough for having a financial self-sustaining system. In big cities like Chicago, can compensate up to 80% of operational costs, but in small cities like Colorado, the farebox can recover just up to 35% of costs. Hence this gap must be covered with other income sources.

- Government funding:

  Government funding can be used to cover capital costs—which means the government owns the assets—and is sometimes used for operating costs. Not unlike many public transportation systems, bikeshare systems often have difficulty covering operating expenses from membership and usage fees alone. Because of this, subsidies may be necessary to cover operational expenses and can come in the form of earmarked funds for sustainable development, innovative initiatives, or even specifically for bikeshare. [A. Cohen et al. 2018]

- Sponsorship: This method has benefits and drawbacks. While it can cover capital, operational or both costs, it can limitate the advertising potential. Moreover, if the entity has image problems it can affect the bikesharing image as well. All these aspects must be assessed in a long-term perspective before closing a deal.
- The system can also obtain private investment or loan financing.
- Advertising: This has two types, outdoor or on bike asset advertising. There is an study from JCDecaux that link general outdoor advertising with annual revenues of 60€ million.

7. **Implementation**

   Implementation can be with a pilot period or a soft launch. Which includes user feedback, test run and media coverage. Once the system is implemented is very important to analyze success and the possibility of the system expansion. Parameters that can measure its performance are:

   - Reduction in CO2 emissions
   - Improvement of air quality
   - Time and cost savings
   - Increase in local economy
   - Reduce road fatalities
   - Accessibility, meaning the location of the asset (stations or dockless bikes)

   Planning for an unknown future rests on the ability to be flexible and responsive to unforeseen developments and having mechanisms in place to measure their impact on existing policies and procedures. The bikeshare landscape is constantly changing; now, cities have the opportunity to capitalize on these new applications of technology to facilitate a more sustainable transportation network. [A. Cohen et al. 2018]

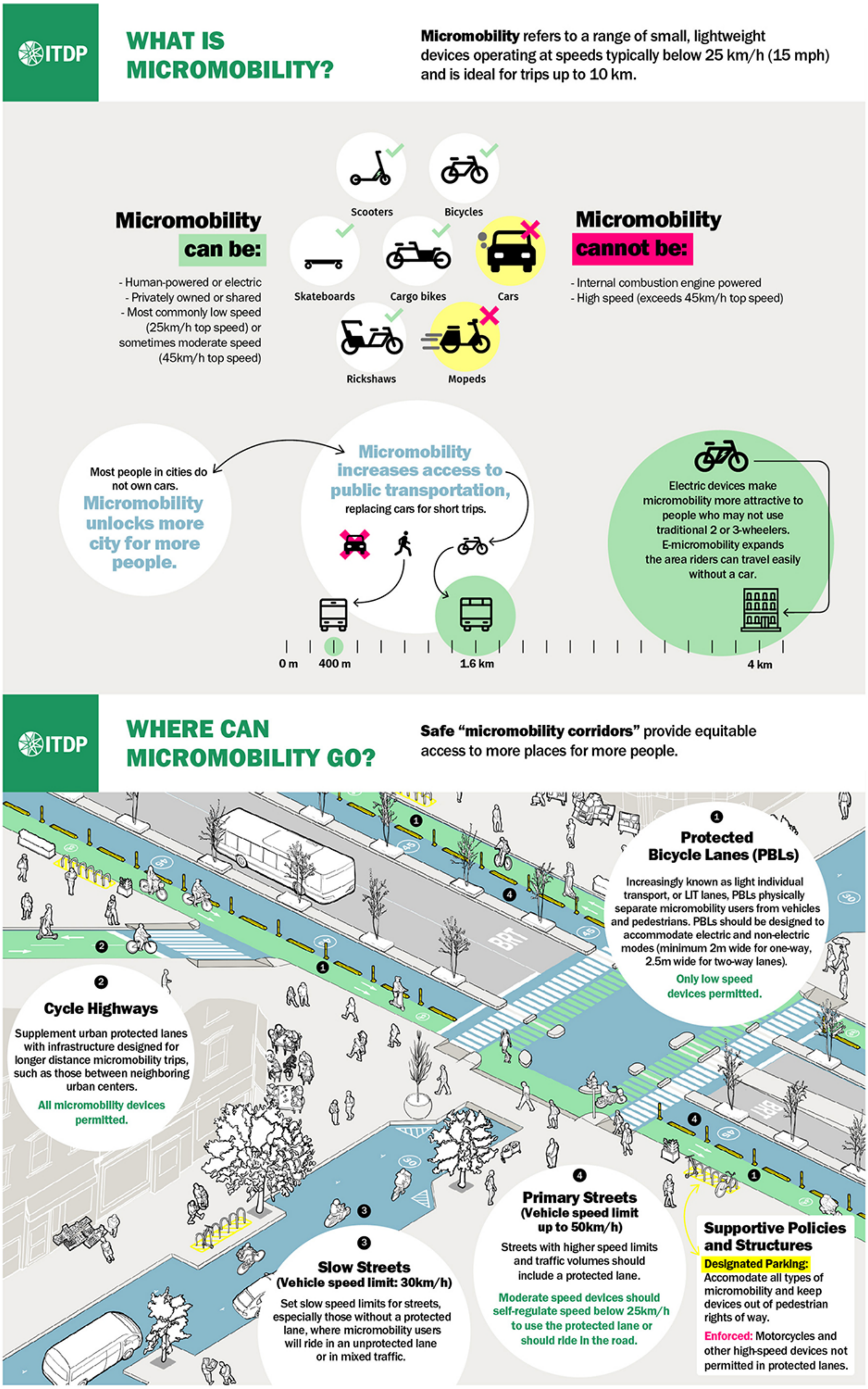



Figure 3.1: ITDP Micromobility infographic. [ITDP n.d.]

# 4 Problem description

Nowadays time is precious and for this reason, people always try to reduce the time of their tasks in order to have more time for themselves. But normally, the most common way of winning some time is in your daily commutes.

This event also happens at the university. Students and professors cannot reduce the length of the lectures, neither their schedule. Thus, the only way for having more time at lunch or arriving soon at home is to commute faster. The problem is that DTU Lyngby campus is pretty big, connectivity between buildings is not very good and not everybody has a bike to move around. Hence, you can spend between 20 and 40 minutes walking to reach your destination.

In 2025, with the arrival of the light rail and the driverless bus, this problem may be palliated when commuting from home to DTU campus, or vice versa. And also for those students with the Ungdomskort, which is a monthly card for students that gives access to public transport with no need of checking in/out. Nevertheless, the rest of the population may need to commute inside the campus and want to do it in a sustainable but economically accessible manner.

On the other hand, there is a connectivity issue with Lyngby's town. Nowadays, after 18:00 the frequency plummets, and from 00:30 at night to 06:00 in the morning, there is no connection. The light rail may reduce evening connectivity problems, but not completely eliminated if bus 300S frequency is reduced [Andersen, Landex, and Nielsen 2006]. And night connection will continue nonexistent even on weekends (Figure C.1).

The lack of connection during the last time zone commented is considered a problem because DTU's library is open 24h, but students that have a group delivery or just want to study until late, can end up walking 35 minutes to Lyngby station if they stay because of the lack of public transport, what does not make sense. Moreover, on weekends, there are many night events that finish later than 00:30 (last public transport service) and therefore, there is no way home if you need public transport.

These problems are for people living in Lyngby-Taarbæk municipality or in municipalities below. Those living through the 150S bus route have service every hour at night, and every 10 to 20 minutes during the day. Considering that the city of knowledge is looking to create a university friendly town [Apli 2019], and taking into account the connectivity problems already commented, a solution is needed. Moreover, increasing mobility could lead to more housing opportunities around DTU.

The objective of this thesis is to reduce travel time by improving the connections within the campus and with Lyngby St., as well as reduce the use of motorized vehicles by improving commute options. To do so, it is going to be designed a bike sharing system and it will be analyzed its feasibility from a sustainable point of view. To guide this project, some research questions have been presented that will be studied during the thesis. During the thesis, some assumptions will be taken and the limitations of the project will be presented.

## 4.1 Research questions

**How could connectivity be improved by implementing new infrastructure?**
Nowadays, many people need to take a private vehicle to get to their job place because there is no efficient public transportation route they can take. This is the already mentioned

first/last mile problem of today's public transportation. While MaaS is really efficient to move large amounts of passengers, still needs to solve this connectivity issue.

> If people lack a convenient, affordable way to get on a bus or train, they are far more likely to opt for a personal vehicle, (...) Or opt to not travel, forgoing job opportunities, access to healthy food, preventative medical care, and more. [Zarif, Pankratz, and Kelman 2019]

Hence, a solution to these "transit deserts" must be found. Micromobility has been presented as the best option to solve this situation. However, no transportation system can succeed without the proper infrastructure that transmits safety to its users. For instance, a bus driving on a dirt road is not as appealing as one on a paved road. The same happens with bicycles and e-scooters, without an appropriate network they cannot reach its maximum efficiency, or do not succeed at all.

Connectivity is improved by both infrastructure and systems, being the infrastructure the key aspect. Therefore, this two aspects are going to be commented and assessed through the thesis. The first one as bike lanes, roads and tracks, and the second one as buses, trains and bicycle systems.

**Is the actual demand enough for being a feasible solution?**
Every system needs to have revenues to be a good business. Hence, the first aspect that can show us whether is profitable or not, is the demand.

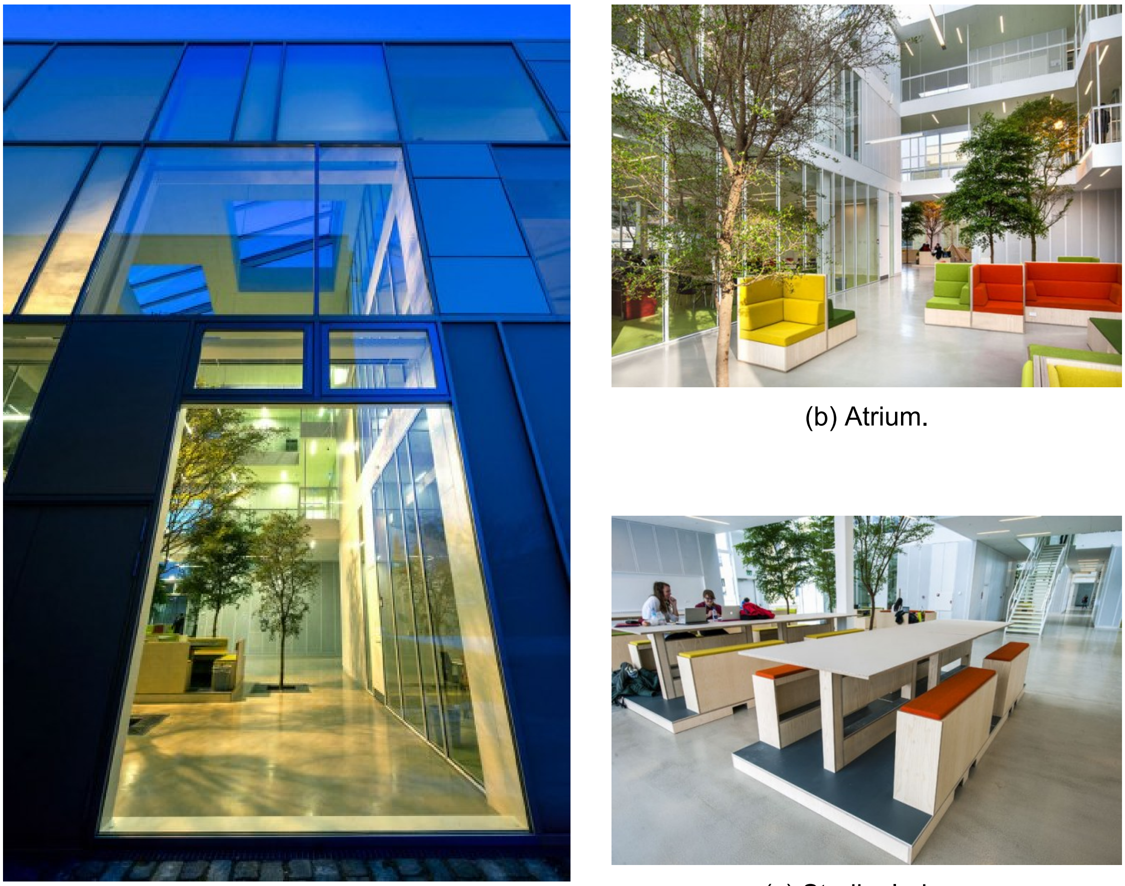
However, other aspects interfere. Aspects like social and environmental benefits. This is the reason why, even if the demand obtained in this project is not enough for being a feasible solution, a sustainability evaluation will be carried out to have a complete overview of the benefits of the solution.

The demand has been obtained through a survey, where many questions have been asked, as shown in Appendix E. The structure is explained in section 5.1, and the evaluation has been carried out in chapter 7 and through the indicators in chapter 9.

**How this network would improve the interaction between users and buildings?**
The interaction user-building is referred to the ability of the user to change the indoor climate to its preferences. More fresh air, different levels of lightning, shadow, etc. However, these aspects may lead to a high energy demand and shortened span-life of the equipment.

> Current building interaction knowledge is facilitated through user-building interfaces. Enabling user control has been shown to have a positive impact on overall user satisfaction with a building's interior. (...)
>
> However, increased user control of building systems often result in poor overall building performance... [Kalvelage and Dorneich 2014]

At DTU, there are plenty of different buildings with different indoor environments. When looking for a fresh area to study, canteens outside rush hours can be a perfect place, on the contrary, the library in 101 can fit perfectly for people hunting warm places. On the other hand, if what the user is looking for is a quiet place surrounded by nature and protected from the weather, building 324 would fulfill these requirements (Figure 4.1). The objective of these examples is to show that when the user-building interaction cannot be fully satisfactory, people try to find other locations where they feel comfortable for studying or meeting. At DTU, nowadays there is already a wide range of opportunities to have a propitious interaction, and the spaces and buildings will increase in number in the following years. But the large distances between buildings make it difficult the decision of change even when productiveness is dropping. This is because it is not the same moving in 5 minutes than in 15.



(a) Glashus.

(b) Atrium.

(c) Studiepladser.

Figure 4.1: Building 324 on DTU campus. "The glass building" [P. Jørgensen n.d.].

Therefore, through this project, the direct interaction user-building is not treated, but it is given a solution for those users that want to change the conditions where they are and continue with their tasks, by moving to other buildings in an easy and quick manner.

## 4.2 Assumptions

Some assumptions have been needed to progress with the project, and are enumerated below.

- It is assumed that the municipality will share the space needed for the implementation of the stations.
- Because of the high number of bike sharing systems in Copenhagen it is assumed that the regulations are favourable.
- It is considered that DTU will build the bike lanes proposed in its Campus Plan and will share some parking space for the system.

- It is assumed that people would not use the light rail as a shortcut on campus unless strictly necessary, due to the generally high cost of the public transportation.
- Calculus comparing time on foot or by bike always include 5 minutes extra for unlock and lock the bike. Hence it is assumed everybody is able to do this process in that period of time.
- Commutes are taken into account when the time it takes by bike is shorter than on foot. If they are equal, commutes are reduced 50%.

## 4.3 Limitations

- Prices are indicatives and can variate.
- Answers from the survey are considered reliable and a proper representation of real commutes on campus. Even tough, up to 5% of error can be assumed.
- The evaluation of some indicators is open to high levels of subjectivity. The solution given has been to gather different evaluations from different people and obtain the average value.
- The mathematical model does not take into account distances between stations when deciding which demand will remain unattended.

## 4.4 Base Scenario

Scenario zero is the common starting point for all scenarios. It is the current situation of Lyngby campus but considering some of the near future implementations contemplated on Campus Plan 2019-2023 [Universitet 2019c].

The description of the sectors and their main activities will be described first, followed by the current bike lanes and the ones planned, together with the public transportation and the new arrivals. After, how this aspects will affect the traffic of motorized vehicles will be commented. And finally, new sidewalks and other facilities like parking for bikes or markets will be implemented as stated on Universitet 2019c.

The campus, as mentioned in section 2.1, is divided into 4 sectors. Each sector has many buildings with different functions, from teaching to research and even office space for administrative and maintenance staff. And each building number starts with the number of the sector (1, 2, 3 or 4), continuing with two more numbers. For example, the library is in building 101, which means that is in sector 1 and the building has the number 01. Below there is a brief explanation of each sector and its activities.

- **Sector 1**: It is located in the north-east of the campus. It has one building lab (119) and other for researchers and educators offices (118). There are two designated to lectures (116 & 127), and finally one of the biggest buildings on campus, building 101. This building has divided its functions into 4, administrative offices, library, sport hall and canteen and cafeteria.

  Therefore, this sector can be divided into 3 sub-sectors depending on the purpose:

  - Research and offices.
  - Students oriented.
  - General facilities.

Being the third one with general facilities, building 101, the most visited in the whole campus.

- **Sector 2**: Is on the north-west separated from sector one by a parking lot. Here, in building 202, is located the National Food Institute. This sector has many buildings designated to lectures, like 210, 208 and 204. And some for offices like 207.

  This sector has one of DTU's accommodation, located on Nordvej. Moreover it has some open sport facilities like the Rugby club.

- **Sector 3**: This sector is pretty diverse regarding its functionalities. There are some important hubs for research in buildings 373A, 381 and 343 called DTU Skylab, DTU Science Park and Fotonik respectively. And the biggest buildings for lectures are 303, 340, 341 and 358 among others. Building 358 is shared with offices together with 328 and 324.

  Moreover, there are three accommodations: William Demant Kollegiet, Campus Village and Hempel Kollegiet.

- **Sector 4**: Finally, sector 4 is located in the south-est, in front of sector 3 and divided by a parking lot, as happens between sectors 1 and 2. This sector has two accommodations: Villum Kann Rasmussen Kollegiet and Kampsax Kollegiet.

  Offices for educators are in buildings 426 to 423. Lectures are given in buildings from 421 to 413. And Campus service is located in building 402. This sector also has a supermarket, Netto, between the two accommodations.

Regarding the bike lanes on campus, nowadays there are located just in the surroundings and in street Anker Engelunds Vej, crossing the campus from east to west, as it can be observed in figure D.1. But in the following years more bike lanes will be included. Actually a whole redistribution of the campus plan will be done. [Universitet 2019c]

The street crossing from north to south (Nils Koppels Allé and Knuth-Winterfeldts Allé) will be a two-way cycle path with also wide areas for pedestrians. Cycle lanes will be added together with road traffic on streets Akademivej and Kollegiebakken, and the one on Nordvej will be completed (Figure D.2). Also a bike path has been projected by the municipality of Lyngby-Taarbæk via the Sustainability Fund, and will go from DTU to Lyngby St. This lane will have 2.3km and it is scheduled to be finished by September 2020.[C. V. Jørgensen 2020]

Moreover, parking for bikes will be established and distributed as shown in Figure D.3.

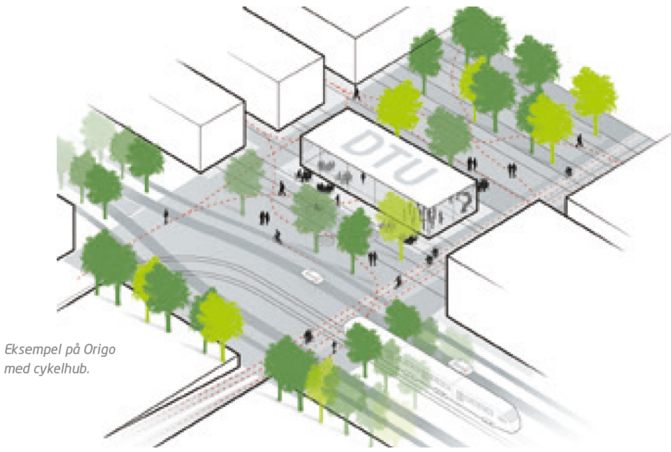
> Bicycle parking options are established, which relate to three levels on campus: the campus level, at the squares and at the local level. The three levels cover different needs. The solutions must signal that DTU appreciates that many people choose the bicycle as their daily means of transport. [Universitet 2019c]

On the other hand, transverse paths will be designed for pedestrians and bicycles, having the pedestrians the preference in these areas. (Figure 4.2)

Figure 4.2: Transverse paths for pedestrians and cyclists on campus.

Regarding the redistribution of the traffic, many car parking buildings will be created in the surroundings of the campus in order to avoid traffic inside (Figure D.6). In addition, the access to those parking lots that will still be located inside, vehicles will have only one access, as shown in figure D.5, depending on which parking are they going. For instance, for going to the parking lot located between sectors 3 and 4, streets *Anker Engelunds Vej* or *Akademikvej* will be the ones used to get into *Kollegiebakken* and arrive to *Vagn Aa. Jeppesens Vej* which will be the only access to that parking lot. The same will happen between sectors 1 and 2, but having access from two streets: *Nordvej* and *Lundtoftevej*.

Markets, hubs and bridges will be implemented to create more life on campus. These spaces are located around campus as shown in figure 4.3b. The most representative one will be Origo, between buildings 101 ans 202, being the main entrance of DTU (figure 4.3a).




(a) Origo.


(b) Market and gathering areas.

Figure 4.3: Projected markets and gathering areas on campus.

This new distribution is due to the arrival of the light rail and the desire of having a compact, sustainable and friendly campus, seeing the arrival of the light rail as an advantage and integrating it on campus life.

Figure 4.4: Sketch of light rail in Anker Engelunds Vej. [GPA n.d.]

In conclusion, scenario zero in this project is considering the arrival of the light rail and all changes that this will lead. Considering that buses from public transport will remain the same as nowadays, even if some will be rescheduled or eliminated. This is because there is a lack of information regarding which ones will be actually removed.

Location of new squares as gathering areas, bike paths and new bicycle and car parking buildings will be taken into account when designing the bike sharing system. So it will the new pedestrian and bicycle bridges, the electric network and the Service, Operation and Rescue network, in case of need establishing bicycle stations.

# 5 Methodology

This chapter is focused on explaining the process followed to elaborate the project, from data collection to the sustainability assessment. The objective is to have an overview of the process that has been followed and the research methods.

## 5.1 Data collection

For the feasibility assessment of a bike-sharing system, lots of different data are needed: The number of commuters, the percentage of people interested, the demand profile, the conditions for cycling, current modal split, existing transit, bicycle and pedestrian networks, and existing major attractions that will draw people to the area. [Gauthier et al. 2013]. To achieve all of them at once, the realization of a survey was chosen as a methodology, together with a deep research of the Campus Plan Strategy.

On the other hand, to evaluate the indicators, data collection is needed. This type of process has been different. It is based on articles, books, and web pages obtained through deep online research. Every document that has been used to assess or explain something of this project, it is mentioned in the bibliography (Chapter 12).

**Survey**

The survey has been developed with *Google Forms*. And was addressed to the whole DTU's population (DTU's professors, staff, and students) from both Ballerup and Lyngby campus. It is structured with different types of questions: multi-choice, drop-down, checkboxes, short answer, paragraph, time, linear scale, and tick box grid, as it can be observed in Appendix E. Being the multiple-choice and drop-down type the most frequent ones.

The information gathered is organized in sections. First of all, there is a section that obtains general data to generate a profile of the surveyed. This includes from aspects like age and gender to the distance they live from campus.

The second section is related to their interest in the bike sharing system. Here, after an explanation of the characteristics of the system, respondents are asked regarding the different fares and prices they would be interested in.

The third section is divided into two. The first one referring to their daily commutes, which have been asked by providing a tick box grid where they had to check the boxes that were representing their schedule. For profiles working or studying on Lyngby campus, a mapping of DTU with different sub-sectors was presented to group their answers and appeal to their memory (Figure 5.2), since it is easy to remember the location than the number of the building. And the second one was related to their hobbies in their leisure time. This question was focused on understanding the need of a bike network in the whole municipality of Lyngby.

Depending on their profile, questions were changing in order to get significant information and make it as short as possible for the respondents. The different paths that can be followed are presented on Appendix E, section E.1.

To obtain the maximum number of answers, different broadcasting methodologies were used. The main one was WhatsApp, the link was shared in different groups and asked to be shared with their colleagues. Facebook groups were also used to broadcast the survey, as well as the internal messaging tool of DTU inside. A massive diffusion through e-mail was done to reach professors and DTU's staff. And finally, an on-site diffusion was planned on both campuses, Ballerup and Lyngby, but due to the coronavirus lockdown, the latter method was impossible to perform.

The survey was opened for 43 days (almost one month and a half), and the curve of answers was continuously followed. Whenever the tendency of the curve was getting flat, more broadcasting was done, finally achieving 307 answers. (Figure 5.1)

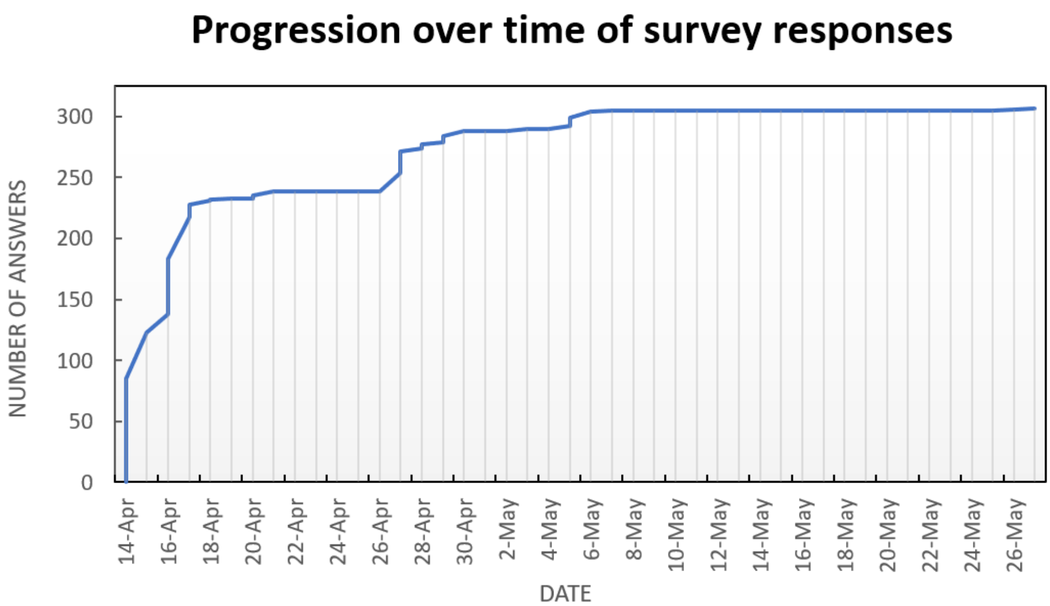



Figure 5.1: Progression over time of survey responses.

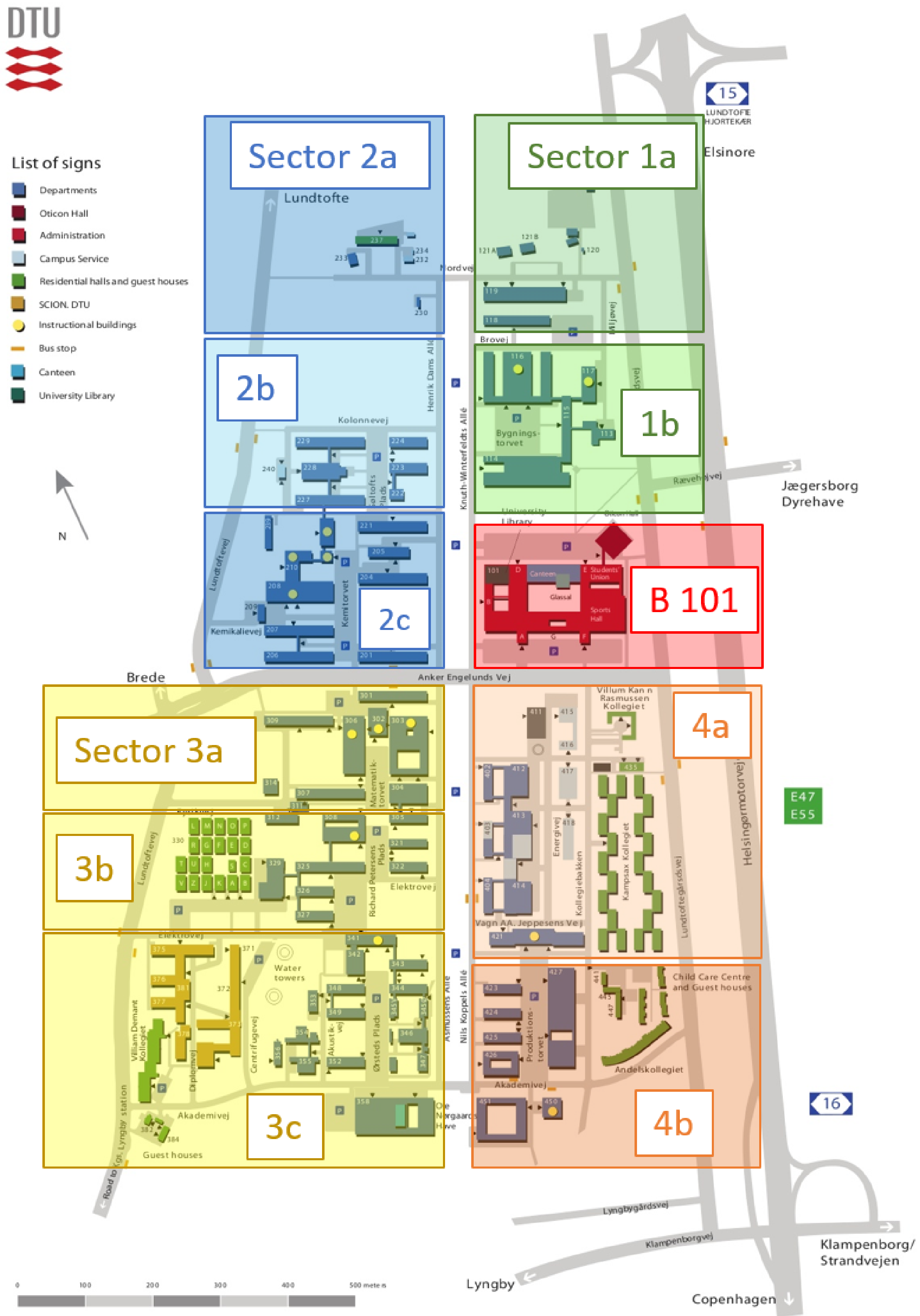



Figure 5.2: DTU's Lyngby campus divided into sub-sectors for the realization of the survey.

## 5.2 Data processing

Firstly, rough data obtained in the survey has been treated and transformed into the format needed for the mathematical model. The information was gathered in data sets that were divided with commas and square brackets. This data represents the commuting on campus and the transformation process has been carried out using the Microsoft Excel tool. Moreover, for the evaluation of the indicators, this tool has been employed to analyze the data obtained in the survey.

For processing the data sets and implementing the mathematical model, an optimization program is needed. In this project, IBM CPLEX Optimization Studio has been the tool chosen for that purpose.

Finally, to better understand the scenarios and the results obtained, some maps have been created with the ArcGIS Desktop tool.

## 5.3 Design

Phases one to three explained in section 3.3 are the reference to this design. However, the process will not be strictly followed.

The first step to design the bike sharing system will be the decision of the typology, which will be based on the characteristics of the area. This is going to be explained and developed in section 8.1.

Secondly, the design of the bike sharing system will be based on the results of the mathematical model (section 8.2). The outputs will be the number of bikes, number of ports needed at each node and amount of demand unmet. With these data some parameters like bikes per 1,000 inhabitants and trips per bike will be obtained to understand the market penetration and the infrastructure usage. (See figure 5.3)

Once the number of bikes and the minimum number of bike racks at each node is known, the calculus of how many stations are needed and its distribution over the sub-sectors will be done (section 8.3). Together with a financial estimation (section 8.4) that will be obtained with indicative values obtained from the bibliography consulted in section 3.3.

Finally, a sustainability assessment will be carried out to evaluate which of the three proposed scenarios is the most feasible from a social, environmental and economic perspective. These indicators will be based on results from the different phases mentioned above.

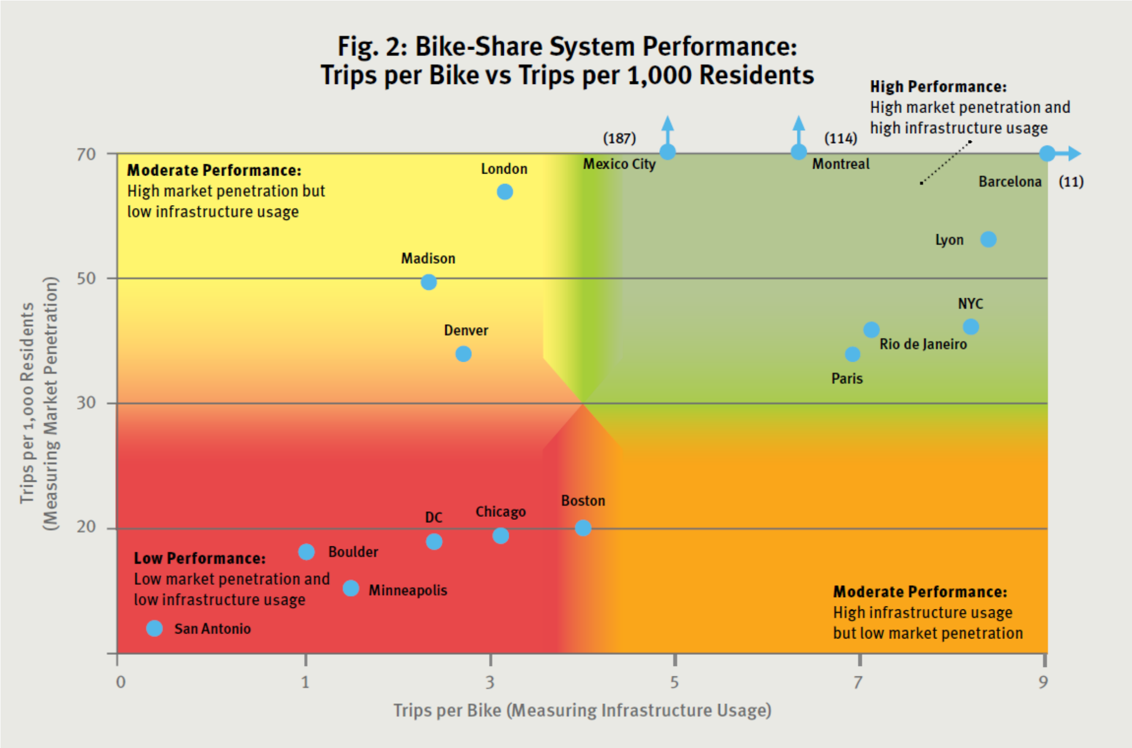



Figure 5.3: System performance based on trips per bike and trips per 1,000 residents. [Gauthier et al. 2013]

## 5.4 Sustainability assessment

DTU has a sustainability policy that aims to create ”functional, safe, and inspiring settings for good study and working life on its campuses”. Part of this policy is focused on mobility and strives for supporting green mobility and safe, accessible, and healthy infrastructure. [Munck 2019]

Therefore, the feasibility assessment of this project is made through a sustainability assessment, which according to Sala, Ciuffo, and Nijkamp 2015 is defined as follows.

> Sustainability assessment (SA) is a complex appraisal method. It is conducted for supporting decision-making and policy in a broad environmental, economic and social context, and transcends a purely technical/scientific evaluation.

The evaluation will be carried out through indicators that will be evaluated in a qualitative and/or quantitative manner.

### 5.4.1 Framework

The indicator framework is needed to properly define the analysis criterion and ensure that the preset objectives of the project will be reached.

In order to achieve an equitable evaluation, three indicators will be chosen for each pillar. And those indicators will be assessed by two or three sub-indicators. The process followed to obtain the indicator set can be explained in a few steps. These steps consider domain-based and goal-based framework methods presented by Masnavi 2007. And consists of two stages for the definition process, theory level (steps 1 to 5) and research level (steps 6 to 7).

1. Background research.

2. Benefits and disadvantages of a BSS from all three points of view (Social, environmental and economic).
3. Brainstorming.
4. Selection of the most adequate sub-indicators.
5. Group them into indicator sets.
6. Data collection.
7. Selection of the ones that are measurable either in a qualitative and/or a quantitative manner.

With a deeper analysis of domain-based and goal-based framework, it can be noticed that goals are the qualitative terms, while the indicators are the quantitative terms of the analysis. Using both methodologies, an evaluation with appropriate links between goals and indicators can be provided.

### 5.4.2 Scale assessment

To evaluate the indicators it is necessary to create a normalized scale in order to have a clear criterion when assessing. In this project, a scale ranging from -3 to 3 has been defined. The score ranges from worse outcome possible to the best one. Having a zero value for those scenarios where the indicator does not affect in the current situation.

- **-3**: the change applied will greatly worsen the current situation.
- **-2**: the change applied will worsen the current situation
- **-1**: the change applied will slightly worsen the current situation
- **0**: the change applied will not change the current situation
- **1**: the change applied will slightly improve the current situation
- **2**: the change applied will improve the current situation
- **3**: the change applied will greatly improve the current situation

# 6 Scenarios

Deciding the scope of the project is really important. Designing for a big area could be pretty expensive and do not give the benefits you could expect from the system. On the other hand, being too cautious could unnecessarily reduce revenue. For this reason, is important to assess more than one scenario using the same indicators and grading system.

Throughout this chapter, three scenarios are presented, with their limitations, novelties and theoretical advantages.

## 6.1 Scenario 1

This scenario is the most basic one. Aims not to be ambitious and to focus on solving the main problem of connectivity between buildings on campus and with Lyngby station. Therefore, the area of influence in this scenario will be DTU Lyngby campus and the main s-tog station in Lyngby (See Figure 6.1).


Figure 6.1: Area of implementation for scenario 1.

The idea is to establish bike stations in all sectors and in the two main bus stops: Rævehøjvej, DTU and Klampenborgvej (Helsingørmotorvejen). The reason why these two stops are so important is due to the large influx of people coming from Copenhagen. Figure 6.2, clearly reflects that almost 50% of students live in Copenhagen. The most forthright route to get to DTU from Copenhagen is the use of bus lines 150S or 15E. These two lines have two stops on campus, that are Rævehøjvej, DTU and Klampenborgvej (Helsingørmotorvejen).

To know how many bikes and stations are needed in each sector, the daily commutes of people around the campus were asked in the survey [Appendix E]. With this data it will be design the exact location and size of the parking stations and the number of bikes needed. Which is developed in chapter 8.

Despite the scenario aims to be small to avoid excessive initial investment. On the other hand, it is limiting the number of users interested and as a result, the incomes.

The expected outcomes, or advantages, of this scenario are the following.

- Simplicity; since the system is small, it is very easy for the user to understand where the stations are and where you can use the bike sharing system.
- Economy; because of its area, it is expected less amount of bikes and stations and therefore a smaller initial inversion.
- Social impact; it is expected to have a clear and fast impact after the implementation of the system.
- Environmental; aims to increase the use of public transpor and reduce the traffic of motorized vehicles on campus.

Although this scenario is not supposed to take into account the accommodations some of them are integrated in the campus, and therefore included in the study. However, are not taken into consideration as specific entry or exit, but as internal movements.

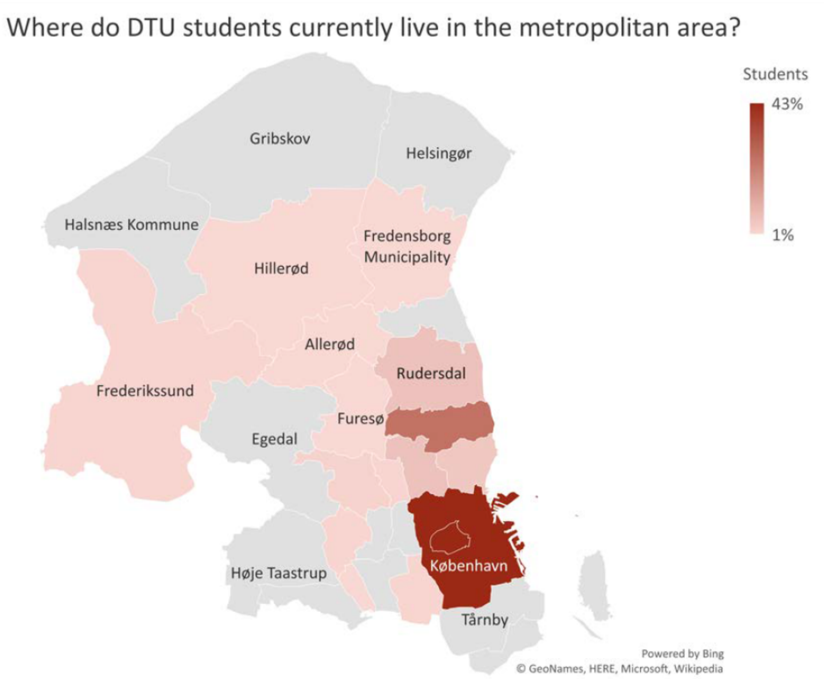



Figure 6.2: Where do DTU students currently live in the metropolitan area? [Apli 2019]

## 6.2 Scenario 2

Scenario 2 increases the area of study. Its objective is to include commutes of exchange students from their dormitories, what will increase the incomes. Hence, the area will be scattered around DTU. It will include the same areas as in Scenario 1, plus some of the DTU accommodations.

The decision of which accommodations will be included have been based on the following aspects stated below.

- The distance to DTU Lyngby campus,
- The percentage of rooms DTU owns at each Boligfonden DTU accommodation,
- Whether the accommodations is a student house or a dormitory, and
- The information obtained from the survey: if it is representative or not of the interest on the network, and the number of commutes obtained from each accommodation.

There are 4 types of accommodation. Student houses, which are houses rented to students and usually have a capacity of 4 to 10 people. Dormitories, which are large buildings where students have their own dormitory and usually share the kitchen with 10 other people. Studio apartments, which are rooms where the bed, the study table, and the kitchen are in the same space. And apartments, which are like student houses but in a building.

There are 32 accommodations offered by Boligfonden DTU (see table 2.1), of which 14 are student houses, 2 are shared apartments, 4 are studio apartments and 12 are dormitories. DTU owns 25 of the 32 accommodations offered. And from the other 7 that are shared, the percentage of rooms owned by DTU ranges from 4 to 50% of the dormitory's capacity (10 to 35 rooms).

Therefore, for this scenario some decisions have been made.

From the survey it is known that only 17% of people living in accommodations is minded to cycle more than 10 kilometers to go to campus (Figure 6.3). Moreover, micromobility solutions like the BSS are ideal for trips up to 10km, as mentioned in section 3.2. Therefore, it has been stated a limit area of 10km from Lyngby campus. This leaves only the accommodations that can be observed in Figure 6.4.

Regarding the students living in student houses (50% exchange - 50% general students) there is an interest in renting a bike to go to University that ranges from 27 to 36%. However, implementing a parking station is pretty expensive and locate it near a student house would not make it accessible except for the 4 to 10 people living there. In addition, student houses are usually located near dormitories, where it will be parking stations for renting a bike. Hence, student houses are not considered either in this scenario.

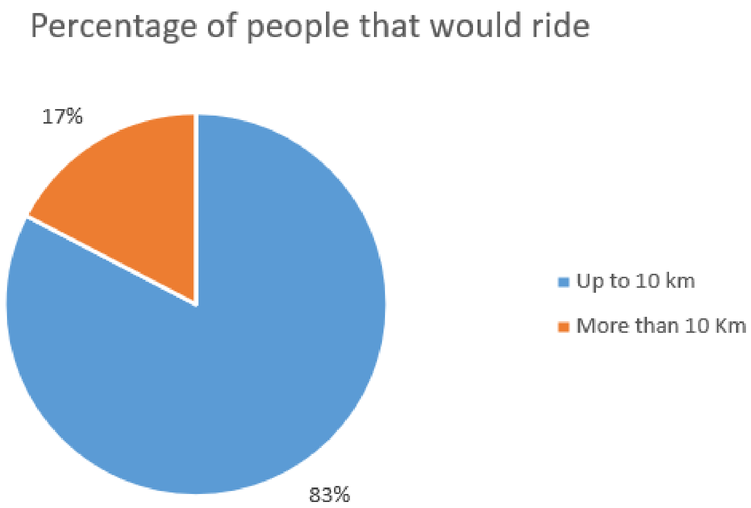



Figure 6.3: Percentage of people minded to cycle to university.

On the other hand, a future study when the system have been running for one year would be recommended. Above all, for those student houses on the western part of DTU campus.

Looking at the number of rooms owned by DTU on the dormitories left outside the campus: Kågså Kollegiet, Linde Alle Student Residence, P.O. Pedersen Kollegiet, Paul Bergsøe Kollegiet and Professor Ostenfeld Kollegiet. It can be observed in table 6.1 that from Kågså there are no answers and DTU owns only 5% of the dormitory. Hence it will not be considered due to the lack of data. Linde Alle is completely owned by DTU and it has had a representation of 5% in the survey, therefore it will be considered in this scenario. In the last 3 dormitories, DTU owns 10% of the rooms and there is around a representation of 7%, 9% and 18% respectively, of the total rooms owned by DTU. And represents around 1% of the whole dormitory. Thus, these three will be also considered in the study.

| | **Answers** | **Rooms owned by DTU** | **Representation** |
|---|---|---|---|
| **Campus Village** | 6 | 160 | 4% |
| **Hempel Kollegiet** | 1 | 200 | 1% |
| **Kampsax Kollegiet** | 4 | 521 | 1% |
| **Linde Alle Student Residence** | 16 | 300 | 5% |
| **Nordvej Student Residence** | 22 | 312 | 7% |
| **P.O. Pedersen Kollegiet** | 2 | 27 | 7% |
| **Paul Bergsøe Kollegiet** | 3 | 35 | 9% |
| **Professor Ostenfeld Kollegiet** | 5 | 28 | 18% |
| **Studio apartment Tåsingegade** | 3 | 22 | 14% |

Table 6.1: Number of answers from the different accommodations and its representativeness.

In regards to the dormitories located on campus, they are all included in this study although there are some without representation from the survey (Villum Kann Rasmussen Kollegiet and William Demant Kollegiet). Nevertheless, a parking station will be added based on the number of movements to that sector in general.

In conclusion, 10 stations will be added to the system:

- Campus Village
- Hempel Kollegiet
- Kampsax Kollegiet
- Linde Alle Student Residence
- Nordvej Student Residence
- P.O.Pedersen Kollegiet
- Paul Bergsøe Kollegiet
- Professor Ostenfeld Kollegiet


Figure 6.4: Boligfonden DTU accommodations located within a 10 km range.

## 6.3 Scenario 3

This scenario aims to increase the flow of people between Lyngby and DTU campus, supporting the idea of creating a student-friendly university town [Lyngby 2012] and the economic growth of the municipality.

To achieve this goal, some parking stations will be implemented around Lyngby. The decision of where locating them as been made from the results obtained in the survey. The questionnaire asked where they will go in their leisure time if they were on campus.

Some options where given, but also the possibility of an open answer. The options are stated below.

- Visit Lyngby
- Go to Lyngby Storecenter
- Watch a film at Lyngby's cinema
- Take the train and visit Copenhagen
- Go to the swimming pool
- Other ...

The open answer shows that many people goes to building 101, either for study in the library, do sport or go to the s-huset. Therefore the parking station in this building should ensure the availability of free ports. Other answers indicate the interest of many people for going to the dyer park, what could increase the 12-24h rentals.

Moreover, participants were asked whether they would take the bike to go to those places and if it would be probable that the frequency of their activities would increase with the implementation of the bike-sharing system. The answers show that 65% would take the bike and from those, 40% may increase the frequency.

In view of this data, it has been decided that from all these places it will be studied the movement to the following locations.

- Lyngby Hovedgade and Lyngby's library for those who want to visit Lyngby or the lakes,
- the Storecenter,
- the Cinema, and
- the swimming pool.

Moreover, Lyngby St. will be reinforced with extra ports in order to supply the extra demand of parking to go visit Copenhagen by train.

Finally, the area of study will be distributed as shown in Figure 6.5.


Figure 6.5: Area of implementation for scenario3.

# 7 Analysis of the demand

Having a good infrastructure is an important aspect to improve citizen's quality of life. But not only the infrastructure is necessary, different transportation systems are also needed to improve the connectivity between different places. And depending on the scale you are looking at, these connections can be between buildings, cities, countries or even continents. Therefore, to understand which systems and infrastructures are needed, it is important to have an overview of the demand within the area of study. In this section the demand of a bike sharing system is going to be analysed using the results obtained from a survey.

## 7.1 Representativeness of the survey

To obtain a representative sample from a known population, the Slovin's formula has been used.

$$n = \frac{N}{1 + Ne^2} \tag{7.1}$$

Where

- N is the size of the population, and
- e the margin of error of the sample, obtained from the confidence level which is normally assumed to be 95%

This formula states that for a population of 15390 inhabitants, considering a representativeness percentage of 95%, the size of the sample must be 390 inhabitants. Since the sample obtained at DTU has had a size of 307, the representativeness of DTU's population drop to 94.3% with a margin of error of 5.7%. Therefore, it can be concluded that for a sample to be representative of a population with these parameters, the number of answers needed must represent the 2% of the population.

The survey has return percentages from 1 to 3%, being the students the most represented (Table 7.1).

| | | | |
|---|---|---|---|
| **Students** | **(2018)** | 8653.5 | 3% |
| | **SURVEY** | 242 | |
| **Staff** | **(2020)** | 2919 | 1% |
| | **SURVEY** | 40 | |
| **Professors** | **(2020)** | 3818 | 1% |
| | **SURVEY** | 25 | |

Table 7.1: Representation of students, staff and professors in the survey.

Moreover, exchange students are considered to be 9% of students' population. From the students that have answered the survey, exchange students are the 10%, which assuming a ± 3% error can be stated that is clearly representative of reality (See table 7.2.

| | | | |
|---|---|---|---|
| **All students** | **(2018)** | 11538 | 9% |
| **Exchange students** | | 981 | |
| **All students** | **SURVEY** | 242 | 10% |
| **Exchange students** | | 25 | |

Table 7.2: Representation of exchange students in the survey.

On the other hand, the heterogeneity of the sample is another important aspect that must be taken into account. Gender, age and roles are important characteristics in our population that can state the heterogeneity of our sample. Results show that percentages of gender, for professors and students, concur exactly with DTU's statistics [Toft 2018]. Therefore, it can be also consider the results of staff, as representative gender values of the population.

| | **Survey results** | | | | | **DTU statistics** | |
|---|---|---|---|---|---|---|---|
| **Gender** | **Female** | | **Male** | | | **Female** | **Male** |
| | No. | % | No. | % | Total | % | % |
| **Exchange student at DTU** | 11 | 45.83% | 13 | 54.17% | 24 | – | – |
| **Professor at DTU** | 3 | 12.50% | 21 | 87.50% | 24 | 12% | 88% |
| **Staff at DTU** | 19 | 48.72% | 20 | 51.28% | 39 | – | – |
| **Student at DTU** | 84 | 39.07% | 131 | 60.93% | 215 | 38% | 62% |
| Total | **117** | | **185** | | **302** | | |

Table 7.3: Comparison between the survey's results and the parameters published by DTU regarding gender.

When comparing role with age distribution, it shows the most common ranges of age regarding its role. For instance, exchange students never exceed the age of thirty, being 18 to 25 its most common range. Students in general have a larger range, from 18 to 50 years, having some differences between genders. Professors start at 30 and is extended to more than 60 years old. Finally, the role of staff is the most heterogeneous one, going from 25 to more than 60.

Due to the wide ranges observed, it can be concluded that all roles are well represented when talking about age distribution.

| | **Female** | **Most common** | **Male** | **Most common** |
|---|---|---|---|---|
| **Exchange student** | 18 - 30 | 18 - 25 | 18 - 30 | 18 - 25 |
| **Professor at DTU** | 30 - 50 | 40 - 50 | 30 - More than 60 | 50 - 60 |
| **Staff at DTU** | 25 - More than 60 | 50 - 60 | 18 - More than 60 | 25 - 40 |
| **Student at DTU** | 18 - 40 | 18 - 25 | 18 - 50 | 18 - 25 |

Table 7.4: Age distribution of population obtained in the sample.

Finally, focusing on the role, it can be observed that students are majority in DTU with a 56% in front of 20% for staff and 24% of professors. Compared with the results, professors and staff have not answer as much as students, with proportions of 8%, 13% and 79% respectively. Therefore, the representativeness is not as good as expected in this field, but can be compensated by the other parameters.

## 7.2 Analysis

Different aspects of the demand are going to be analysed. First, the interest towards the Bike sharing system shown in the survey. Secondly, which type of demand do we have. And finally, the methods to forecast the data of commutes for designing the system.

In order to assess the potential number of users, the interest on different fares are going to be evaluated. 89% of population is interested at some type of fare. To know how many regular users the system will have, the focus has to be on the semester fares. This value shows that 44% will usually use the system. Moreover, 37% will use it sometimes, renting by minute, and 8% may do excursions using this system. (Table 7.5).

| | | |
|---|---|---|
| **Pay a fare per semester** | 177 | 44% |
| **Minute renting fare** | 148 | 37% |
| **12h or 24h renting fare** | 33 | 8% |
| **Not interested** | 45 | 11% |

Table 7.5: Interest on the different bike sharing fares.

The survey has shown that only 11% of population would not be interested in renting a bike from this system.

Therefore, it can be concluded that the interest in the system is pretty high. These results can be related to the huge amount of commutes that occur on campus. But in can also be pretty related with the low average age and the biking culture of Copenhagen.

Regarding the methodology to forecast the demand, the Institute for Transportation and Development Policy (ITDP) in one of its Guides for Bikeshare planning defines two methods [Gauthier et al. 2013].

1. To create a Price-Elasticity of Demand (PED) analysis according to various customer types.
2. To create an estimation of demand based on a percentage of the population, known as the uptake rate.

In this project, it has been decided to follow the second methodology. But, despite the positive result in the interest analysis, the system cannot be designed for such a high percentage of population.

> ...Paris saw a 6 percent uptake, meaning that 6 percent of the population used the system. (...) New York City ran three scenarios: a 3 percent uptake by the existing population, a 6 percent uptake and a 9 percent uptake... [Gauthier et al. 2013]
>
> Mexico City's Ecobici is close to 10%, which may be explained by the heavy commuter population that enters the service area (and uses Ecobici) but does not live within that area. [A. Cohen et al. 2018]

Due to the high interest shown and the large amount of commutes on campus, it has been decided to forecast the demand with a 10% uptake of population. Nevertheless, during the design stage, parameters as bikes per 1,000 inhabitants and Trips per bike, will be checked to ensure that this percentage is the appropriate.

# 8 Design

Throughout this section, it is going to be chosen the type of bike sharing system, the number of bikes needed, and the stations' location and size. Anything related to the number of bikes and stations will be calculated with a mathematical model explained and developed in section 8.2.

## 8.1 Typology

Throughout this section is going to be developed the characteristics of the system: type of system, type of bikes, fees offered, and specific details recommended.

**System model**

For this project it has been decided to choose a station-based system with e-bikes. The reasons are the following.

- The area of study is a university campus, which means that the number of young people is higher than in other places. Hence, the probability of being less careful and organized with bikes increases. In order to maintain an arranged landscape, station-based systems are the best solution.
- Moreover, stations can give a greater degree of service. For instance, bikes can remain dry by establishing ceilings over them, which in Denmark is an important aspect.
- Regarding the type of bikes, due to the location of the campus, those coming from Lyngby St. will experience a 4km uphill ride. Hence, for giving to users the option of working out or having a pleasant ride to get to university, and trying to gather the maximum number of users, a pedal-assisted bike has been chosen.
- On the other hand, it has been proved that people will ride longer distances if bikes are electric (Figure 8.1). Hereby, to obtain as many users as possible, and thinking in the accommodation's scenario (2), this bike has been considered the best option.

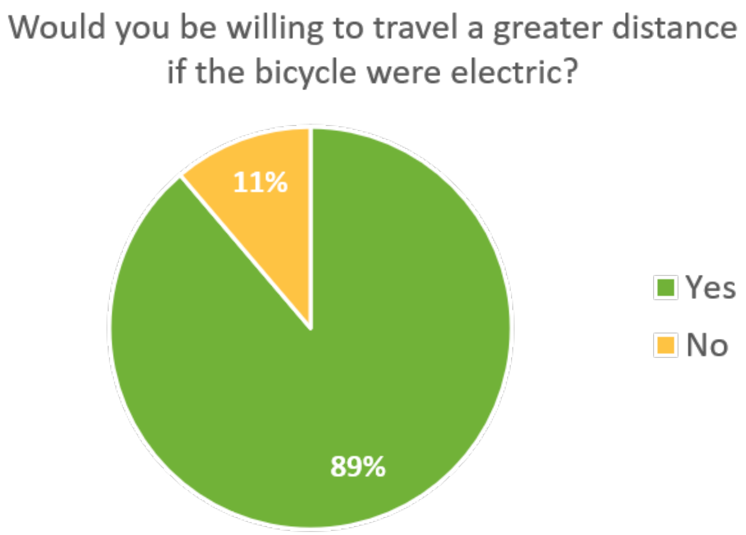



Figure 8.1: Assessment of whether e-bikes will increase user's travel distances. [E]

**Characteristics**
The system will offer payment through the app by credit card or in bike stations, both by credit card or by cash to include also exchange students without danish bank accounts.

The BSS will allow booking a bike 10 minutes in advance (paying a penalty fee in peak hours if they do not take it afterward). Once the bike has been unlocked the app will ask the user whether he wants to book a rack in their destination. The app will show a map with all stations and the number of racks available, so if the preferred station-destination is full, the user will be able to check nearby stations and choose to book one available rack. The time of the booking will be the google's estimation for the route plus 10 minutes to include all user's speeds. (Other options like 20 minutes on campus, 1h30' for accommodations and 30 minutes from campus to Lyngby can be also considered). Nevertheless, it will be possible to use the system without booking.

> We believe in the future, we will be able to increase the predictability of a scooter being available at certain times. In the meantime, it would greatly benefit users and MaaS operators if micromobility companies would support reservations of 15 minutes or so in advance. Even if the user's journey is longer than that, Iomob could at least automatically reserve a scooter within the 15 minute arrival time if the user requests this. [B. Cohen 2020a]

In the case of including accommodations, an option of locking bikes outside stations (Lock-to bikes) will be considered to avoid that after riding long distances they do not have racks available. This will release the system on campus and to promote the use of stations, the fact of locking them outside will have an extra cost of 20 dkk (This is an indicative value that must be studied and increased in case of not being effective). This option will turn the system towards an hybrid system.

The locking and unlocking process will be done by QR codes or DTU card. Therefore, stations must have the option of delivering cards for those paying a minute package without the app.

**Fees**
In reference to the fees offered, two groups will be made: casual and long-term users. Having different options inside these two groups.

**Long-term users:** Fees for long term were stated in the survey as 6-month fees. Prices were asked, ranging from free to more than 250 dkk. The percentage of users interested in this type of fees is 50% (See table 8.3).

Two sub-groups can be differentiated, Campus users and Accommodation users.

- Campus users: Answers in graph 8.2a show that for having the demand satisfied in more than 50%, the maximum price per semester should be between 100 and 150 dkk (satisfying 71% of the demand). Thus, to obtain the maximum revenue, 150 dkk per semester has been chosen as campus fee.
- Accommodation users: Since different fares are proposed to people living at accommodations, the graph varies (Graphic 8.2b), as it does the situation. Pricing for people in accommodations has to be competitive because it has to compete against private rentals of 175 dkk per month. These companies bring the benefit of owning a bicycle during that period. Hence, taking a look to the graphic, it can be observed that the most popular fee ranges from 100 to 150 dkk. Following the method of choosing the maximum value to get the most revenue, will leave a difference of 25 dkk with the competition. It has been considered that the risk of loosing users is

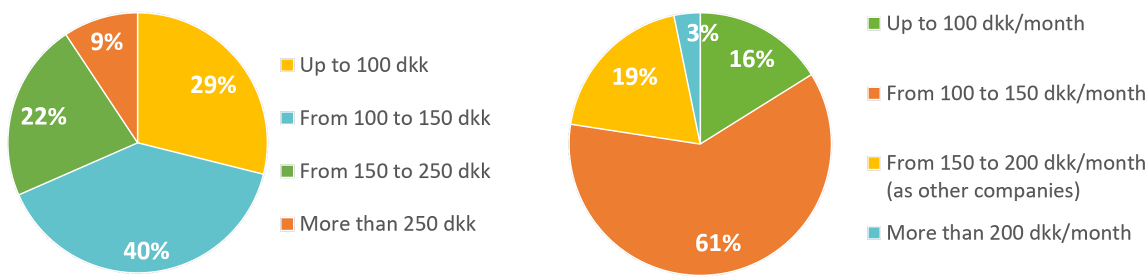
pretty big with such a small difference. Therefore, even if the revenue gets reduced, the price has been set to 100 dkk per month. With the decision, the whole population will be considered, and the difference of revenue is small (900 dkk/month) [Calculus explained below in table 8.1].

DTU's population is 15,400 people, for this system a 10% of population has been considered when designing. Hence 1,540 people, but only 10% are from accommodations, from those only 32% is interested in renting a bike, and just 67.7% is interested on monthly fees. Therefore, population interested is 105 people from accommodations.

| Users | Fee [dkk/month] | % population interested in that fee | Revenue [dkk/month] |
|---|---|---|---|
| 34 | 100 | 100 | 3,400 |
| 34 | 150 | 84 | 4,284 |

The difference is not big and will avoid that users choose the competition -884

Table 8.1: Calculus for deciding accommodation's monthly fee




(a) Survey question: If you are interested in a semester fare, how much would you be willing to pay per semester?

(b) Survey question: Given that the most popular renting company offers fares around 175 dkk/-month. What fare you would be willing to pay for DTU's monthly renting network (internal and external use)?

Figure 8.2: Survey graphs for deciding bike fees.

**Casual users:** Casual users are those who do not pay a semester or monthly fee, but do make use of the system by paying per minute or renting bikes for a period of time. There are two sub-groups:

- Minute renting: BSS usually offer rides with a first 30 minutes free. Considering that distances on campus does not take that long, and aiming to obtain some revenues, the minute renting fee has been based on Copenhagen's bycyklens. This is purchasing tickets that can be from 30 minutes to 4 hours, the greater the cheaper the minute of ride will cost. There are five packages, which are explained below [Bycyklen n.d.]. The interest of population on this type of fee, according to the survey results, is 41%.
  - 30 minutes: It costs 1dkk/minute (30 dkk in total).
  - 2 hours: 80 dkk package, which means 0.67 dkk per minute.
  - 10 hours: The package is 300 dkk and the minute 0.50 dkk.
  - 20 hours: The price is 500 dkk which means 0.42 dkk/minute.
  - 40 hours: Finally this package is 900 dkk, 0.38 dkk per minute.

- Period renting of 12 or 24 hours in a row. This renting aims to encourage users to take DTU bikes for day excursions. In order to be more economic than the minute fee, the 12 hours must be less than 300 dkk and the 24 hours less than 500dkk. Hence, it has been decided to state them to 225 dkk and 300dkk after comparing with a Copenhagen's bike rental shop (see table 8.2). The interest on period renting is the lowest, being the 9% of population.

| Timeslot | City Bike | City bike with a childseat | Electric bike | Family bike | Family bike premium | Helmet |
|---|---|---|---|---|---|---|
| **Up to 3 hours** | 90 | 120 | 200 | 450 | 500 | 40 |
| **Up to 6 hours** | 110 | 140 | 250 | 500 | 550 | 40 |
| **Up to 24 hours** | 120 | 150 | 300 | 600 | 650 | 40 |
| **2 days** | 180 | 210 | 400 | 850 | 900 | 50 |
| **3 days** | 230 | 260 | 500 | 1000 | 1050 | 60 |
| **4 days** | 280 | 310 | 600 | 1100 | 1150 | 70 |
| **5 days** | 330 | 360 | 700 | 1300 | 1350 | 80 |
| **6 days** | 380 | 410 | 800 | 1500 | 1550 | 90 |
| **1 week** | 430 | 460 | 900 | 1600 | 1650 | 100 |
| **Add day** | +50 | +50 | — | — | — | +10 |
| **2 weeks** | 600 | 630 | — | — | — | 170 |
| **3 weeks** | 700 | 730 | — | — | — | 210 |

Table 8.2: Copenhagen's bike rental shop (prices in dkk) [Bicycles n.d.]

Below, it can be observed the different percentages of population who is interested in each type of fee.

| Type of renting | Accomodations | Campus | Total interest per type [%] |
|---|---|---|---|
| **12/24h** | 8 | 25 | 9% |
| **Minute fee** | 10 | 138 | 41% |
| **Semester fee** | 22 | 155 | 50% |

Table 8.3: Interest on the different fees offered

It has to be considered that all these specifications are recommendations for this specific case considering the characteristics of the area of study and its population.

## 8.2 Mathematical model

### 8.2.1 Objective

The model aims to obtain the minimum number of bikes needed in the system so the supply of the demand can be ensured, while avoiding large parking stations.

Repositioning is not considered during the day. It will be done every night forecasting the demand for the next day based on the data gathered with the survey.

Moreover, it has to be mentioned that this model aims to obtain a rough estimation of the bikes needed by establishing some conditions. However, for a detailed solution, distances between stations, and therefore, priorities when fulfilling the demand, must be taken into account in the future.

### 8.2.2 Sets

V: Set of nodes. Made up of sub-sectors, bus stops and other points of interest depending on the scenario.

W: Set of all nodes, adding a source and a sink to the set V (V + 2 ).

T: Set of time steps. It includes the periods of time shown in table 8.4. It starts with value 2 and ends in t+1[1].

TS: All time steps, which include the set T plus a virtual time step for entering bikes in the system and other for taking them out to the sink.

| **Time step** | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Time of the day** | 8:00h | 12:00h | 13:00h | 17:00h | 20:00h |

Table 8.4: Time steps.

### 8.2.3 Parameters

$n$: Number of nodes in set V.

$source$: Node that works as a source of bikes during the first time step (n+1). It works as a virtual node since it actually does not exist.

$sink$: Node that works as a sink of bikes during the last time step. (n+2). It is also a virtual node to ensure all bikes arrive to the end of the process.

$t$: Number of time steps in set T.

$tstart$: First time step in set TS, representing the time step needed for the bikes moving from the source to the nodes in set V.

$tend$: Last time step in TS, representing the time step needed for the bikes moving from the nodes in set V to the sink. (t+2)

$d^t_{out_i}$: Theoretical demand going out of a node (i) at a time step (t).

$Cost_A$: Cost of including a bike in the system. [Cost/bike]

$Cost_B$: Cost of leaving the demand unfulfilled, either because of not having bikes available at the node or because there are no ports available to park them. [Cost/bike]

$Cost_C$: Cost of implementing a station. [Cost/bike]

Values chosen for these costs are related between each other. The prices are based on the ones stated in The Bikeshare Planning Guide [A. Cohen et al. 2018], where says that a bike with high technology can cost up to 2,000$, and a station can cost between 40,000$ and 50,000$. Considering that a medium size station has between 10 and 15 bikes, the cost per bike will go from 5,000$ to 3,000$ approximately. If the average is obtained (4,000$), it is exactly double of the cost of buying a bike. Therefore, in the model the cost A and C have been stated as 5 and 10 respectively. And the cost of unmet demand (Cost B) has been stated to 11, a bit higher than A and C to avoid large amounts of unmet demand. With this assumption it has been calculated a margin of error of 2.6%.

[1] t value explained in section 8.2.3.

### 8.2.4 Decision Variables

$x^t_{i,j}$: Number of bikes actually moving from node (i) to node (j) at time step (t).

$g^t_{i,j}$: Unmet demand from node (i) to node (j) at time step (t).

$s_i$: Minimum number of ports needed at each station to be able to park at each node and time step, the number of bikes we are serving ($x^t_{i_j}$).

$y$: Total number of bikes in the system.

### 8.2.5 Mathematical model

$$minimize \quad yCost_A + \sum_{t\in T}\sum_{i\in V}\sum_{j\in V} g^t_{i,j}Cost_B + \sum_{i\in V} s_iCost_C \tag{8.1}$$

$$s.t.$$

$$\sum_{i\in W}\sum_{j\in W} x^t_{i,j} = y \qquad \forall t \in TS \tag{8.2}$$

$$x^t_{i,j} = d^t_{outi,j} - g^t_{i,j} \qquad \forall t \in T, i \in V, j \in V\{i \neq j\} \tag{8.3}$$

$$\sum_{j\in W\{j=source\}} x^{t-1}_{j,i} - \sum_{j\in V} x^t_{i,j} = 0 \qquad \forall t \in TS\{t = tstart + 1\}, i \in V \tag{8.4}$$

$$\sum_{j\in V} x^{t-1}_{j,i} - \sum_{j\in V} x^t_{i,j} = 0 \qquad \forall t \in T\{t > tstart + 1\}, i \in V \tag{8.5}$$

$$\sum_{j\in V} x^{t-1}_{j,i} - \sum_{j\in W\{j=sink\}} x^t_{i,j} = 0 \qquad \forall t \in TS\{t = tend\}, i \in V \tag{8.6}$$

$$s_i \geq \sum_{j\in V} x^t_{j,i} \qquad \forall t \in T, i \in V \tag{8.7}$$

- (8.1) The objective function aims to minimize the number of bikes in the system, while penalizing the unmet demand and optimizing the size of the parking stations.
- (8.2) This constraint is defining variable $y$. Which is the number of bikes in the system. Hence, this number has to be the same in every time step.
- (8.3) Defines variable $x^t_{i,j}$ as the demand minus the unmet demand.
- (8.4,8.5 and 8.6) are equations for flow conservation. This means that everything that goes into a node has to go out at each time step. Equations (8.4) and (8.6) are specific for the entry and exit. These two are constraining the flow from the source to all nodes in the set V at time step 1 (the ones that are no source or sink), and from all nodes in set V to the sink at time step tend.
- (8.7) The last constraint is obtaining the minimum number of ports at each node to park all the bikes that are actually arriving to each node ($x^t_{i,j}$) taking into account also, those that stay in the node ($x^t_{i,i}$).

The model is not taking into account the capacity of each node, obtaining the number of bikes established by the demand. This is because the design is starting from zero and the nodes are wide areas, thus it has been decided to leave it free. Nevertheless, a capacity could be easily added to the model by limiting $s_i$ at each node or in general with a new capacity parameter ($s_i \leq capacity \quad \forall i \in V$).

The re-positioning is assumed to be done once at the end of the day. Repositioning is a big issue that every bike sharing system has. Some papers bring solutions to this problem with mathematical models, [Høyer 2015] and [Sayarshad, Tavassoli, and Zhao 2011]. But in this project, the repositioning is considered at the end of the day or very early in the morning.

### 8.2.6 Data sets

Data sets have been completely obtained from the data acquired in the survey. Commutes around campus have been obtained thanks to the schedule that respondents have provided. And the mean of transport they use to get to university has been obtained from the questions: ”How do you get to DTU”, ”In case of using diverse means of transport, how do you combine them?” and ”In case you take the bus 150S, which stop do you use more frequently?”. These data has been employed in all scenarios, but the differences between scenarios have modified it to adequate it to the case.

- **Scenario 1**: The list of mean of transport used by people just includes *Lyngby St*, *Rævehøjvej, DTU* and *Klampenborgvej (Helsingørmotorvejen)*. People going by car, their own bike, or on foot have not been considered as users of the network when entering or exiting the system.

- **Scenario 2**: To include people coming from accommodations, the data has been modified. In this scenario, the entrance and the exit of the system can be done from the three nodes stated in scenario 1 plus eight DTU accommodations: *Nordvej*, *Linde Alle*, *P.O. Pedersen*, *Kampsax*, *Campus Village*, *Ostenfeld*, *Hempel*, and *Poul Bergsøe Kollegiet*.

- **Scenario 3**: This scenario considers people’s commutes during their leisure time, namely when finishing their lectures on DTU campus. Therefore, the entrance to the system is the same as scenario 1, but the exit changes. Some facilities or interesting places are added: *Visit Lyngby*, *Storecenter*, *Cinema*, and *Swimming pool*. These four nodes are representing the answers obtained from the questions: ”During my leisure time on campus I usually like to ...” and ”Would you like to get there by bike?”. The answers considered where obtained from those who said yes to get there by bike. And the most common replies were the default answers presented in the survey: *Go home, Visit Lyngby, Go to Lyngby Storecenter, Watch a film at Lyngby’s cinema, Take the train and visit Copenhagen, and Go to the swimming pool*, together with open answers like *Visit the deer park* and *Go for a walk to Lyngby lakes*.

Once these decisions are understood, the process for the data treatment, which has been done with Microsoft Excel, has been carried out. This process is further explained in Appendix F. But it can resume in a few steps.

1. Primitive data is transformed into four tables per day. Corresponding to time periods 8-12, 12-13, 13-17, and 17-20.

2. Then, these tables are joined into 5 (each per weekly day).

3. Afterward, four lists with the mean of transport that is used by the respondent for exiting and entering in the system. And the times when this is done.

4. Pivot tables are created to analyse commutes, and finally data sets are obtained in the format required by IBM CPLEX Studio Optimization.

### 8.2.7 Results & interpretation

Results obtained after the process explained in section 8.2.6, have shown high number of docks at each station, above all in stations located in public transportation nodes (See Appendix F, tables F.10, F.11 and F.12). Therefore, data sets have been refined.

Commutes going from or to adjacent sectors, have been evaluated. Checking whether was faster going by bike or on foot (adding 5 minutes for locking and unlocking the bike) and eliminating or reducing those that were faster on foot. Thus, table F.9 has been obtained. As it can be observed, those trips that were faster by bike have been stated in the table as ”BY BIKE” and those on foot, as ”ON FOOT”. For cases where the travel time was the same, for the evaluation it has been considered half of commutes. This process has been included in step 5 explained in section 8.2.6.

After this calculus, the mathematical model has been run again. Obtaining new, but similar solutions.

- Docks have been reduced in most stations, being the general reduction around 20% of the initial calculus. The same has happened with the number of bikes in the system, which have been reduced around 15%.

  It has to be considered that stations can be relocated after some weeks of the implementation if the operator notices that some are inadequately located and no users are making use of them. However, this is only for an specific type of station, the modular ones. For other type it will be more difficult.

  > If a station location is found to be inadequate after it is built—as is sometimes discovered after some weeks of operation—modular stations can be fairly easily relocated to a place with better demand. Stations like this are also more easily scaled up or down, adding or removing docking spaces or racks as real usage is determined after opening. [Gauthier et al. 2013]

- Unmet demand takes place in its majority at 08:00 and 17:00 from and to transportation nodes respectively. Usually to and from sectors 3 and 4. This result makes sense considering the number of lectures that take place in those two sectors. And taking into account that it happens at peak hours when the most population is starting and finishing the day.

  With the new evaluation, unmet demand has slightly increased regarding the initial calculus. However, it is always around 20% of the theoretical demand (g/d = 20%).

  Due to the mathematical model limitations, unmet demand is now spread around campus, sometimes being big for long distances. Considering that our model only takes into account on repositioning at the end of the day, these problems can be solved by repositioning more than once (two to four as recommended by Shu et al. 2013).

  > when the total number of bicycles invested in the system is more than 30,000, frequent periodic redistribution does not add much to the number of bicycle trips supported by the system. Furthermore, a small number of daily redistributions (e.g., two to four) suffices, since more frequent redistribution will not add much to total supported bicycle trips. [Shu et al. 2013]

  Other solution could be painting some parking areas where bikes can be parked by paying an extra fare of 20dkk, if there is no space. Or stablishing ”corrals” where bikes can be dropped at specific times. The latter is a method used by Capital bikeshare to avoid complaints regarding empty or full docks [Maus 2016]. But this could lead into future problems of unmet demand if more bikes are not added to the system since it will work as a dockless system.

In order to design and fulfill the demand obtained from the data sets processed by the mathematical model, the greater number of bikes is going to be chosen for each scenario. This will mean that for quiet days like Fridays (see Appendix F, tables F.5, F.5 and F.5), there will be more bikes than those calculated by the model. Hence, it is logical to think that unmet demand will be reduced while still having an optimized bike-sharing system. On the other hand, unmet demand obtained for the busiest day of the week (usually Monday or Tuesday), will not increase either decrease since the number of bikes available will be exactly the one obtained from the model.

The number of bikes and docking stations decided for each scenario are the ones presented in table 8.6.

Market penetration is defined as trips per residents. And some parameters like Trips per bike per day, bikes per 1,000 residents and trips per 1,000 residents can help assessing this aspect. Table 8.5 shows the results obtained in each scenario for these parameters. It is considered a good market penetration when

- Trips per bike per day should be between 4 and 8.
- Bikes available per 1,000 residents should range from 10 to 30.
- Trips per 1,000 residents does not have a clear range, but systems with high market penetration like Mexico has 105, being this value the highest between the systems analysed in A. Cohen et al. 2018. And a lower value will be around 10 bikes per 1,000 residents.

DTU population: 15400

| | **Scenario 1** | **Scenario 2** | **Scenario 3** |
|---|---|---|---|
| **Trips/bike/day** | 5 | 5 | 6 |
| **Bikes/1,000** | 26.1 | 28.1 | 28.8 |
| **Trips/1,000** | 139.4 | 153.7 | 171.9 |

Table 8.5: Market penetration

As it can be observed, all three scenarios would be well introduced into the market if assumptions taken are correct (e.g. 10% of population will make use the system).

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Number of bikes** | 402 | 432 | 443 |
| **Docks** | | | |
| **Rævehøjvej, DTU** | 157 | 79 | 43 |
| **Klampenborgvej** | 39 | 33 | 24 |
| **Lyngby St** | 158 | 176 | 202 |
| **S1a** | 11 | 12 | 29 |
| **S1b** | 21 | 27 | 33 |
| **B101** | 157 | 170 | 162 |
| **S2a** | 12 | 12 | 11 |
| **S2b** | 11 | 11 | 6 |
| **S2c** | 37 | 37 | 34 |
| **S3a** | 82 | 94 | 61 |
| **S3b** | 37 | 34 | 54 |
| **S3c** | 85 | 85 | 101 |
| **S4a** | 24 | 26 | 44 |
| **S4c** | 12 | 12 | 23 |
| **Nordvej S.R.** | – | 70 | – |
| **Linde Alle S.R.** | – | 28 | – |
| **P.O. Pedersen K.** | – | 6 | – |
| **Kampsax Kollegiet** | – | 6 | – |
| **Campus Village** | – | 7 | – |
| **P. Ostenfeld K.** | – | 6 | – |
| **Hempel Kollegiet** | – | 6 | – |
| **Poul Bergsøe K.** | – | 2 | – |
| **Visit Lyngby** | – | – | 25 |
| **Storecenter** | – | – | 70 |
| **Cinema** | – | – | 6 |
| **Swimming pool** | – | – | 23 |

Table 8.6: Number of bikes in the system and docks per area of study.

## 8.3 Distribution of the stations

When deciding how many stations are necessary and where to locate them, some parameters must be taken into account. These parameters are the station density and the docks per bike. Before assessing these aspects, it has to be decided where stations are going to be located. The optimum characteristics are presented below.

| On sidewalk | On street |
|---|---|
| • Sunny, minimal tree cover<br>• At least 2 meters of clear walking space<br>• Close to intersections<br>• Close to public transit stations<br>• High-visibility area and street lighting<br>• Easy access for users, as well as maintenance and rebalancing vehicles<br>• Close to bicycle infrastructure | • Close to intersections<br>• Close to public transit stations<br>• High visibility and street lighting<br>• Low volume of cars, low speed limits<br>• Adjacent to bicycle infrastructure<br>• Not blocking manhole cover, storm drain, etc. |

Table 8.7: Ideal station location characteristics. [A. Cohen et al. 2018]

Following these instructions and taking into account the characteristics of scenario 0 (light rail, new bike lanes and bridges), some locations have been chosen as it can be observed in figures F.1, F.2 & F.3.

Considering this data and calculating the area of influence at each scenario, the market penetration can be assessed. (Table 8.8) The station density must be between 10 and 16 stations per square kilometer, and the number of docks per bike in medium and large systems are recommended to round from 2 to 2.5.

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Docks/bike** | 2.10 | 2.17 | 2.15 |
| **Area [sq. km.]** | 1.9 | 14 | 2.3 |
| **Stations** | 20 | 28 | 25 |
| **Station density [per sq. km.]** | 10.5 | 2.0 | 10.9 |

Table 8.8: Market penetration from station point of view

As observed, all docks per bike are withing the range, but regarding the station density, Scenario 2 is outside the range with a very low value of 2. And even if scenarios 1 and 3 are within the range, they are pretty near to the lower limit.

### 8.3.1 Software

The software is an important aspect to take into account when designing a micromobility solution. Everything works through an application. Choosing the fee, booking a bike, starting/ending rental, and the payment between others. Therefore, it is interesting to know which options are available that can make the operator save some money.

For instance, there are many ”white label” apps that let you customize the interface. These apps already include the basic functions needed to make the system work. Velvioo and Devathon are two examples of apps that are already assembled. The operator just has to change the interface and introduce the codes of the equipment (bikes in this project). This brings many advantages: The app is working in a few weeks rather than months. It is more affordable than hiring a third party. The payments are received by credit cards. It has inbuilt analytics. It is already prepared for both Android and IOS. And finally, there is free support.

Velvioo offers an app that does not need to code anything. It is a customizable, self-service and data-driven app. As they say, made by operators to operators. It includes analytics to get an insight of the market and being able to understand business behavior. The functioning is very simple as it can be seen in figure 8.3.


Figure 8.3: How Velvioo app works. [**Velivoo**]

Devathlon is the app that companies like LIME, BIRD or BOUNCE are using. It is pretty similar to Velvioo. It brings the opportunity of customization and analytics. And the cost is one time 999$ or monthly 99$ plus 5$ per vehicle added to the system.

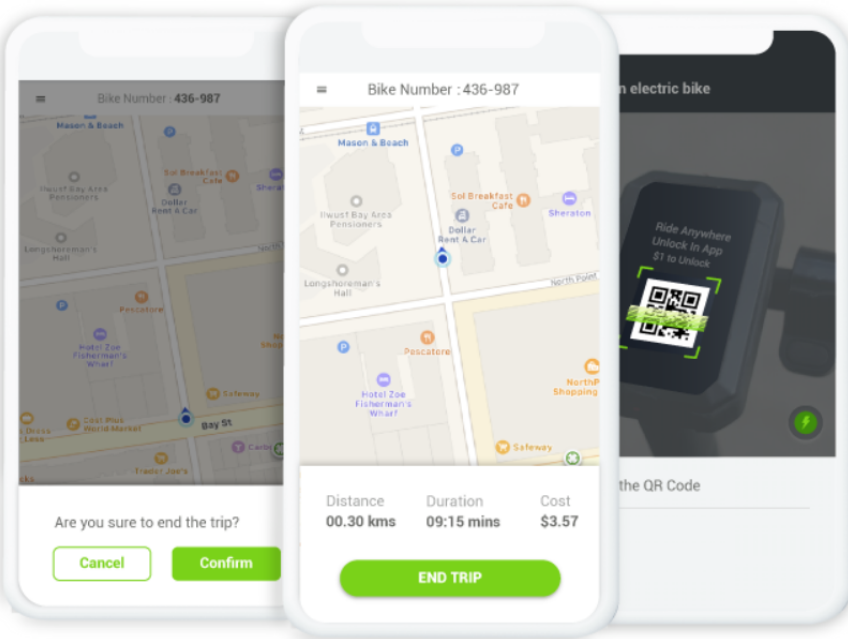



Figure 8.4: How Devathon app looks like to customers. [Devathon n.d.]

On the other hand, it exists the option of developing your own app. But this will be more time consuming, which will lead to a late release. And it is more expensive because of the hours of the workforce needed.

## 8.4 Cost estimate

In order to obtain a rough estimation of the costs, the capital costs and expected revenue from fees offered have been calculated.

Capital costs include the price of bikes and stations. Rebalancing vehicles or equipment and the control center must be included in a more detailed budget. Operational costs include rebalancing and staff. This cost has not been obtained because the range is too wide and changes from country to country [A. Cohen et al. 2018].

Revenues consist of incomes from long-term and casual users. Sponsorships, government funds, advertisements, etc have not been considered because are very variable numbers.

There are two long-term fees has stated before. One for accommodations (100 dkk/-month) and other for the campus (150 dkk/semester). The calculus has been done over the 50% of population in Scenarios 1 and 2. Scenario 3 has been divided into two groups: 90% with campus fee and 10% with accommodation's fee. To the first one a 48% has been applied. For the latter, over the 32% of people interested in renting, it has been applied the 55% that interested in long-term fees. After summing them, a 10% has been applied because is the percentage of population considered interested in the system.

For casual users, some assumptions have been necessary. The same calculus as before has been carried out, but with different percentages. Scenarios 1 and 3 with a 41%. Scenario 2, for campus a 44% has been applied and for accommodations 25% over the 32% commented.

Moreover, it has been obtained from which amount of trips per month a long-term fee is more profitable considering an average trip of 9 minutes (Table 8.9). Different time horizons have been presented depending on the package. For the evaluation, a 1 year horizon has been chosen for doing the comparisons. Therefore, the 2h and 10h packages are the ones in that group. The 2h package has been chosen for the revenue calculations because it is cheaper and therefore a conservative decision. And the 10h package has been used for the accommodation's minute fee (Scenario 2).

| **Packages offered** | **Cost of the package [dkk]** | **Trips/semester (Assuming an average trip of 9 minutes)** | **After how many trips/month the long-term fee is more profitable in a time horizon of 1 year?** | **Time horizon** |
|---|---|---|---|---|
| **30 min** | 30 | 3.3 | 2.78 | 6 months |
| **2h** | 80 | 13.3 | 4.17 | 1 year |
| **10h** | 300 | 66.7 | 5.56 | 1 year |
| **20h** | 500 | 133.3 | 6.67 | 2 years |
| **40h** | 900 | 266.7 | 7.41 | 3 years |

Table 8.9: After how many trips per month the long-term fee is more profitable in a time horizon of 1 year?

| BUDGET | | | | |
|---|---|---|---|---|
| | **Scenario 1** | **Scenario 2** | **Scenario 3** | |
| **Capital costs (CC)** | | | | |
| **Bikes** | -3,823,020 | -4,108,320 | -4,212,930 | dkk |
| **Stations** | -5,706,000 | -7,988,400 | -7,132,500 | dkk |
| Rebalancing vehicles | - | - | - | |
| Control center | - | - | - | |
| **Revenues (R )** | | | | |
| Funding/sponsorship/advertisement | - | - | - | |
| **Long-term campus** | 231,000 | 207,900 | 231,000 | dkk/year |
| **Long-term accommodations** | - | 40,035 | - | dkk/year |
| **Minute renting** | 101,024 | 90,921 | 101,024 | dkk/year |
| **Minute renting accommodations** | - | 7,392 | - | dkk/year |
| **TOTAL revenue [dkk per month]** | 332,024 | 346,248 | 332,024 | dkk/year |

Table 8.10: Financial estimate

# 9 Development of indicators

Thorough this section, the data collection and evaluation of each indicator is going to be explained. There are nine indicators in total, three per each pillar of sustainability: social, environmental and economic. All indicators will have sub-indicators that will cover different aspects related to the indicator.

Moreover, to decrease subjectivity on the assessment, a few interviews have been carried out, asking them to grade the sub-indicators within a goal-based framework. The purpose, decreasing the weight of the subjective assessment.

On the other hand, domain-based indicators can be measured following the SMART methodology [Gudmundsson et al. 2016] (Specific, Measurable, Attainable, Relevant, and Timely) and therefore, giving more precise and objective results.

## 9.1 Indicators framework

In order to reach a sustainable based solution, the three pillars of sustainability and their interdependence have been considered (Figure 9.1). And the indicator framework has been developed following the methodology explained in section 5.4.1.


Figure 9.1: Sustainability pillars

Nine indicators (three per pillar) have been considered necessary to evaluate the feasibility of the project, as well as the accuracy of the scenarios. These indicators include from two to three sub-indicators each to complete the evaluation and cover as many related aspects as possible.

When possible, a combination of domain-based and goal-based framework has been used to reach the maximum accuracy of each indicator. The objectives followed for the realization of the framework are focused on the three pillars of sustainability. A bike sharing system has to reduce travel times, increase the value of the university, and be inclusive. Moreover, it has to improve mobility and health. Finally, enhances economic growth and prestige, while being affordable for the users and the operator.

| | Description | Measurement | Evaluation |
|---|---|---|---|
| **Inclusion** | The indicator will evaluate how much impact would have a BSS within inclusion. | Use of station density. | Negative=worst impact, 0=Steady, Positive=better impact |
| **Quality of life** | How the living conditions will vary with the implementation of a BSS | Travel times (Google), on foot travel times on campus (Survey), Fees (Survey) | Negative=worst impact, 0=Steady, Positive=better impact |
| **Values** | How the BSS can bring value to the university ans its users | Number of stations, number of parking lots, number of bike lanes and streets, number of buildings | Negative=worst impact, 0=Steady, Positive=better impact |
| **Healthiness** | Health benefits that the BSS can provide to its users. | % of interest in long-term fees, 12/24h renting fees | Negative=worst impact, 0=Steady, Positive=better impact |
| **Mobility** | Assess the improvement on mobility. | Number of Public transport stops, means of transport used by population (Survey), distance to DTU (Survey), benefits users will experience from using the network (Survey) | Negative=worst impact, 0=Steady, Positive=better impact |
| **Awareness** | Measures the awareness towards environment. | benefits users will experience from using the network (Survey), car sharing (Survey) | Negative=worst impact, 0=Steady, Positive=better impact |
| **Investment** | Measure whether investments are reasonable or not regarding the size of the system | Station price estimation, user fee incomes, expected number of repositioning per day | Negative=worst impact, 0=Steady, Positive=better impact |
| **Economic growth** | Economic impact of the BSS on DTU | Minimum number of employees to run the system, location of canteens (Campus Plan), location of stations | Negative=worst impact, 0=Steady, Positive=better impact |
| **Prestigious** | How the image of DTU can be affected by a BSS | Number of universities with BSS implemented | Negative=worst impact, 0=Steady, Positive=better impact |

Table 9.1: Description of indicators and the measurements needed to evaluate them

# 10 Data collection and evaluation

## 10.1 Social Indicators

### 10.1.1 Inclusion

Northern countries are well known by its cycling culture,

> Netherlands, Denmark and Germany have made bicycling a safe, convenient and practical way to get around their cities. (...) Extensive cycling rights of way are complemented by ample bike parking, full integration with public transport, comprehensive traffic education and training of both cyclists and motorists, and a wide range of promotional events intended to generate enthusiasm and wide public support for cycling. [Pucher and Buehler 2008]

Moreover, "biking" is one of the most usual topics in a conversation, at least between foreign students. Usual questions between the students of DTU are: Do you ride your own bike? Have you tried the new e-bike sharing system? Does it make your commute to university way easier?. And this is because, using a bike gives you the freedom of movement. It is the perfect mean of transport for short distances since it is faster than some public transportation, commonly cheaper and covers parts of the city that does not have a proper connection.

Therefore, people end up using a bike. But what if you do not know how to ride a bike? Bicycles from bike sharing systems are very stable and easy to use, what can help the most fearful people to try. And it helps people to *become more mobile, independent, confident, and empowered [Jennings 2018]* as it has been proven in Amsterdam city with the Mama Agatha's course.

**Social inclusion**

**Description:** This indicator aims to assess any improvement of social inclusion derived of the implementation of a bike sharing system. It is believed, that cycling can be a way of bridging cultural differences. People that participated in the documentary of Mama Agata, stated that cycling provides empowerment and societal inclusion. [Jennings 2018]

> "The physical mobility cycling provides, actually comes with social mobility and personal freedom." [Goodyear 2015]

The World Bank Group defines social inclusion as [Group n.d.]:

1. The process of improving the terms for individuals and groups to take part in society, and
2. The process of improving the ability, opportunity, and dignity of those disadvantaged on the basis of their identity to take part in society.

In Copenhagen, a female foreign student tells how difficult it was for her to attend the meetings with her friends without knowing how to ride a bike. "It is a new culture, new friends, and you need to adapt up to some extent if you want to consolidate a group". Therefore, her landlord lent her a bike and she learnt how to ride by herself. Nowadays, she has her own bike and is very happy with the freedom of movement it gives to her. "You can go anywhere faster than with public transportation, you can meet up with friends and do excursions. I am glad I have learnt".

**Calculus method:** The indicator will be graded based on how much impact would have this service within social inclusion on the different scenarios.

1. Scenario 1: On-campus there are always new students from different nationalities, seeking new friends. During the firsts weeks you are new, do not know how the public transport works or how long it takes to arrive to the next lecture. A bike sharing system established on campus, could help those students to easily move around, get to know their surroundings, and feel more comfortable in their new home. Moreover, while renting a bike is a perfect excuse to talk to someone, ask them regarding how it works, where is the building you are looking for. This will make a connection and at least you will smile at each other next time you meet if not becoming friends.
2. Scenario 2: Including the accommodations would not but increase this phenomenon. People living next to each other will meet on the stations everyday and if you are doing the same commute, why not starting a conversation?
3. Scenario 3: Going to the cinema, the mall or the swimming pool is more fun with friends. Establishing stations on these places will help to meet people with the same hobbies. Moreover, in these places it is more probable to meet people from outside university, increasing your network and being more included in the local community.

**Numerical evaluation:** The grading in this indicator is attached to subjectiveness, hence four people has been asked to grade it. The results are:

| | **Scenario 1** | **Scenario 2** | **Scenario 3** |
|---|---|---|---|
| **Person 1** | 1 | 2 | 2 |
| **Person 2** | 1 | 2 | 3 |
| **Person 3** | 2 | 2 | 1 |
| **Person 4** | 1 | 2 | 1 |
| **Result** | **1.25** | **2** | **1.75** |

Table 10.1: Social inclusion evaluation for three scenarios

#### Meeting point

**Description:** When meeting, having clear references to find your friends is very important. Everyone uses popular shops, restaurants or public transport stops to meet up with their companions, but having a bike-sharing station can be an interesting meeting point. Because you may use it later when you are together to visit a place, or probably some of your colleagues are going to arrive by using this system. These stations are very visible, they are well announced, and normally, are called and located near the most representative thing of the street. Moreover, they are covered to remain bikes dry and there is plenty of space for meeting. According to Cambridge dictionary a meeting point is *"an area in a large public place, such as an airport or station, where people can arrange to meet" [Cambridge-dictionary n.d.]*, which can be applied to bike stations and its surroundings. This indicator aims to assess how beneficial these stations can be in each scenario.

**Calculus method:** Every scenario is going to be evaluated to have an understanding on how those stations can help people socialize.

1. Scenario 1: On campus is pretty easy to arrange meetings. The most usual place is at the door of any building, but sometimes there is more than one door, which can lead to confusion. The stations for bike sharing are normally located near to the

main door, and since it will be geolocated with the mobile app, it will eliminate those few misunderstandings.

2. Scenario 2: In the case of including the accommodations, the bike sharing stations will create a new and interesting meeting point. People living in those accommodations may meet before going to their lectures, and if using the system, which place better than the station itself. Moreover, it will make visitor's life a bit easier, since DTU accommodations usually have the same look from the outside and it is difficult to get oriented if it is the first time you go there.

3. Scenario 3: In the street is very important to have references, and the stations can help a lot to find a friend or an establishment. Moreover, it will be very useful when meeting for going to the cinema, the swimming pool or any other facility where you prefer to wait for your companions before going in.

**Numerical evaluation:** The assessment is based on the observations mentioned above. It can lead to subjectiveness, hence the same method as before is going to be used. Four people will evaluate the scenarios and the average will be taken.

| | **Scenario 1** | **Scenario 2** | **Scenario 3** |
|---|---|---|---|
| **Person 1** | 1 | 3 | 3 |
| **Person 2** | 3 | 2 | 1 |
| **Person 3** | 2 | 3 | 1 |
| **Person 4** | 2 | 2 | 1 |
| **Result** | **2** | **2.5** | **1.5** |

Table 10.2: Meeting point evaluation for three scenarios

**Accessibility of the system**

**Description:** A bike sharing system is accessible to everyone, but it does have some exemptions. There are age restrictions (users generally need to be more than 16 years old). Moreover, some systems only accept payments by credit cards. And there is a big handicap for those with some disabilities that cannot reach this type of service because of the limitations of the system or just due to its own physical limitations. For instance, a deaf person would be able to use the system, but not a visually impaired one. The same happens with people with mobility disability, some special bikes could be included to the system in order to decrease the number of people without access. But these special bikes are not being considered in this assessment, even though the possibility of doing it in the future should be studied.

Another aspect that should be included in the accessibility evaluation, is the distance between stations or the density per square kilometer. Being from 250 to 300m the most recommended distance, and from 10 to 16 stations per square kilometer [A. Cohen et al. 2018]. In section 8.3 the stations have been designed and organized. Therefore it can be evaluated whether it is accessible or not using these parameters.

**Calculus method:** The indicator seeks to measure the accessibility impact of a bike-sharing system on people. Despite not everyone will have access, it will not affect negatively either to their current situation. On the other hand, it will have a good impact in part of the population, because their transport possibilities will be increased with the implementation of a bike sharing system.

On the other hand, from the point of view of the stations density, the evaluation will follow a criterion where 0 will be a situation without bikes. Because the current accessibility situation cannot worsen with the implementation of a bike sharing system. And the values from 1 to 3 will be assigned as follows:

- 1 if density is equal or lower than 10 stations, or whether distance between stations is equal or greater than 500 meters.
- 2 if density is in between 10 and 15 stations, or whether distance between stations is around 250 to 500 meters.
- 3 if density is equal or greater than 15 stations, or whether distance between stations is equal or less than 250 meters.

**Numerical evaluation:** The numerical assessment for this indicator is +2 for scenarios 1 and 3, and +1 for scenario 2. Results according to table 8.8 and the evaluation mentioned above.

| Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|
| +2 | +1 | +2 |

Table 10.3: Evaluation of accessibility for the three scenarios

### 10.1.2 Quality of life

The Organization for Economic Cooperation and Development (OECD) uses eleven indicators to measure the quality of life in each country. These are housing, income, jobs, community, education, environment, civic engagement, health, life satisfaction, safety and work-life balance. Depending on the country, the importance that people give to each indicator is different. Generally in Europe, health, education and environment have been stated as the most important aspects to people. [Economic Cooperation and Development 2016]

Denmark's quality of life index is above the average stated by the OECD in many aspects, except income and wealth. Nevertheless, its average grade is 7.6 which is higher than the OECD average of 6.5 [Economic Cooperation and Development n.d.]. Either way, quality of life is an aspect that can always improve and the aspects that define it, are in continuous change.

According to Britannica dictionary, the term "quality of life" has two senses:

> The term quality of life (...) can refer both to the experience an individual has of his or her own life and to the living conditions in which individuals find themselves [Britannica n.d.].

This indicator aims to evaluate the second part of the definition, how the living conditions of DTU's population will vary with the implementation of a bike sharing system. To meet this purpose, three sub-indicators are going to be assessed: time saving, accessible pricing and traffic.

**Time saving**

**Description:** Nowadays time is precious, and many people prefer to use a non-sustainable way in their daily commutes in order to arrive as fast as possible to their destination. However, with the implementation of micromoblity solutions, like the bike sharing system, the time of many commutes gets very similar to motorized vehicles, that due to traffic jams can become slower.

The implementation of this system will help improve not only access to public transport but also the communication between buildings. It is considered that the average speed on foot is 5 km / h, while cycling at a moderate speed is 20 km / h. Hence, the use of bikes will lead to reducing the travel time by approximately 75 %.[Kaloc 2018]

**Calculus method:** This indicator aims to measure the impact of establishing a bike sharing system in time saving. To measure how beneficial it can be, the time it takes on foot or by public transport will be compared to the time it will take using a bicycle. Five minutes will be added to the bicycle trip to take into account the unlocking and locking of the bike. The data will be obtained from Google Maps or, for the displacements on campus, from the answers of the survey.

**Numerical evaluation:** Each scenario will be assessed independently since distances are different. The numerical evaluation will be negative if travel time is increased with the use of the bike, zero if there is no change, and positive if it gets reduced. For both the increase and the decrease, up to 25% will be $\pm$ 1, from 25 to 50% $\pm$ 2 and greater than 50% will be $\pm$ 3.

1. Scenario 1: To evaluate if the bike sharing system will reduce commuting times, the results from the survey have been consulted. On DTU Lyngby campus, people spends an average of 16 minutes walking around campus, being the maximum time 53 minutes and the minimum 2 minutes (Graphic 10.1). Considering that bike trips can reduce this time by 75%, the average trip will be done in 9 minutes, 4 minutes for the trip and 5 minutes for locking-unlocking the bike. Therefore, the positive impact is pretty clear. Travel time is reduced almost to half to what it will take on foot (44% of reduction). And hereby, numerical evaluation is (+2).

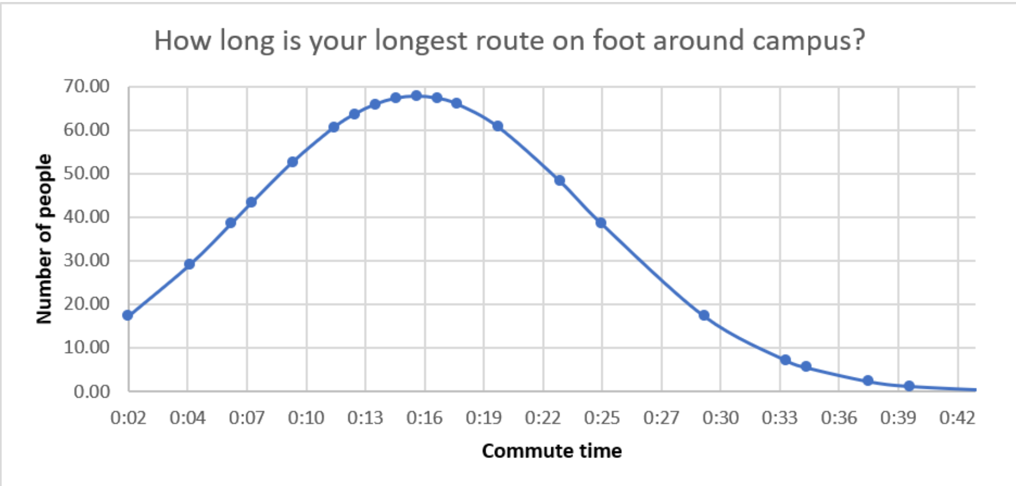



Figure 10.1: How long is your longest route on foot around campus?

2. Scenario 2: This scenario has two clear differences, accommodations located within the campus and the ones located outside. Calculus has been made from the accommodation to building 101 in order to have a clear reference. Building 101 has been chosen because it is the central building and the most visited one.

   Hardly anyone uses public transportation to get around campus if there is a more affordable alternative [Appendix E, section E.2]. This can be due to the elevated cost of commuting on campus, which is minimum 16 kroner. Therefore, the time-saving comparison on campus will be done between commuting on foot or by bike.

On the other hand, for those accommodations outside campus, it is more usual to go by public transportation. Thus, the comparison will focus on the difference between using public transport or a bike.

Table 10.4 shows that biking is usually the fastest way to arrive at university, and when it is not, the difference is within 1 to 3 minutes range.

| Scenario 2 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | To B101 | | | | | | Going by bike increases or decreases travel time? | | | |
| *Accommodations* | On foot | By bike | | | Public transport | Km | On foot vs Bike | | Public transport vs Bike | |
| Campus Village | 13 | 3 | 5 | 8 | 11 | 1 | -5 minutes | -38% | -3 minutes | -27.27% |
| Hempel Kollegiet | 10 | 2 | 5 | 7 | 8 | 0.8 | -3 minutes | -30% | -1 minute | -12.50% |
| Kampsax Kollegiet | 5 | 2 | 5 | 7 | - | 0.4 | 2 minutes | 40% | No service | No service |
| Linde Alle Student Residence | 57 | 17 | 5 | 22 | 21 | 4.9 | -35 minutes | -61% | 1 minute | 4.76% |
| Nordvej Student Residence | 12 | 3 | 5 | 8 | 13 | 1 | -4 minutes | -33% | -5 minutes | -38.46% |
| P.O.Pedersen Kollegiet | 59 | 20 | 5 | 25 | 24 | 4.7 | -34 minutes | -58% | 1 minute | 4.17% |
| Paul Bergsøe Kollegiet | 56 | 16 | 5 | 21 | 22 | 4.5 | -35 minutes | -63% | -1 minute | -4.55% |
| Professor Ostenfeld Kollegiet | 10 | 3 | 5 | 8 | 9 | 0.8 | -2 minutes | -20% | -1 minute | -11.11% |
| Lyngby St | 38 | 11 | 5 | 16 | 15 | 3 | -22 minutes | -58% | 1 minute | 6.67% |

Color legend with numerical evaluation -3 -2 -1 0 1 2 3
(Data in minutes)

Table 10.4: Travel time comparison for scenario 2.

Following the criterion stated above, values have been assigned to the results in table 10.4, a positive average evaluation of 1 has been obtained for those living on campus and an small negative average of -0.2 for those living outside (Table 10.5). Considering that accommodations located on campus will be also considered in scenario 1, it can be concluded that the evaluation of this scenario is negative with a value of -0.2 .

| | Quantity | |
|---|---|---|
| | On campus | Outside campus |
| Numerical Evaluation | Foot vs Bike | Public transport vs Bike |
| -3 | 0 | 0 |
| -2 | 1 | 0 |
| -1 | 0 | 3 |
| 0 | 0 | 0 |
| 1 | 0 | 2 |
| 2 | 3 | 0 |
| 3 | 0 | 0 |
| **Average** | **1.00** | **-0.20** |

Table 10.5: Numerical evaluation of time saving in scenario 2.

3. Scenario 3: For the third scenario, the travel time comparison has been done between bike and public transport, because extra stations are located outside campus. (Table 10.6)

| Scenario 3 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | To B101 | | | | | | Going by bike increases or decreases travel time? | |
| | On foot | By bike | | | Public transport | Km | Public transport vs Bike | |
| Swimming pool | 21 | 6 | 5 | 11 | 12 | 1.7 | -1 minute | -8.33% |
| Lyngby storecenter | 30 | 8 | 5 | 13 | 16 | 2.3 | -3 minutes | -18.75% |
| Cinema | 30 | 10 | 5 | 15 | 17 | 2.4 | -2 minutes | -11.76% |
| Lyngby Hovedgade | 34 | 10 | 5 | 15 | 16 | 2.7 | -1 minute | -6.25% |
| Lyngby Bibliotek | 32 | 10 | 5 | 15 | 24 | 2.5 | -9 minutes | -37.50% |
| Lyngby St | 38 | 11 | 5 | 16 | 15 | 3 | 1 minute | 6.67% |

Color legend (Data in minutes) -3 -2 -1 0 1 2 3

Table 10.6: Travel time comparison for Scenario 3

In two out of six stations, the travel time gets reduced by more than 2 minutes, and only in one station it increases by one minute comparing to public transport (Table 10.7).

| Numerical Evaluation | Quantity<br>Public transport vs Bike |
|---|---|
| -3 | 0 |
| -2 | 0 |
| -1 | 1 |
| 0 | 0 |
| 1 | 4 |
| 2 | 1 |
| 3 | 0 |
| **Average** | **0.83** |

Table 10.7: Numerical evaluation of time saving in Scenario 3

It is important to point out that these numbers are from google maps and they are not considering traffic jams. Hence, long distances must be observed deeper, because as stated by Karolina [Karolina 2018], in Denmark with a bike you can save loads of time and become independent of public transport.

**Accessible pricing**

**Description:** A reasonable pricing when implementing a system is very important for both the user and the operator. Denmark's public transport is expensive, and therefore people usually commutes with their own bike or mixing means of transport to reduce the price.

According to UNESCAP and CITYNET 2012, for a sustainable service be affordable *the percentage of total income that people spent on using the transport system should be less than 15 – 20 percent* and *the cost of travel using a public transit should be much lower than the cost of using a personal transport*.

Moreover, according to Henderson-Bird 2020,

> By implementing more accessible pricing programmes and other equity-focused services as well as through the CBO partners, there is a concerted effort to improve the quality of life for the broadest spectrum of people through expanded mobility offerings.

Survey respondents have been asked, what would be the right price for them, and which types of fares would they be interested at. The options given for a semester fare were, from less than 100 dkk to more than 250 dkk. And types of fares offered were semester fare, 12/24h renting and minute fare.

As decided in section 8.1, semester fares will cost 150 dkk and minute renting will be 1dkk/min (Or less depending on the package chosen). For accommodations, the price will be 100 dkk/month. If these fares are compared with the price of public transportation ( minimum 16 dkk within the same sector, even if it is just one stop), the bike sharing system is definitely more accessible. [Rejseplanen n.d.]

**Calculus method:** In order to evaluate this indicator, it is going to be considered as ”accessible price” if the semester price satisfies more than 50% of population. Being 3 when the value is $\in [0, 10] \cup [90, 100]$, 2 for the percentage $\in ]10, 30[ \cup ]70, 90[$, and finally 1 for those $\in [30, 50[ \cup ]50, 70]$. Values will be negative from 0 to 50 and positive otherwise.

**Numerical evaluation:** Graph 8.2a shows that demand is satisfied in more than 50% when choosing 150 dkk as a semester fare. It satisfies 71% of the demand, which gives a numerical value of +2. This evaluation is valid for both, scenario 1 and 3, but will be different for scenario 2.

Since different fares are proposed to people living at accommodations, the graph varies, as it does the situation. Pricing for people in accommodations has been decided to be 100 dkk/month in section 8.1. This means taking into consideration 100% of the demand. Therefore, it will be assessed with a value of +3.

**Traffic**

**Description:** It has been proved that giving better access to public transport, car rides are reduced. [Consulting 2020] Which is understandable after the first/last mile problem commented in section 3.2.

> e-scooters have the potential to serve as a catalyst toward post-car inner cities by becoming the missing last-mile complement to public transport and helping change urban mobility habits [Consulting 2020]

Moreover, an study carried out in Eindhoven by mobility experts has shown that enhancing shared mobility can reduce car usage. Also Voi launched a survey to its users from where it obtained that 63% of them combine e-scooters with public transport. And according to Consulting 2020 *12% of e-scooter rides replace cars, taxi or ride hailing*.

> ...researchers in France found that the best predictor of switching between a car ride and public transit was easier access to public transport, rather than an improved public transport quality. [Consulting 2020]

One of the benefits stated by Consulting 2020 is getting people out of their cars:

> Commuter trips and car replacement increase over time. This suggests that as a service matures, the more likely it is to be used for commuting purposes rather than leisure. This could be linked to increased reliability of service, and to the fact that citizens have now had the time to integrate the new service in their daily commutes.

This indicator aims to assess the reduction of traffic on and towards DTU campus due to the bike sharing system.

**Calculus method:** Taking into consideration the data commented above, no calculus is needed. It has been demonstrated that micromobility reduces car usage. This data shows a general number that includes cars, taxi and ride hailing. And the value is not very high. Hence, every scenario will have the same evaluation (+1), which means that an improvement in the reduction of traffic will be noticed, but slightly.

The overall evaluation of Quality of life is summarized below.

| **Quality of life** | **Scenario 1** | **Scenario 2** | **Scenario 3** |
|---|---|---|---|
| **Time saving** | +2 | -0.2 | +0.83 |
| **Accessible pricing** | +2 | +3 | +2 |
| **Traffic** | +1 | +1 | +1 |
| **Average** | **+1.67** | **+1.27** | **+1.28** |

Table 10.8: Summary table of sub-indicator: Quality of life

### 10.1.3 Values

The word "Value" has different meanings, but the one chosen for this indicator is the following.

> The regard that something is held to deserve; the importance, worth, or usefulness of something.[Oxford n.d.]

Nowadays, everyone owns many things, some are trivial and others more valuable. For instance, comparing between throwing a mobile phone or a framed photo, people rarely will decide to throw the phone. This is because the photo can be printed again for a few coins, while the mobile phone will cost way more to fix. The purpose of this example is to show that everything has a value, when talking about economics it is easier to see preferences. But when looking into people's hobbies, friendships or food tastes it is difficult to generalize.

However, some daily preferences are general, like efficient mobility. Almost everyone wants to arrive to their destination in the most efficient and fast way. And bike sharing can bring that to DTU campus.

Achieving better connections can improve the value of the campus from a staff-proffesor-student perspective. Also, the environmental approach that a bike sharing system can bring, could improve the attractiveness of the campus, making people stay longer, socialize, and do group activities. Finally, but not least, the implementation of bike lanes on campus and towards Lyngby will increase the safety feeling and create prosperous conditions for the use of the bike sharing system as it has been commented in section 3.2.

Along this section, three sub-indicators are going to be assessed to complete the indicator definition of Value. These sub-indicators are attractiveness, cyclability and building connectivity.

**Space released**

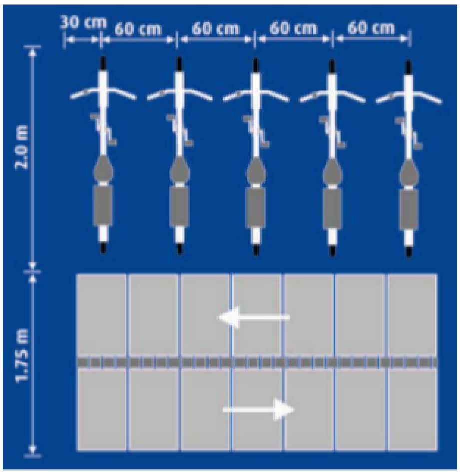
**Description:** A station-based bike sharing system can bring space and neat seeing to the place where it is located. This system will reduce the number of cars on campus, as mentioned in section 10.1.2, realising some of the car-parking spots that can be reused to bike sharing stations or to create new space for leisure.

According to Consulting 2020, a micromobility parking is way more productive than a car parking . This is because devices in sharing systems are continuously moving while private cars are parked 95% of the time.

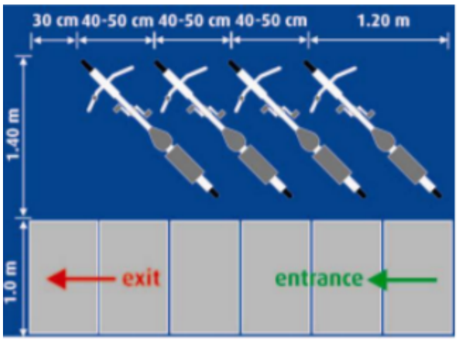
> Bikeshare stations enable more potential consumers to access a commercial area compared to vehicle parking, (...). A parking space would have to turn over 10.3 times per day to generate the same amount of revenue generated by a seven-dock bikeshare station.[Gauthier et al. 2013]

A parking space is 2.5x5 meters. If a bike usually does between 4 to 8 trips (when the system is properly designed) and according to figure 10.2 7 bikes can be accommodated in one car-parking area. If we compare capacities, the car can carry between 1 and 5 people and the station minimum 7. Being up to 24 or 56 people if bike usage is taken into account. Considering that the average passenger occupancy in a car is 1.2, it can be clearly seen how bike sharing stations are way more efficient.

Therefore stations will not create negative landscape impacts or reduce space on campus, rather will bring new spaces while reducing car usage.




(a) Perpendicular bike parking.




(b) Angled bike parking.

Figure 10.2: Light rail ring 3

Including in this evaluation the safety feeling of bike lanes that will be implemented according to Universitet 2019c. Attractiveness of the network will increase.

Therefore, this indicator is evaluating the use of space and all the new implementations on campus that may lead to greater use of bicycles.

**Calculus method:** The number of stations needed and the space occupied in each scenario will be obtained. And it will be compared with the 12% reduction of car usage. Hence, whether or not the space needed is greater/minor than the space released by cars, the evaluation will be negative or positive respectively.

Therefore, if the final space released is from 0 to 4% of total parking lots, the evaluation will be up to $\pm1$, between 4 and 8% up to $\pm2$ and from 8 to 12% up to $\pm3$.

**Numerical evaluation:** Considering a total of 1384 parking lots (table 10.9) which dimensions are 5x2.5 meters (12.5 sq. m.). The 12% reduction will lead to release 2076 square meters.

| Parking lot Amount | |
|---|---|
| **Building 116** | 110 |
| **Building 325** | 100 |
| **Building 421** | 134 |
| **Between quadrants 1 and 2** | 536 |
| **Between quadrants 3 and 4** | 504 |

Table 10.9: Number of parking space at each parking lot [Þrastarson 2017]

On the other hand, a bike parked perpendicular occupies an area of 2x0.6 meters (1.2 sq. m.). Therefore, depending on the Scenario, it can be compared whether or not the space released thanks to micromobility systems is actually released or reused by the system itself.

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Number of docks needed** | 843 | 939 | 951 |
| **Space needed for stations [sq. m.]** | 1011.6 | 1126.8 | 1141.2 |
| **Space released by cars [sq. m.]** | 2076 | | |
| **Difference [sq.m.]** | 1064.4 | 949.2 | 934.8 |
| **% of parking lot** | 6.15% | 5.49% | 5.40% |

Table 10.10: Space released by implementing the BSS.

Summing up, the evaluation for each scenario will be the following.

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Evaluation** | +1.54 | +1.37 | +1.35 |

Table 10.11: Caption

**Cyclability**

**Description:** Having an adequate infrastructure is really important when attracting people. No matter how amazing your system is, if the infrastructure supporting it is not appropriate, users will not make use of it. Therefore, this indicator aims to assess how many bike lanes or paths are in the area of study of each scenario.

**Calculus method:** This indicator will count the kilometers of bike lanes on each scenario over the streets in the area of influence. In the case of the accommodations the shorter route will be chosen and evaluated.

**Numerical evaluation:** The assessment will consider that half of the streets with a bike lane will be an steady situation (0). Then if they are more or less the evaluation will take positive or negative values.

Forty-five streets have been counted on DTU Lyngby campus. Scenario 1, has eighteen bike lanes. Scenario 2 has 18 plus 7.9, from the 8 accommodations chosen. This 7.9 is because around 10% of the path towards Linde Allé is cycling friendly but not a bike lane. And Scenario 3, has been evaluated as 18 plus 4.9. Being the 0.9 because the path to the swimming pool is not considered as bicycle friendly.

Therefore, evaluation for these 3 scenarios, considering that for accommodations and Lyngby locations only one street has been considered (the shorter path), is the following.

| | Streets | Bike lanes | | Evaluation |
|---|---|---|---|---|
| **Scenario 1** | 45 | 18 | 40% | -0.60 |
| **Scenario 2** | 53 | 25.9 | 49% | -0.07 |
| **Scenario 3** | 50 | 22.9 | 46% | -0.25 |

Table 10.12: Evaluation of indicator: Cyclability

**Physical building connections**

**Description:** Every construction, from a park to a building needs good infrastructure and access to be connected with the rest of the world and attract people. When being on a university campus, there are sometimes forgotten buildings. This mean that even though they may have access through sidewalks or small streets, the network available does not invite to discover them.

On DTU, people is pretty busy and usually goes to study/work and comes back home. And in case they have small breaks they will go to their comfort areas. Hence, those unknown buildings will remain the same. But what if a BSS is implemented and stations are established nearby?

Karolina 2018 says in her post

> I visited many incredible places which I would not have been able to see when traveling by bus, or would have been too lazy to walk to.

Thus, the indicator seeks the evaluation of how new stations can help improving/deteriorating physical connections.

**Calculus method:** A list of buildings has been created and the number of modes of transport that can be used to get there have been counted (in a 300 meters range, considering it accessible by car if there is a parking lot next to it). Considering scenario 0 as the current situation and scenarios 1,2,3 for the evaluation. The percentage of them that suffer from an improvement or a deterioration in its connections will be the method to measure this indicator.

The values will be from -3 to +3 depending on the percentage of buildings that have an improvement, stays steady or the connections suffer from a deterioration.

**Numerical evaluation:** Table G.1 shows the results of the study and the following table (10.13) shows the evaluation. It has been assessed by obtaining a percentage of improvement over the total number of buildings. Hence, if improvement goes from $\pm0$ to 34% will be evaluated up to $\pm1$, from $\pm34$ to 67% will be up to $\pm2$ and from $\pm67$ to 100% will be up to $\pm3$.

| | Buildings | DETERIORATES | STEADY | IMPROVES | | Evaluation |
|---|---|---|---|---|---|---|
| **Scenario 1** | 97 | 0 | 5 | 92 | 94.85% | +2.69 |
| **Scenario 2** | 105 | 0 | 5 | 100 | 95.24% | +2.71 |
| **Scenario 3** | 101 | 0 | 5 | 96 | 95.05% | +2.70 |

Table 10.13: Evaluation of indicator: Physical building connections.

### 10.1.4 Overall social evaluation

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Inclusion** | 1.75 | 1.83 | 1.75 |
| **Quality of life** | 1.67 | 1.27 | 1.28 |
| **Values** | 1.21 | 1.34 | 1.27 |
| | | | |
| **Overall evaluation** | 1.54 | 1.48 | 1.43 |

Table 10.14: Overall assessment of Social Pillar.

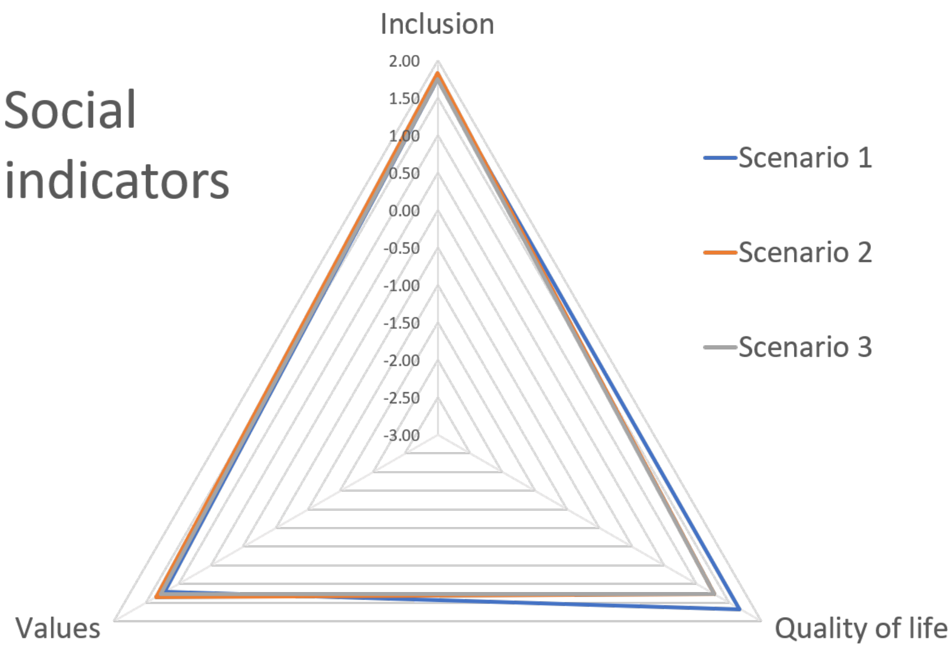



Figure 10.3: Spider graph comparing the results of the three scenarios for the social pillar.

## 10.2 Environmental Indicators

### 10.2.1 Healthiness

Being and feeling healthy should be a priority to everyone, and sometimes is as easy as walking or cycling everyday for a period of time. However, not everyone has the time to do so. Bike sharing systems can solve this problem by introducing a workout in daily commutes.

> To be fit and healthy you need to be physically active. Regular physical activity can help protect you from serious diseases such as obesity, heart disease, cancer, mental illness, diabetes and arthritis. Riding your bicycle regularly is

> one of the best ways to reduce your risk of health problems associated with a sedentary lifestyle...[Health 2013]

Cycling is a low impact exercise, time-efficient and accessible to people of all ages. When using a bike on an everyday basis, there is a large list of benefits it can be obtained. [Health 2013]

- increased cardiovascular fitness
- increased muscle strength and flexibility
- improved joint mobility
- decreased stress levels
- improved posture and coordination
- strengthened bones
- decreased body fat levels
- prevention or management of disease
- reduced anxiety and depression.

In order to assess how benefitial or not would be a bike sharing system on the scenarios presented in this project, two indicators will be evaluated: Benefits of including biking on daily commutes and Outdoor activities.

**Benefits of including biking on daily commutes**

**Description:** Being fit does not necessarily mean go to the gym. Sometimes workout is as simple as taking the bike or walking to your job place.

> Researchers from London investigated the relationship between various commuting methods and obesity risk. Data from 150,000 participants revealed that both walking and cycling showed better results than taking a car or public transport. Walking was associated with significantly reduced BMI and body fat, but to a lesser extent than cycling. The average study participant who cycled to work would weigh about 5 kg less than a similar person commuting by car." [Kaloc 2018]

Moreover, according to Kaloc 2018, *Cycling is more time-efficient, burns more calories, and is better at keeping you fit and slim.* However, it has a drawback, which is maintenance of the bike. You can end up enjoying it, as stated in the article, or you can use a bike sharing system and skip that "tough" part of cycling.

**Calculus method:** Considering that around 50% of DTU's population is interested in long-term fees, it can be assumed that this percentage will make use of the BSS and therefore improve their healthy habits. Dividing the total population into three (0-34%,34-67% and 67-100%) benefits will be assessed.

**Numerical evaluation:** Due to the usage assumption, which considers that only 10% of population will make use of the bike sharing system and applying the 50% of long-term fees, only 5% of population will have healthier habits due to the BSS. Therefore for scenarios 1 and 3 the evaluation will be up to +1.

For scenario 2 calculus must be adjusted. And hereby, those coming from the accommodations must be included (10% of total DTU's population). If 32% is interested in renting and 67% in long-term fees, 0.21% must be applied. And therefore, from the interest of people on campus, the 5% will be converted in a 4.5% after applying the 90% of the total population. Hence, 4.71% of population will benefit form the BSS. This assigns +1 to the evaluation.

| | Interest in long-term fee | Evaluation |
|---|---|---|
| **Scenario 1** | 5.00% | 0.15 |
| **Scenario 2** | 4.71% | 0.14 |
| **Scenario 3** | 5.00% | 0.15 |

Table 10.15: Evaluation of indicator: Benefits of including biking on daily commutes

**Outdoor activities**

**Description:** The system offers rentals of 12 or 24 hours. Considering that a person experiences a general improvement on health only with two to four hours a week of exercise, this renting fee aims to encourage people to do biking excursions. Moreover, since the system designed is with pedal assisted bikes, everyone will be able to make long excursions without fear of running out of energies.

This indicator seeks the evaluation of how many people from DTU would be interested in this type of renting, and therefore how many people will increase their healthy habits.

**Calculus method:** The interest in 12/24 hours renting obtained from the survey will be assessed. As it has been done previously, three stages will be evaluated (0-34%,34-67% and 67-100%), going from zero (no change) to +3 (the whole population gets benefits from it).

**Numerical evaluation:** According to results from the survey, 8% of respondents in scenario 1 and 3 will be interested on that renting (survey that has been considered representative of population). Considering that the system is based on the assumption of ”only 10% of population will make use of the system”, 0.8% of population will benefit from this fare.

Regarding scenario 2, the 20% of accommodation users is interested on that fare. But it has to be taken into account that only 10% of population comes from accommodations and from those only 32% is interested in renting bikes to go to DTU. Hence, it represents an interest of 0.64% (20% x 32% x 10% ). Therefore, from the 90% of popoulation remaning, the interest is the already mentioned 8%. Hereby, 7.2% (8% x 90% ) will be interested. Again, considering only the 10% of DTU’s population as interested people in the system, 0.784% of population [(0.64% + 7.2% ) x 10% ] is interested in renting a bike with a 12/24 hours fare in scenario 2.

| | Interest in 12/24h fare | Evaluation |
|---|---|---|
| **Scenario 1** | 0.80% | 0.0240 |
| **Scenario 2** | 0.78% | 0.0235 |
| **Scenario 3** | 0.80% | 0.0240 |

Table 10.16: Evaluation of indicator: Outdoor activities

### 10.2.2 Mobility

According to Cambridge-dictionary n.d. dictionary, mobility is defined as

> the ability to move freely or be easily moved.

But in order to be moved, some systems are needed. For instance, buses, metro, train, bikes etc. And these systems need established stations where to stop and pick-up/leave the passengers. However, sometimes available stations are not enough and cannot be increased. Hence, a backing from other systems is necessary.

This reinforcement of the transportation system can be done by micromobility solutions, as it has been mentioned throughout the whole project. This new way of moving aims to create multi-modal stations where transfers get easier. According to Consulting 2020,

> "The main upside of micromobility is that it contributes to building a more sustainable city, with well-connected seamless mobility while reducing traffic. We aim to provide citizens with a shared mobility network that improves urban sustainability by encouraging multi-modal transport rather than cars." Christian Humpert.

Throughout the following sub-indicators it is going to be assessed whether mobility is going to be improved with the implementation of a bike sharing system.

**Multi-modal stations**

**Description:** Station is defined by Cambridge-dictionary n.d. as

> a building and the surrounding area where buses or trains stop for people to get on or off.

But bus stations can be as simple as canopies in the middle of a street. Therefore, stations are buildings or small structures, like canopies, where generally buses or trains stop for people to get on or off.

Hence, a multi-modal stations are those where more than one mode of transport stops.

At DTU campus, on scenario 0, there are 2 light rail stations, 14 bus stops, and a multi-modal station on Rævehøjvej, DTU where both light rail and bus stops.

This indicator aims to assess whether the BSS will increase multi-modal stations.

**Calculus method:** The calculus will be simple. For instance, if 10 stations are implemented and all of them are multi-modal stations, the indicator will measure a 100% improvement within the system.

**Numerical evaluation:** The numerical evaluation will follow the system implemented in section 10.2.1. Which is dividing the total population into three groups (0-34%,34-67% and 67-100%) being assessed as 1,2 or 3.

Five stations are multi-modal in scenario 1, the two bus stops on the highway (Rævehøjvej, DTU and Klampenborgvej), one in sector 3a, other in sector 4b and finally one in Lyngby St.

Scenario 2 has all these five stations plus one in Poul Bergsøe Kollegiet. Having a total of 6 multi-modal stations.

Finally, in scenario 3 the bibliotek, the cinema, the storecenter and the swimming pool stations are included as multi-modal stations. This lead to a total of 9.

Comparing these numbers with the total numbers of stations implemented, already mentioned in table 8.8, to obtain the percentage.

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Multi-modal stations** | 5 | 6 | 9 |
| **Total stations** | 20 | 28 | 25 |
| **Percentage** | 25.0% | 21.4% | 36.0% |
| **Evaluation** | 0.75 | 0.64 | 1.08 |

Table 10.17: Assessment of multi-modal indicator

**Variability of means of transport used by DTU's population**

**Description:** There is a wide variety of means of transport arriving to DTU or that can be combined to reach the campus. The most common ways are buses, trains, cars and bikes. People who lives far away has the tendency of change more frequently the mean of transport to get to their destination. This can be observed on Figure 10.4, where the further they live the more transport means they use.

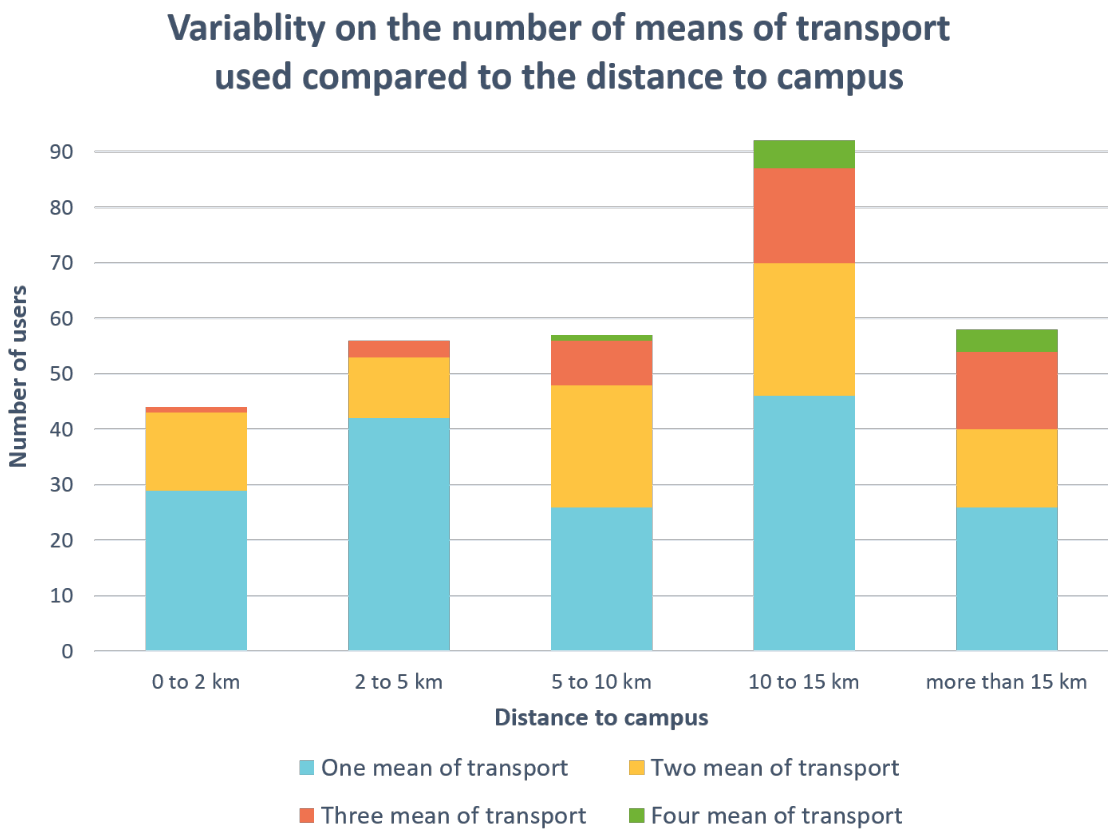



Figure 10.4: Variability of means of transport used by DTU's population depending on distance to campus.

Focusing on the means of transport used, people that uses a private car usually just make use of that mean of transport, the same happens with people who owns a bike. And those who rent a bike rarely use another mean of transport.

On the other hand, bus and train are the ones with a wide variety of options, meaning that are not used as the preferred mean, being more obvious in the case of the train, where almost no-one use it as unique mean of transport. Walking is equitably distributed, and the same happens with shared car. (Figure 10.6)

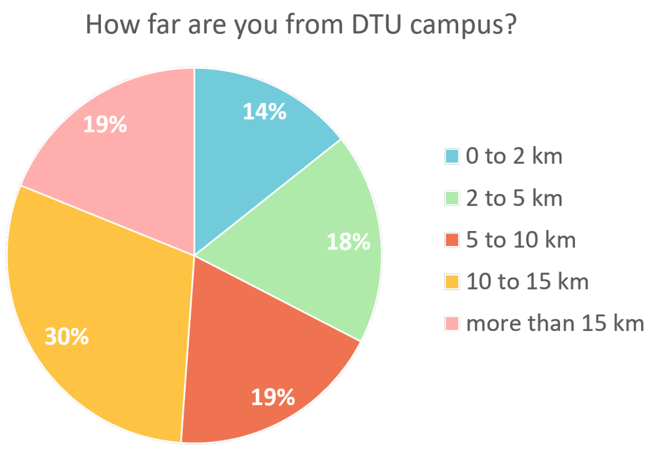



Figure 10.5: Population percentage depending on the distance they have to travel to get to DTU.

Potential users of the network are those living far away and often changing the mean of transport, since indicates predisposition to different alternatives. This is people living further than 5km as shown in Figure 10.4. Hence, going deeper into population's profiles, the percentage of people living further than 5 km is 68%, which has been obtained from figure 10.5.

This indicator aims to assess how many people will benefit from the implementation of a bike sharing system. According to the number of means of transport that they use and therefore, due to their predisposition towards trying new systems.

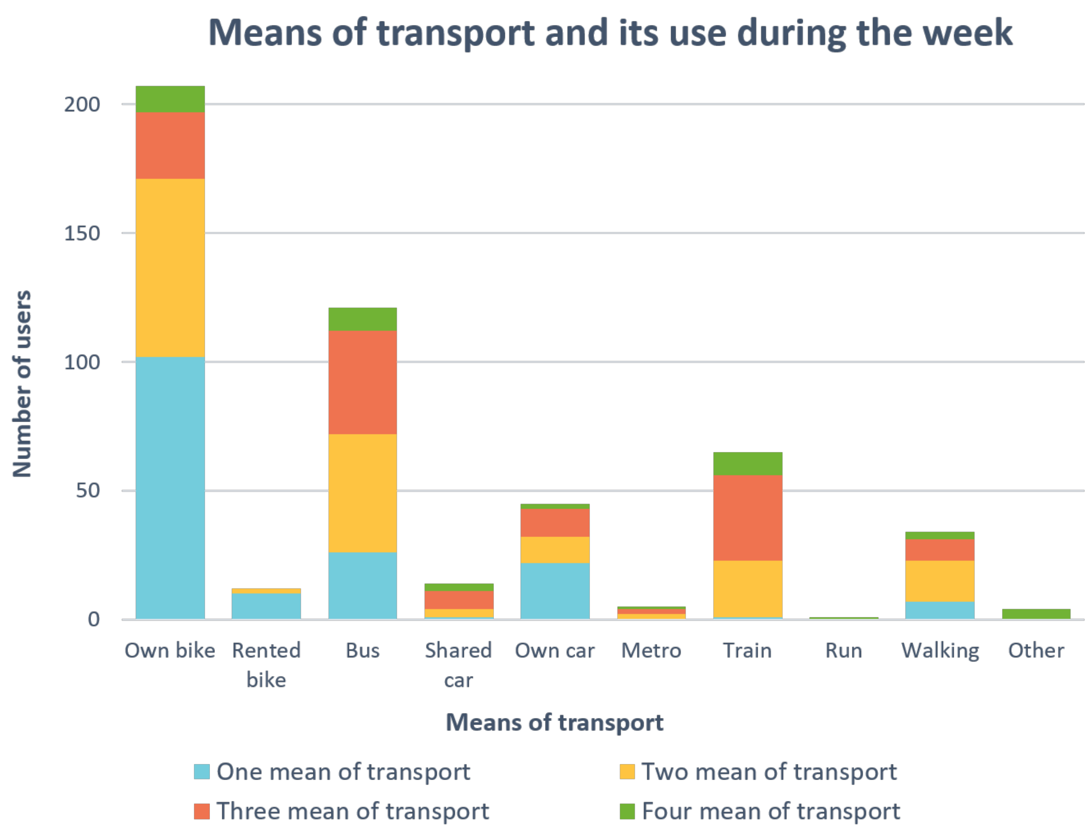



Figure 10.6: Means of transport used by DTU's population.

**Calculus method:** To obtain the percentage of people who is probable that will benefit from the system, the percentage of people living further than 5 kilometers has been obtained. Which is 68% as already mentioned in the description. But these percentage is including population who only uses one mean of transport. Hence, these people will be eliminated. Finally, 36% of population will get benefit from the system, which will probably improve their daily mobility.

| | Means of transport | | | | |
|---|---|---|---|---|---|
| | One | Two | Three | Four | Total |
| **0 to 2 km** | 66% | 32% | 2% | 0% | 44 |
| **2 to 5 km** | 75% | 20% | 5% | 0% | 56 |
| **5 to 10 km** | 46% | 39% | 14% | 2% | 57 |
| **10 to 15 km** | 50% | 26% | 18% | 5% | 92 |
| **more than 15 km** | 45% | 24% | 24% | 7% | 58 |

Table 10.18: Representation of the variability within the different distance ranges.

**Numerical evaluation:** This indicator has the same evaluation for all scenarios since it is considering DTU's population distance to the campus. Applying the methodology already commented, dividing into three blocks the percentage from zero to one hundred, this indicator has a value of +1.07.

| | |
|---|---|
| **More than 5 km** | 67% |
| **Minus those using only one mean** | 36% |

| Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|
| 1.07 | 1.07 | 1.07 |

Table 10.19: Caption

#### Crowdedness of public transportation

**Description:** Even though the light rail is comming, many people will still use the bus and the train. Actually, many people takes the train even if takes longer because of the crowdedness of the 150S. Having alternatives to release the public tranportation is very important and a bike sharing system can help in these aspect.

Throughout the survey, respondents were asked " How do you think a BSS would improve your daily routine?". 36% answered that "It will allow me to go to Lyngby without using public transport" and "It would let me choose whether I want to take the train or the bus to get to DTU". These results show that at least 36% is interested in avoiding public transportation when other options are available.

**Calculus method:** Considering the facts mentioned above, and taking into account that the most crowded mean of transport is usually the bus. Crowdedness of buses will be reduced in a 36% maximum.

**Numerical evaluation:** Considering that an augment of the users will have a negative punctuation, this indicator will be measured from -100% of change and 100%. Being -100 duplicating the amount of people on buses and 100 being empty.

Scenario 1 and 3 will have the same grade, with a reduction of 36%. But regarding scenario 2, it will only reduce its crowdedness when deciding how to get to Lyngby. Therefore it will be reduced in a 21%.

| | Crowdedness | Evaluation |
|---|---|---|
| **Scenario 1** | -36% | 1.081 |
| **Scenario 2** | -21% | 0.628 |
| **Scenario 3** | -36% | 1.081 |

Table 10.20: Data and evaluation of indicator: Crowdedness of public transportation

### 10.2.3 Awareness

From a few years ago the term ”eco friendly” is present in our everyday life, which means

> designed to have little or no damaging effect on the environment. [Cambridge-dictionary n.d.]

Governments implement sustainable policies, the television is continuously telling us that the planet needs our help. Plastic, CO2 emissions, non-renewable energies and other important aspects must be reduced if we want future generations to live safely. Even some young celebrities have become viral on social media transmitting this important message.

Despite all these efforts, there are still people using their private cars when other options are available, usually as cheap as walking. But on the other hand, there are many people who has internalized this problem and is now aware of the huge environmental problem that our planet is facing.

Bike sharing systems and in general micromobility and MaaS, try to help the environment by improving mobility and discouraging people from using private motorized vehicles. Throughout the survey, the feeling of being more environmentally friendly and the importance that people give to it have tried to be evaluated.

**Environmental awareness**

**Description:** Environmental awareness is ...

> ...being aware of the natural environment and making choices that benefit–rather than hurt–the earth. [Sullivan 2019]

These choices can be switching off the lights when are not necessary, closing the tap when brushing our teeth, and using environmentally friendly solutions when traveling. DTU is a university dedicated toward sustainability. The 17 SDGs are something that every course has implemented in its summary.

Hence, this indicator aims to evaluate the awareness people have of sustainable mobility. Not everyone gives the importance that it has using eco-friendly solutions when commuting to work. Then, how many people has this awareness in DTU?. Throughout the survey, the answer to this question has been searched.

**Calculus method:** The percentage of people that answered that a bike sharing system will help them to be more environmentally friendly will be counted. The evaluation process will be the same as in indicator *10.2.2 Crowdedness of public transportation*.

**Numerical evaluation:**

| | Awareness | Evaluation |
|---|---|---|
| **Scenario 1** | 13% | 0.402 |
| **Scenario 2** | 16% | 0.474 |
| **Scenario 3** | 13% | 0.402 |

Table 10.21: Evaluation of indicator: Environmental awareness

**Use of sharing mobility systems**

**Description:** Another indicator of environmental awareness is the use of shared means of transport for daily commutes. This practice denotes interest towards the environment and is an important step towards having an eco friendly life.

People organize to drive together, usually to save time or money. But intentionally or not, they are collaborating in the fight against climate change.

This indicator aims to measure how many people choose this mean of transport when going to university.

**Calculus method:** From Graphic 10.6, it can be observed that at least one person uses car sharing for commuting everyday. Followed by people using two or four means of transport per week. And finally, those using 3 means of transport are the potential users of car sharing. In total 3% of DTU's population makes use of car-sharing for commuting.

**Numerical evaluation:** The value obtained is really low and so it is its evaluation, which is positive but almost steady.

| | Awareness | Evaluation |
|---|---|---|
| **Scenario 1** | 3% | 0.08 |
| **Scenario 2** | 3% | 0.08 |
| **Scenario 3** | 3% | 0.08 |

Table 10.22: Caption

### 10.2.4 Overall Environmental evaluation

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Healthiness** | 0.09 | 0.08 | 0.09 |
| **Mobility** | 0.97 | 0.78 | 1.08 |
| **Awareness** | 0.24 | 0.28 | 0.24 |
| **Overall evaluation** | 0.43 | 0.38 | 0.47 |

Table 10.23: Overall assessment of Environmental Pillar.

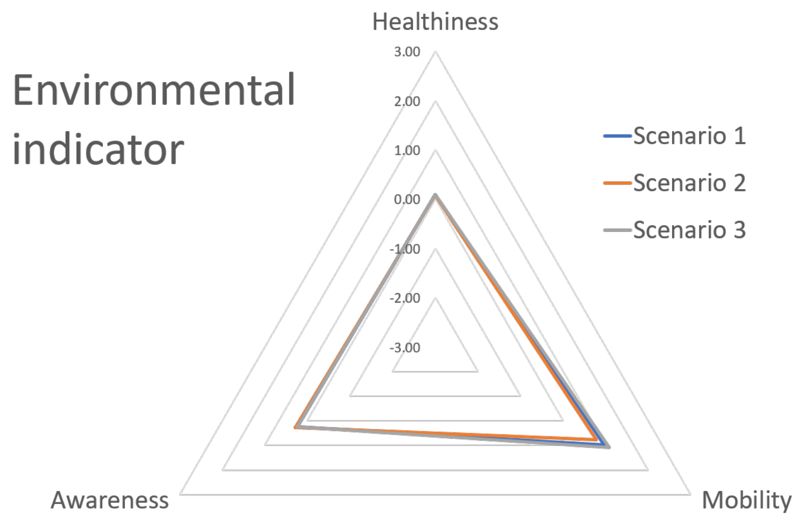



Figure 10.7: Spider graph comparing the results of the three scenarios for the social pillar.

## 10.3 Economic Indicators

### 10.3.1 Investment

One of the best manners to assess an economic impact is looking into the costs of implementation and the incomes. In a bike sharing system this is the cost of bikes, stations, repositioning equipment, process and staff. Software is also a high cost in this systems because is the core of the system for it to functioning.

On the other hand, there are incomes that can help with the amortization of the system. However, the system usually is not economically sustainable. Meaning that incomes from users fees does not cover operational costs neither the capital. But incomes does not only come from the fees, sponsorship, government funds and advertising are some of the most common procedures to get a profitable system.

Indicators will bring some examples of bike sharing systems in order to evaluate them. Capital bikeshare and Ecobici have been chosen for being two extreme cases. Capital bikeshare has a low market penetration while Ecobici is one of the systems with the most impact in the market. [A. Cohen et al. 2018]

**Capital costs**

**Description:** Costs in station-based systems are pretty high because of the stations cost. Stations are the larger cost in this type of systems, so it is in the one presented in this project.

According to A. Cohen et al. 2018, stations cost between 40,000 and 50,000$. And bikes cost from 100 to 2,000$, being 1,500$ a normal price for a bicycle with high specifications.

This indicator aims to evaluate whether the cost is similar to other systems. Once it is known to what extent is similar, it will be evaluated from -3 to -1. In scenario zero university do not spend money (0). But when implementing a bike sharing system, it is spending money on the equipment. Therefore, even if afterwards generates benefits, the initial investment is always negative.

**Calculus method:** Considering the case of Mexico (Ecobici), Virginia and Washintong DC (capital bikeshare), it would be possible to understand whether the cost has been properly forecasted or not. Whashington is including costs of planning and implementing the network, hence it has not be considered for the interpolation. Data of number of bikes and stations is from the first implementation in order to be compared with the initial costs.

Table 10.24 shows that there is a difference between real initial investment and the forecast. Considering that the forecast is not taking into account the rebalancing vehicles/equipment neither the control center.

| | | Bikes | Stations | Initial cost [$] | Cost Estimate [$] | Difference [$] |
|---|---|---|---|---|---|---|
| **Ecobici** | | 1,000 | 85 | 5,750,000 | 5,325,000 | 425,000 |
| **Virginia** | | 54 | 6 | 400,000 | 351,000 | 49,000 |
| **Capital bikeshare** | | 400 | 49 | 5,000,000 | 2,805,000 | 2,195,000 |
| | | | | **Interpolation** | | |
| **The case** | **Scenario 1** | 402 | 20 | 1,348,101 | 1,503,000 | -154,899 |
| | **Scenario 2** | 432 | 28 | 1,889,873 | 1,908,000 | -18,127 |
| | **Scenraio 3** | 443 | 25 | 1,686,709 | 1,789,500 | -102,791 |

Table 10.24: Capital costs forecast and comparison with real cases

The costs are within the ranges provided. Therefore, it is considered representative.

**Numerical evaluation:** The system presented is an small system that covers a small area even in scenario 2. Hence, it has been considered that even if costs are big, it could be even bigger if the system is expanded to a medium or large system. And therefore, the evaluation considers a slight negative change (-1) from scenario 0. Assessment that is generalized to all scenarios.

| | Evaluation |
|---|---|
| **Scenario 1** | -1 |
| **Scenario 2** | -1 |
| **Scenario 3** | -1 |

Table 10.25: Evaluation of indicator: Capital costs

### Incomes

**Description:** Some bike sharing systems are for free, which leads to no user incomes. But usually cover its expenses (operational costs) with sponsorships, advertisements on the vehicles and stations, or government funds.

In the case at hand, the latter parameters are unknown and would need to be established by the operator or the owner of the system. But fees are known and can be used to forecast annual incomes. This has been done in section 8.4. Results obtained show that only with those incomes it will not be enough to compensate the initial investment.

Therefore, with this indicator is going to be measured whether the fees proposed are within the usual ranges or not.

**Calculus method:** A comparison between different systems will be carried out. This systems are the same as mentioned before in indicator ”Capital costs”.

| | | Capital bikeshare | | Ecobici | | This case | |
|---|---|---|---|---|---|---|---|
| Fees | Monthly | 28 | $ | - | | 16 | $ |
| | Annual | 85 | $ | 480 | $ | 47 | $ |
| | single trip | 2 | $ | - | | - | |
| | 24h | 8 | $ | 108 | $ | 47 | $ |
| | 3 days | 17 | $ | 216 | $ | - | |
| | 7 days | - | | 360 | $ | - | |
| Free travel of | | 30 | min | 45 | min | - | |

Table 10.26: Comparison of different fares. Sources: [bikeshare n.d.] & [Ecobici n.d.]

It can be concluded from table 10.26 that the system presented is cheaper than others when speaking about long-term fees. Regarding casual user fees, the 24h show that the system is in between both cases. Moreover, travel time is calculated by maps, and extra free 15 minutes are added to ensure users can arrive without paying any extra. Nevertheless, if they overcome this time, extra costs will be imputed as other companies do.

The evaluation will be -1 is it is cheaper than others, -2 if it is in between and -3 if is more expensive.

**Numerical evaluation:** The system is less expensive and more permissive in some fares, and it is in between for casual users. Hence, it has been decided to evaluate it with a value of -1.5. Negative because not being free for users, and in between -1 and -2 due to the differences from long-term or casual user fees.

**Operational costs**

**Description:** A bike sharing system has many costs, and operational is a group of them. It includes from the process of repositioning itself to the cost of employing staff.

The system has been designed to repositioning only once a day. However, unmet demand is 20% of the total displacements. Thus, at least one repositioning must be added.

According to Shu et al. 2013, repositioning should be done from 2 to 4 times a day. More will be excessive and will increase the costs of the process. Moreover, repositioning is estimated to be 50% of the total operational costs. The rest will be assigned to employees.

**Calculus method:** Studying the number of repositions done by other companies, it has been dicovered that Ecobici has to add bikes on certain stations on rush hours (morning generally) and remove them from stations with high demand of docks [Aguinaga, Ramirez-Nafarrate, and Moncayo-Martínez 2016]. Others do a continuous repositioning by volunteers who get points for each bike they rebalance from a full station to an empty one [Vanderbilt 2018]. These points are usually for membership extensions or gift cards.

This indicator aims to assess in a qualitative manner, whether the operational costs of the system will be high (-3), average (-2) or low (-1).

**Numerical evaluation:** From the design point of view, the system only has to be rebalanced at night which will lead to low operational costs. From the unmet demand perspective, it needs to be rebalanced more times in order to reduce from 20% of unmet demand to 2-5% maximum [Aguinaga, Ramirez-Nafarrate, and Moncayo-Martínez 2016].

Therefore, even if the design is focused on one rebalancing (-1) the system needs more, and therefore the evaluation is going to rise to -2.

**Overall evaluation of inversion**

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Capital costs** | -1 | -1 | -1 |
| **Incomes** | -1.5 | -1.5 | -1.5 |
| **Operational costs** | -2 | -2 | -2 |
| | -1.5 | -1.5 | -1.5 |

Table 10.27: Evaluation of indicator: Investment

### 10.3.2 Economic growth

When implementing new transportation systems objectives can go further than improving mobility in the area. An example could be to boost economic growth. This could sound confusing, but looking deeply into it when connectivity is improved it also improves the access to some business (restaurants, shops, even pharmacies). This could lead to an increment of incomes to them and therefore an overall improvement in the economy.

But not only from the customer point of view. With greater mobility options, workers can choose to expand their area of job hunting. Therefore, employers have a wider range for hiring the appropriate employee, resulting in better job matches.

> Better job matches lead to more productive employees, resulting in higher wages, greater employee job satisfaction, and more profitable businesses. More productive job matches promote business expansion and faster economic growth. Furthermore, since many jobs have moved from the central city to suburbs, increased mobility makes it easier for residents in the inner city to find jobs, expanding opportunities for lower-income residents. [Krol 2017]

In conclusion,

> The real value of transportation systems is in promoting mobility and, therefore, economic activity. [Krol 2017]

Along this section three sub-indicators will be evaluated in order to obtain an overview of how bike sharing systems can contribute in the economic growth of Lyngby-Taarbæk kommune.

**Generation of employment**

**Description:** As in any other business, bike sharing systems need employees to operate. There are many functions that need to be covered. Call center staff, and manteinance and rebalancing staff are the most important. But there are more positions like IT technician, administrative staff, marketing staff and accountants between others.

According to ROUGE 2016, different staff is needed from the implementation and the operational phase.

Implementation:

- Launch Manager (who could transition to the Operations Manager post-launch),
- a Marketing and Promotions Coordinator,
- events staff (these could be contract employees),

- and staff to assemble and install the equipment and set-up the back-end operations system (depending on the equipment vendor, these services may be provided)

After launch, as a minimum, the following employees must be included:

- an Operations Manager,
- a Marketing and Promotions Coordinator (ideally this person or the Executive Director would also be the sponsorship liaison),
- a Station Technician who understands the back-end software and its interface with the stations,
- a Field Checker who addresses problems with the stations and the bicycles in the field and may also rebalance the fleet, and
- a Bicycle Mechanic to repair and maintain the bicycles.

Legal, accounting and other similar services can be contracted to a third party (depending on the business model).

**Calculus method:**This evaluation is going to be divided by the size of the business. According to Data 2017, business can be divided into 4 groups: micro, small, medium-sized and large enterprises. This division depends on the number of employees:

- Up to 10 employees, from 10 to 49 employees, from 50 to 249 employees, and 250 or more.

Therefore, the assessment will range from 0 to 3. It starts at zero because job creation is seen as a positive aspect of economic growth.

**Numerical evaluation:** According with the staff presented in the definition, seven employees will be necessary. Consequently, the evaluation will be 0.975 for the three scenarios. Although time for repositioning may be larger in Scenarios 2 and 3. But this will not mean more employees but more hours working.

| **Evaluation** | | |
|---|---|---|
| **Scenario 1** | **Scenario 2** | **Scenario 3** |
| 0.975 | 0.975 | 0.975 |

| | |
|---|---|
| Number of employees | 7 |

Table 10.28: Evaluation of indicator: Generation of employment

### Facilities popularity

**Description:** Bike sharing system can help to discover some places or at least making them more accessible. For instance Lyngby cinema and storecenter. These two stops are critical for the economic growth of Lyngby. They are both near the city center where apart from these two big businesses, there are restaurants and grocery shops.

On the other hand, inside DTU campus there are many facilities that can also be benefited from the connectivity provided by the network. These are the canteens and cafeterias located as shown in figure G.1.

This indicator aims to assess the accessibility and therefore the potential economic growth of some business near the stations.

**Calculus method:** The number of stations that are next to canteens or have the ”name” of a facility will be counted over the total number of stations. This will show whether a scenario is focused on using mobility towards economic growth.

**Numerical evaluation:** Scenario 1 has 9 stations located near canteens or cafés (Figures G.1 % **??**). Scenario 2 has the same amount because stations on accommodations will be focused on those buildings and not in its surroundings. Scenario 3 adds three interesting places: The storecenter, the cinema and the swimming pool. In table 10.29 are shown the results of the evaluation.

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Stations** | 20 | 28 | 25 |
| **Stations next to facilities** | 9 | 9 | 12 |
| **Percentage** | 45% | 32% | 48% |
| | | | |
| **Evaluation** | 1.35 | 0.96 | 1.44 |

Table 10.29: Evaluation of indicator: Facilities popularity

### 10.3.3 Prestigious

The economic impact of a bike sharing system also affects the university that implements it. When thinking about economic impacts the first thing it comes to our minds is expenses. But implementing a service that improves mobility within campus can bring incomes in an indirect manner.

Being an innovative and environmentally friendly university can increase the prestige of the university and attract new students, researchers, etc. Moreover, the bikes can provide the university with a ”free” marketing. This can help the university to get noticed in the surroundings and become more popular.

> Columbia’s 1st ranking was achieved for its electric and alternative fuel vehicle fleet; sustainable commuting options; bicycle-friendly amenities; carpool and car share incentives; and high percentage of students, faculty and staff that utilize sustainable transportation. [University 2018]

**Marketing**

**Description:** When implementing a bike sharing system, sponsors give some money to the system in order to advertise themselves. Their logo or advertisement is located on the rare wheel. This practice is commonly used by, usually, fast food restaurants to obtain some extra revenues. These sponsors are looking for expanding their marketing to other groups of people that traditional advertisement may not reach.

But looking it from the university’s perspective. This system may be an opportunity to expand its name around other villages. For example with the accommodations, the logo will move around Nærum thanks to Linde Alle and Paul Bergsøe.

This indicator aims to assess how beneficial or not this marketing can be.

**Calculus method:** The methodology will be based on a qualitative assessment. Values will strictly follow the scale assessment stated on section 5.4.2. The wider the area the higher the impact these bikes will have on marketing.

**Numerical evaluation:** The area between scenarios varies. Hence, different evaluations will be obtained.

Scenario 1 will have no impact on marketing since bikes will move around people who is already at the university and therefore knows about it. This scenario will be evaluated with 0. No change expected.

Scenario 2 is the one with a wider area of influence, 14 sq.km. Therefore its influence will be higher. Nevertheless, since only two municipalities will be crossed, Lyngby and Nærum, the evaluation will be 2. Which means that there will be an improvement on DTU's marketing.

Finally scenario 3 is focused on Lyngby. Arguments are pretty similar to scenario 2. But since only one municipality is crossed, it has been considered an evaluation of 1. An slightly improvement.

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Person 1** | 0 | 2 | 1 |
| **Person 2** | 0 | 1 | 2 |
| **Person 3** | 0 | 1 | 2 |
| **Person 4** | 0 | 3 | 3 |
| **Result** | **0** | **1.75** | **2** |

Table 10.30: Evaluation of indicator: Marketing

**Recruitment and retention**

**Description:** The better the facilities and the higher the ranking of the university, the more students want to study there. Nowadays, DTU is a highly prestigious university, which is ranked 85 in the ranking of the best European universities. But this position may rise if mobility on campus is improved. And therefore, students, researchers or PhD students looking for a university to develop their skills may get interested.

According to Bikeshare 2018, bike sharing systems can bring to universities many advantages.

- Distinguishing amenity,
- student recruitment and retention,
- commitment to environment, and
- alternative transportation.

Moreover, the more technologies the more popular and innovative will be the campus. If these aspects are compared with the number of universities that have bike sharing systems on their campus, results become interesting.

**Calculus method:** This indicator is directly related to the image the university gives to population and its ranking among other universities worldwide. In order to calculate how much impact this bike sharing system will have on the number of students, PhD, and researchers when choosing a university, it is going to be compared with the number of universities that already have a bike sharing system and its ranking position.

Table **??** shows a list with the universities who have a bike sharing system included in its campus. Some of them are ranked worldwide within the first best universities.

It can be observed that in Europe universities does not have their own bike sharing systems. Some in england have rental possibilities, like at the university of Nottingham. And others allow bike sharing systems established in cities nearby to have stations or operate in the campus. Hence, DTU would be the first university in Europe to include a bike sharing system on its campus.

**Numerical evaluation:** The evaluation is going to be in a qualitative manner. Depending on the scenario, it will be evaluated how studetns would be attracted by the university's facilities. Four evaluations will be given from different people to reduce subjectivity.

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Person 1** | 1 | 3 | 2 |
| **Person 2** | 1 | 3 | 2 |
| **Person 3** | 2 | 1 | 1 |
| **Person 4** | 1 | 2 | 3 |
| **Result** | **1.25** | **2.25** | **2** |

Table 10.31: Evaluation of indicator: Recruitment and retention

### 10.3.4 Overall Economic evaluation

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Investment** | -1.50 | -1.50 | -1.50 |
| **Economic growth** | 1.16 | 0.97 | 1.21 |
| **Prestigious** | 0.63 | 2.00 | 2.00 |
| | | | |
| **Overall evaluation** | 0.10 | 0.49 | 0.57 |

Table 10.32: Overall assessment of Economic Pillar.

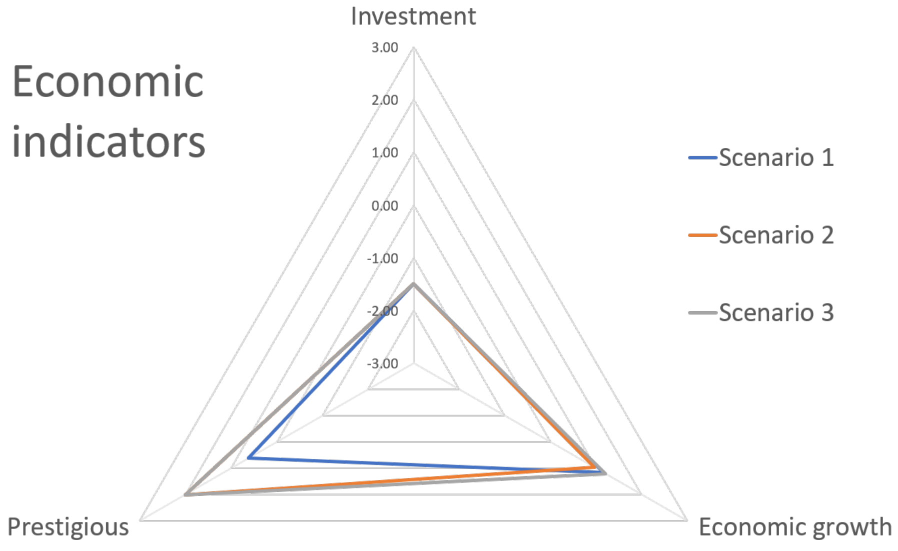



Figure 10.8: Spider graph comparing the results of the three scenarios for the economic pillar.

# 11 Summary

This chapter aims to present the results of the sustainability assessment. Table 11.1 shows the numerical values and Figure 11.1 helps visualizing them with a radar chart.

The overall score from the scenarios has been obtained through an average of all indicators' values. According to these results, scenario 3 is the most feasible from a sustainability point of view. However, all scenarios are very similar, sometimes with very close results.

| | | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|---|
| Social | Inclusion | 1.75 | 1.83 | 1.75 |
| | Quality of life | 1.67 | 1.27 | 1.28 |
| | Values | 1.21 | 1.34 | 1.27 |
| Environmental | Healthiness | 0.09 | 0.08 | 0.09 |
| | Mobility | 0.97 | 0.78 | 1.08 |
| | Awareness | 0.24 | 0.28 | 0.24 |
| Economic | Investment | -1.50 | -1.50 | -1.50 |
| | Economic growth | 1.16 | 0.97 | 1.21 |
| | Prestigious | 0.63 | 2.00 | 2.00 |
| | **Overall Evaluation** | **0.69** | **0.78** | **0.82** |

Table 11.1: Assessment summary

Despite all scenarios have a positive impact, changes with respect to scenario 0 are minimums. Moreover, the fact that all pillars have been considered with the same weigh influences this result. Hence, if another weighing system is considered, solutions will probably differ more ones from the others.

Another reason why these solutions are so similar could be that it has been assumed that only the 10% of the population will use the system. These have decreased the impact of many indicators within the environmental pillar. For instance, healthiness. Which could have risen to 0.9, 0.8, and 0.9 respectively if benefits were measured for the whole population. However, this has been considered not representative of reality and that is why the 10% has been applied.

Scenario 1 varies from the others in quality of life and prestigious aspects. Being higher in quality of life and lowers in prestigious. The latter is because sub-indicator "marketing" has been evaluated as 0, and even though the fact of having a BSS on campus will attract more students, in comparison with scenarios 1 and 2 this change is minimal. Regarding the quality of life, time -saving is the main responsible of this upturn. However, this parameter must be studied deeply. Because time has been obtained with google maps and traffic jams are not considered. Thus, at peak hours the difference in time-savings may rise in the benefit of bikes. Mainly for scenario 2 and in a less extent for scenario 3.

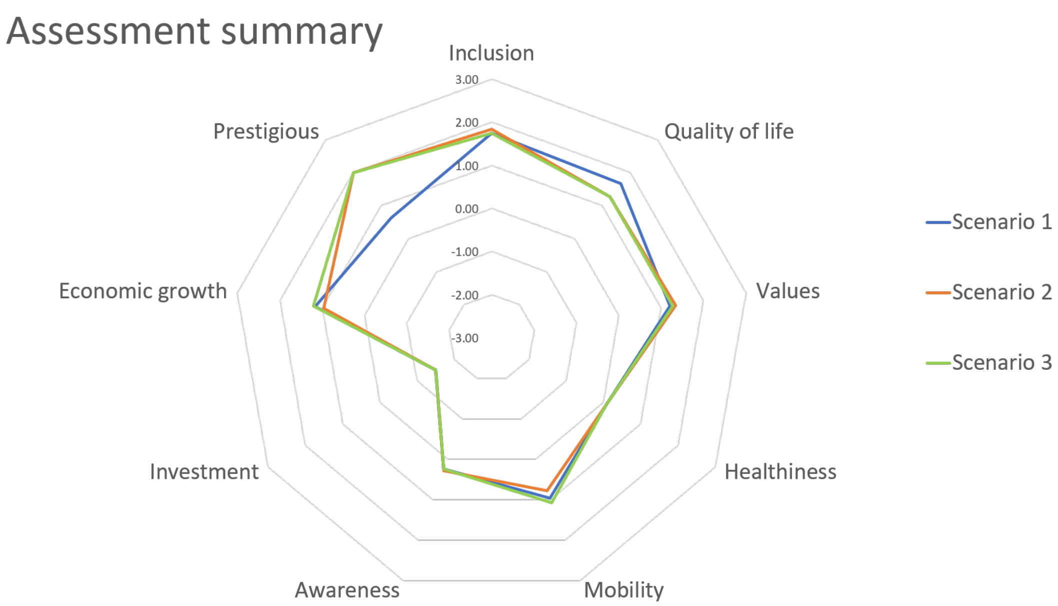



Figure 11.1: Radar chart showing the assessment summary

From the graph, it can be concluded that the implementation of a shared bicycle system has a great impact on social aspects. As it does with prestige and mobility but to a lesser extent.

# 12 Discussion and conclusion

Throughout the project it has been presented a solution for the lack of connection between buildings and some other interesting places, like Lyngby and DTU's accommodations.

Firstly, this project has been focused on analyzing demand. Once the demand has been studied and results have shown to be positively high, the design of the network for the three different scenarios has been done. Where the market penetration recommended by the Bike Sharing Guide has been checked [A. Cohen et al. 2018]. Finally, an indicator set has been created and the feasibility has been evaluated through a sustainability assessment.

One important aspect derived from the analysis of the demand, is the percentage of population interested in using the network. Usually, people tend to answer questionnaires that they feel appealing to their interests. Hence, percentages of interest must not be fully trusted but applied to a percentage of the population.

After some research, it was observed that normally systems are designed for three to nine percent of the whole population, depending on the characteristics of the area and the population itself. It has been found that cities with large amounts of commuting people uses large percentages of the population when designing, almost 10% (Mexico city, Ecobici). Due to a large number of commuters on university campuses and the high interest obtained in the survey, it was decided to do the design with a 10%.

On the other hand, it is important to know that after the implementation of any bike sharing system, a period of observation is needed. Because some locations chosen for the stations may be unused, others may need more tracks, or a lot/ too little people are using the system and therefore must be incremented or reduced. If it turns out that not that many people was interested, the initial investment on huge stations like the one in Rævehøjvej, DTU will be lost. Hence, my proposal will be to do a trial of a few months with 50 bikes with GPS and see how it responds. Whether bikes do not stop running at any time, will mean that the system may succeed.

The survey has also shown how people's commuting around DTU, its hobbies and schedules. But it has also shown the acceptance of the future light rail and the driver-less bus. According to the second survey launched, "the short survey", 90% has never used buses to commute on campus. But 50% will consider the use of the light rail, and 60% will be up for using the driver-less bus. However, it has been recognized that other means of transport like BSS or scooters, would be more used due to the flexibility it brings and the lower fares. Another aspect to take into consideration is the amount of students using the Ungdomskort, which give them free access and therefore they will use other means rather than paying a BSS.

Regarding the design of the system, some aspects should be discussed.

In the first place, the decision of designing a station-based system. The main reasons for choosing this system were, ensuring tidiness on campus and protecting bikes from the weather. However, after looking at the results obtained in the sustainability assessment, with such a small general impact, other solutions may be studied. It must be considered that the whole design is based on this decision. Hence, if the system changes to a dock-less or hybrid system, results will substantially change, and the mathematical model will need to be rearranged.

Another interesting aspect is the evaluation of market penetration. The assessment is carried out by a few parameters that solely depend on the number of bikes and stations, the area of study, and the population. With these parameters and their interpretation with the use of some graphics, the number of bikes and stations needed per square kilometer can be estimated. But in this project, while still obtaining estimated values, some deeper research has been sought. Therefore, a mathematical model was created to understand how many bikes and stations would be necessary. But, it is really important to have a look at the unmet demand. Usually, BSS seeks to reduce the unmet demand to 3-2% of the total demand. In our system, this value raises to 18-20%. This can be reduced as much as zero in the calculation, but looking for an initial balance between docks, cost, and demand, it was decided to leave it with that pondering. For future calculus, this can be changed and better results will be obtained, but also more bikes and therefore docks.

One of the factors commented to measure market penetration of BSS is the number of stations per sq. km. Thanks to the mathematical model, results of bike and dock quantities, have lead to well introduced systems. The only parameter that has created trouble is related to the number of stations. However, this has been decided using the model's results but not being a variable within the same.

Considering results obtained in table 8.5 & 8.8, it can be stated that scenario 2 is not fulfilling all the parameters for market penetration. The result makes sense due to the amount of stations spread around Nærum and Lyngby municipalities. Since only one station is being located on accommodations and these are not nearby each others, this parameter drops exponentially.

Hence, scenario 2 does not fulfil all the conditions for having a good market penetration. But in case the operator wants to include it on the scheme, it is still possible but will not have the same revenues as other solutions. However, a most feasible solution can be reached. For instance, give the option of owning a rented bike by paying a fee per month. Which will remove the necessity of parking the bikes at any specific location. Hence, the cost of the station at the accommodations will be removed. Reducing initial investment and still receiving incomes from the accommodations.

It has to be considered that some departments of DTU already have established a rough bike sharing system. This system shares one or two bikes between professors and researchers to move around DTU Lyngby campus. Information obtained from the comments in the survey.

On the other hand, the location of stations has been decided following the recommendations of the A. Cohen et al. 2018. Nevetheless, it is pretty subjective and many aspects must be taken into account. For instance, whether are going to be solar powered or if an electric connection will be needed. For this, campus plan should work close to the planning group to ensure that all these small aspects are covered.

Finally, the mathematical model aims to take into account commutes on campus, but it is not a real visualization of commutes. A further study using microsimulations should be done. This will help visualizing and getting an overview of the crowdedness of the public transportation on rush hours.

It must be taken into account that some stations need many racks and therefore a wider area. This aspect has not been detailed in this project, but it has been considered when deciding the locations.

Regarding the fees, many universities that have BSS are usually free. However, I they do not fully follow the structure of bike sharing systems like LIME or Donckey Republic. They are bikes painted in the same way and located around campus so everyone can take it and park it wherever it fits them best. Others, do have different fees available, like those hired with Zagster. And usually more expensive than the ones proposed on this project. Hence a revision of the fees must be done by future operators if university wants to cover part of the operational costs with the fees.

Technology and anti-theft security are included in the model proposed. This is due to the different locations where the system will be located. For instance, in scenarios 2 and 3 station will be in isolated areas where it will be no security. On the contrary, if the system is implemented only on campus, this specifications may be more relaxed and reduce the initial investment. An example of a more relaxed system would be the use of automated key boxes. This system is used by the university of Yale and has been greatly successful. [Parker 2014]

Once the planning stage arrives to the point were it is necessary to search for an operation. There are some companies, like Zagster and Onbikeshare, that provides the equipment necessary to start the business as soon as possible. This companies may be interesting, since it removes all worries related.

Concerning the set of indicators and its evaluation, some aspects should be discussed.

First of all, indicators are not an exact science. They are always partly subjective, either when choosing them, when deciding the calculus methodology, or when evaluating them. Anyhow, in this project, subjectiveness has been tried to be reduced by involving four different people in the evaluation. It has not been in all indicators, but in those with no quantitative part.

On the other hand, focusing on the indicators framework. It has been tried to gather as many aspects as possible, looking for variability and ensuring objectiveness as far as possible. Parameters from market penetration have been incorporated as far as possible in the calculus method. With the purpose of ensuring harmony between the two methods, the market penetration and the sustainability assessment.

However, some others have not been possible to include, as it is the case of casual users. It is very difficult to include these groups of people without knowing their frequency of usage. Some may use the system once a week, but others a month or even once a semester. This can have influenced the results of the Sustainability assessment, since a 41% of population demand is not being considered.

There are many unknowns that must be clarified before continuing with the project. All related to decisions that must be taken by the operator of the system. For instance, operational costs. Rebalancing is very expensive, but for evaluating its cost some decisions like number of rebalances, number of employees, which vehicle will be used, etc. There are many systems that have started using bikes to rebalance bikes [Maus 2016]. This is a way of giving example of their own service and encouraging people to do the same.

Other unknown would be the type of system, publicly funded or privately funded. Or the typology of the stations, solar, electric, etc.

The typology of bikes is also important when choosing the system, but e-bikes are more expensive. Hence, considering the results from the assessment, either a sponsor is found, or the change towards traditional bikes must be seriously considered.

Even though a BSS cannot improve the relation user-building from an specific building, it does improve the connections with other buildings where the user may feel more comfortable. Moreover, by implementing new infrastructure it is enhanced the incorporation of systems that could make use and profit from the infrastructure. Which will be given in return to the community as services.

In conclusion, the three scenarios presented are feasible. But scenario 3 is the most beneficial to the area. Followed by scenario 2, that has been disregarded due to the low station density. And scenario 1, which is the one with better quality of life levels.

The solution has been highly accepted since it is more efficient than waiting for buses and less time-consuming than walking. Many students have commented their interest due to the freedom that bring them not to depend on schedules.

Nevertheless, variants and other solutions must be studied in order to obtain the most efficient one. In fact, this thesis was looking for including Ballerup campus in one of its scenarios, but due to the COVID lockdown it has been impossible to reach enough students. Hence, this could be studied in future projects since it will be very interesting to know how many students have lectures in both campus and how do they commute from one to another.

Future studies should also include more accommodations, once the characteristics of the system are known (Typology of bike and system). One accommodation that has not been included but it had enough information and interest, is Tåsingegade studio-apartment. This studio is in the city center and many students live there and commute to campus by 150S, or by bike (10km).

Moreover, some answers have shown the interest of having an station also in Norreport, Copenhagen. In order to be able to commute around the city without having to take the bike from campus.

I believe, and results have shown, that a bike sharing system can be beneficial for an university like DTU. Because it can help solving some of the mobility and connectivity issues around campus and within the areas next to it. It will bring social inclusion and quality of life to students, professors and staff. While still being environmentally friendly and increasing the prestige of the university. On the other hand, a station-based system may be too expensive and complicated. Hence, outsourcing it to companies like Onbikeshare and Zagster could be the best solution.

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# A Appendix: Bike sharing systems (BSS)

| | Financing | Coordination with city | Service delivery | Weaknesses |
|---|---|---|---|---|
| **SINGLE OPERATOR (PPP) Barcelona, London, Manchester, New York City, Rio de Janeiro** | Long-term contract between a private operator and the city establishes a long-term commitment to financial sustainability. Goals of both parties align through revenue-sharing agreements. | Often responding to an RFP, operator understands and agrees to meet city demands to secure a contract. City has significant involvement in major decisions, i.e., station locations, data sharing. | A contracted operator is expected to meet service-levels for maintenance, rebalancing, marketing, customer service, etc set by the city. Failure to do so results in penalties. Thus, operators are financially incentivized to provide quality service. | Traditional singleoperator bikeshare contracts are multiyear (sometimes 10 or more), which may not encourage innovation or incorporation of new technologies that would improve service delivery. |
| **MULTIPLE PRIVATE OPERATORS Seattle, Singapore, Tianjin** | Requiring no upfront costs to the city for bikeshare assets reduces the time needed for planning and implementation, and can be more politically palatable than the city providing funding to start a bikeshare program. | Cities that demand certain operating standards using a regulatory framework (permit, MOU, code of conduct, etc.) can achieve optimal outcomes including public space management, equitable access to bikeshare, data sharing and transit integration, etc. | Competition between operators for rides encourages constant improvement on and responsiveness to the user experience. | The city relegates routine operational decisions to private companies. Without regulation, dockless bikeshare will neither be thoughtfully integrated into city goals nor connected with the transportation network. Oversupply leading to negative outcomes, such as bike piles and underutilized bikes, could occur. |
| **SINGLE (PPP) OPERATOR & PRIVATE OPERATOR(S) Guangzhou, Washington, DC** | Service area expansion becomes fiscally viable if private operators are able to “fill in the gaps,” providing service in areas where the PPP operator could not afford to expand into. | City staff and processes already in place to coordinate with an existing bikeshare operator will likely provide capacity and support when drafting and implementing new policies that allow for a multi-operator system. | Different systems (i.e., station-based, dockless) and bike types (i.e., e-bikes, lightweight models) can be provided, offering a range of choices to riders that may encourage more trips made by bike. | Requires users to navigate multiple platforms to find and rent a bike, and may present additional coordination challenges between the city, PPP operator and private companies. |

Table A.1: Comparing Bikeshare Operator Scenarios [A. Cohen et al. 2018]

# B Appendix: Correspondence with stakeholders

## B.1 Campus Service

**Query to Anders B. Møller (09/04/20):**

1. (...) The number of students/staff/professors on each campus and those that have lectures in both Lyngby and Ballerup campus. With this information, I will be able to ensure that the data obtained from a survey is representative. I have found some general data at DTU's web page but does not differentiate between campuses.
2. Section drawing of Asmussens Allé with the implementation of the light rail. I would like to know how the main road will look like in 2025, to adjust the bike lane design. I have found general drawings of the route, but any detailed one.
3. Self-driving Bus: Do you know if it will be free? And regarding its route, it will go around campus or just from the light rail to specific stops? I need an overview of the different means of transport to assess the need of the network.
4. DTU: Do you know if a bike network would sound interesting to DTU and if so, whether it exists any kind of economic support? Like for instance if there are specific grants for mobility projects. (...)

**Answer Anders B. Møller (13/04/20):**

@Rikke will you send an updated drowning off the light rail tracks

1. This information i don't have, i believe that you can have this from education AUS. department.
2. Rikke will send this to you
3. The Selfdriving busses are just a test and are not yet allowed to drive at campus, they are planned to go from "Netto" to crossover between 4xx to 3xx near by Skylab, I hope we will be able to test in september.

   www.lincproject.dk/en/
4. No there are no economic support to transportation from DTU, this is not allowed, but i hope we are able to establish a bike shop, from our sustainable CAS department where used bikes can be dispatched sold from DTU bike shop to students

**Answer from Rikke Brinkø Berg (20/04/20):**

Dear Helena

I forwarded your email below to the project manager in charge of the lightrail project at CAS, and received the attached file back.

Hope it suits your needs.

## B.2 Human resources and administrative

Number of students, professors and staff on the different DTU campus.

**Query to Claus Tonsberg (19/05/20):**

Dear Claus,

...I need to know how many people belong to each DTU campus. I have found some data on the web page https://www.dtu.dk/english/about/facts-and-figures/education and https://www.dtu.dk/english/about/facts-and-figures/human_resources, but I think this data is general for the whole DTU not from each campus. Could you please tell me where I can find that information or at least a rough percentage of each category for each campus?

I would be pleased if you can share with me this information. (...)

**Answer (20/05/20):**

> Hi Helena Unfortunately, I cannot give you an accurate answer to your question or refer you to a statement as many students receive tuition at several of our campus areas. Furthermore they are not enrolled at a specific address. However, I believe that 35% of our students have their daily walk at the Ballerup Campus and 75% at the Lyngby Campus.

**Query (21/04/20):**

I would like to ask regarding the number of students, professors and staff at DTU Lyngby and Ballerup campus, as well as those who have lectures/work in both. (...) I hope you can share with me this data or give me some percentages.

**Answer from Peter Nam Pham (27/05/20):**

> Below please find the numbers of employees at DTU in the three campuses (per 18 May 2020):
>
> DTU Lyngby: 6736 employees DTU Risø: 388 employees DTU Ballerup: 364 employees
>
> The numbers above represent the number of staff (in persons) in the three different campuses, and are not the number of full-time equivalents (FTE).

# C Appendix: Light rail information

## Friheden - Nærum/Lyngby

| | L | | | L+ mon-sat daytime | | |
|---|---|---|---|---|---|---|
| **Friheden st.** | **10** | **30** | **50** | **04** | **24** | **44** |
| Brostykkevej | 12 | 32 | 52 | | | |
| Arnold Nielsens Boulevard | 14 | 34 | 54 | | | |
| Hvidovre Hospital | 16 | 36 | 56 | 08 | 28 | 48 |
| Park Allé | 18 | 38 | 58 | | | |
| **Rødovre st.** | **20** | **40** | **00** | **11** | **31** | **51** |
| Roskildevej | 22 | 42 | 02 | | | |
| Rødovre Centrum | 24 | 44 | 04 | 14 | 34 | 54 |
| Jyllingevej | 26 | 46 | 06 | | | |
| Slotsherrensvej | 28 | 48 | 08 | | | |
| **Husum st.** | **30** | **50** | **10** | **19** | **39** | **59** |
| Husum Torv | 32 | 52 | 12 | 21 | 41 | 01 |
| Kobbelvænget | 33 | 53 | 13 | | | |
| Tingbjerg | 34 | 54 | 14 | | | |
| TV-Byen | 35 | 55 | 15 | | | |
| Gladsaxe Trafikplads | 37 | 57 | 17 | 25 | 45 | 05 |
| Buddinge Rundkørsel | 39 | 59 | 19 | | | |
| **Buddinge st.** | **40** | **00** | **20** | **27** | **47** | **07** |
| Gammelmosevej | 42 | 02 | 22 | | | |
| **Lyngby st.** | **44** | **04** | **24** | **30** | **50** | **10** |
| Lyngby Storcenter | 45 | 05 | 25 | | | |
| Sorgenfrigårdsvej | 46 | 06 | 26 | | | |
| Lundtoftegårdsvej | 47 | 07 | 27 | | | |
| Anker Engelunds Vej | 49 | 09 | 29 | | | |
| Lundtofteparken | 51 | 11 | 31 | | | |
| **Nærum st.** | **53** | **13** | **33** | | | |

**From Friheden to Nærum**
mon-fri 5.10 - 0.30
sat 5.10 - 0.30
sun 6.10 - 0.30

**From Friheden to Lyngby**
mon-fri 6.04 - 18.44
sat 7.04 - 15.44

## Nærum/Lyngby - Friheden

| | L | | | L+ mon-sat daytime | | |
|---|---|---|---|---|---|---|
| **Nærum st.** | **16** | **36** | **56** | | | |
| Lundtofteparken | 18 | 38 | 58 | | | |
| Anker Engelunds Vej | 20 | 40 | 00 | | | |
| Lundtoftegårdsvej | 22 | 42 | 02 | | | |
| Sorgenfrigårdsvej | 23 | 43 | 03 | | | |
| Lyngby Storcenter | 24 | 44 | 04 | | | |
| **Lyngby st.** | **25** | **45** | **05** | **19** | **39** | **59** |
| Gammelmosevej | 27 | 47 | 07 | | | |
| **Buddinge st.** | **29** | **49** | **09** | **22** | **42** | **02** |
| Buddinge Rundkørsel | 30 | 50 | 10 | | | |
| Gladsaxe Trafikplads | 32 | 52 | 12 | 24 | 44 | 04 |
| TV-Byen | 34 | 54 | 14 | | | |
| Tingbjerg | 35 | 55 | 15 | | | |
| Kobbelvænget | 36 | 56 | 16 | | | |
| Husum Torv | 37 | 57 | 17 | 28 | 48 | 08 |
| **Husum st.** | **39** | **59** | **19** | **30** | **50** | **10** |
| Slotsherrensvej | 41 | 01 | 21 | | | |
| Jyllingevej | 43 | 03 | 23 | | | |
| Rødovre Centrum | 45 | 05 | 25 | 35 | 55 | 15 |
| Roskildevej | 47 | 07 | 27 | | | |
| **Rødovre st.** | **49** | **09** | **29** | **38** | **58** | **18** |
| Park Allé | 51 | 11 | 31 | | | |
| Hvidovre Hospital | 53 | 13 | 33 | 41 | 01 | 21 |
| Arnold Nielsens Boulevard | 55 | 15 | 35 | | | |
| Brostykkevej | 57 | 17 | 37 | | | |
| **Friheden st.** | **59** | **19** | **39** | **45** | **05** | **25** |

**From Nærum to Friheden**
mom-fri 4.56 - 0.36
sat 4.56 - 0.36
sun 5.56 - 0.36

**From Lyngby to Friheden**
mon-fr 5.59 - 18.59
sat 6.59 - 15.59

Figure C.1: Schedule of the Greater Copenhagen Light Rail. First proposed schedule in [Andersen, Landex, and Nielsen 2006]


Figure C.2: Light rail ring 3 Greater Copenhagen. [Nicolaisen, M. Olesen, and K. Olesen 2017]

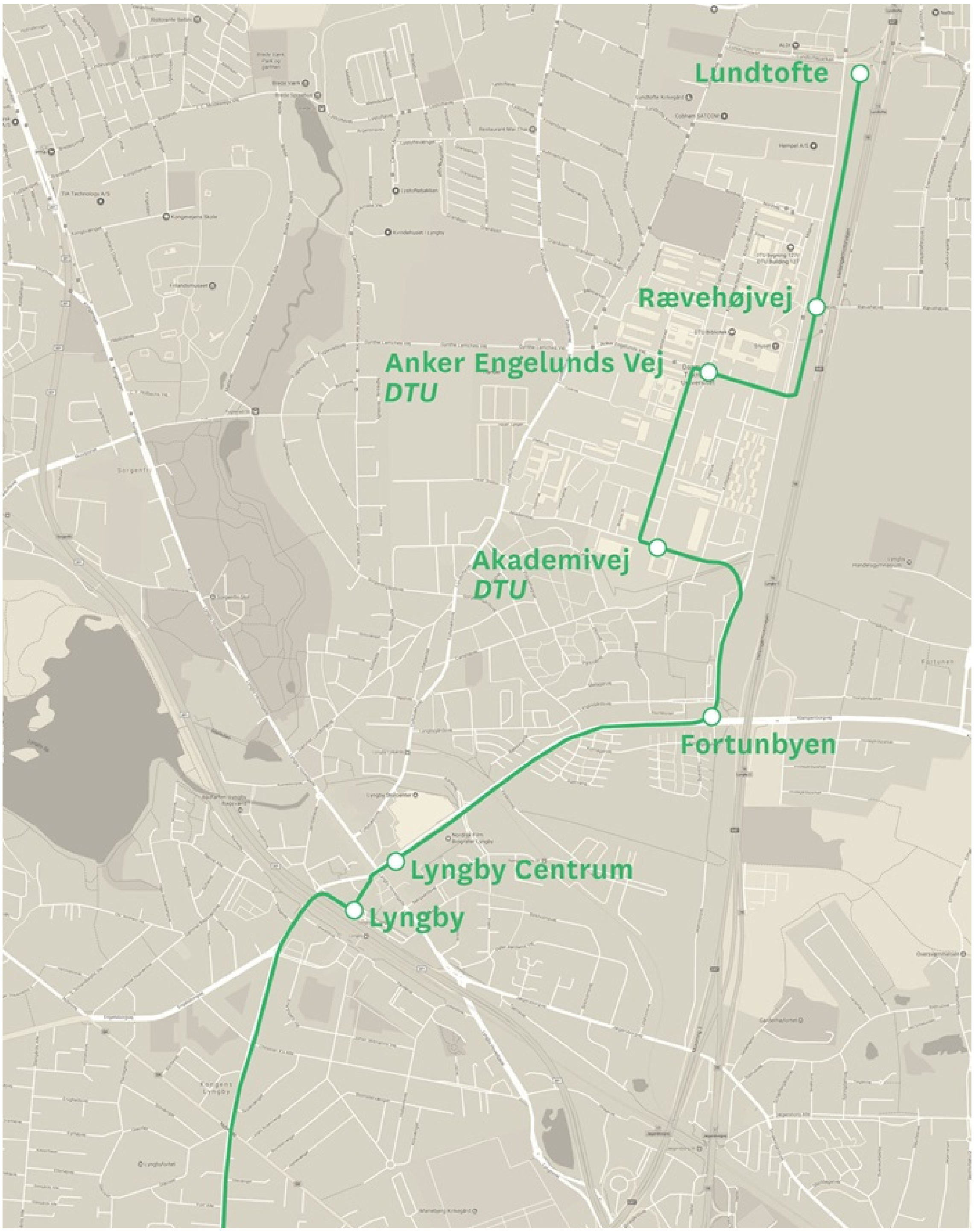



Figure C.3: Light rail ring 3 Greater Copenhagen when passing by DTU campus.

# D Appendix. Campus plan images

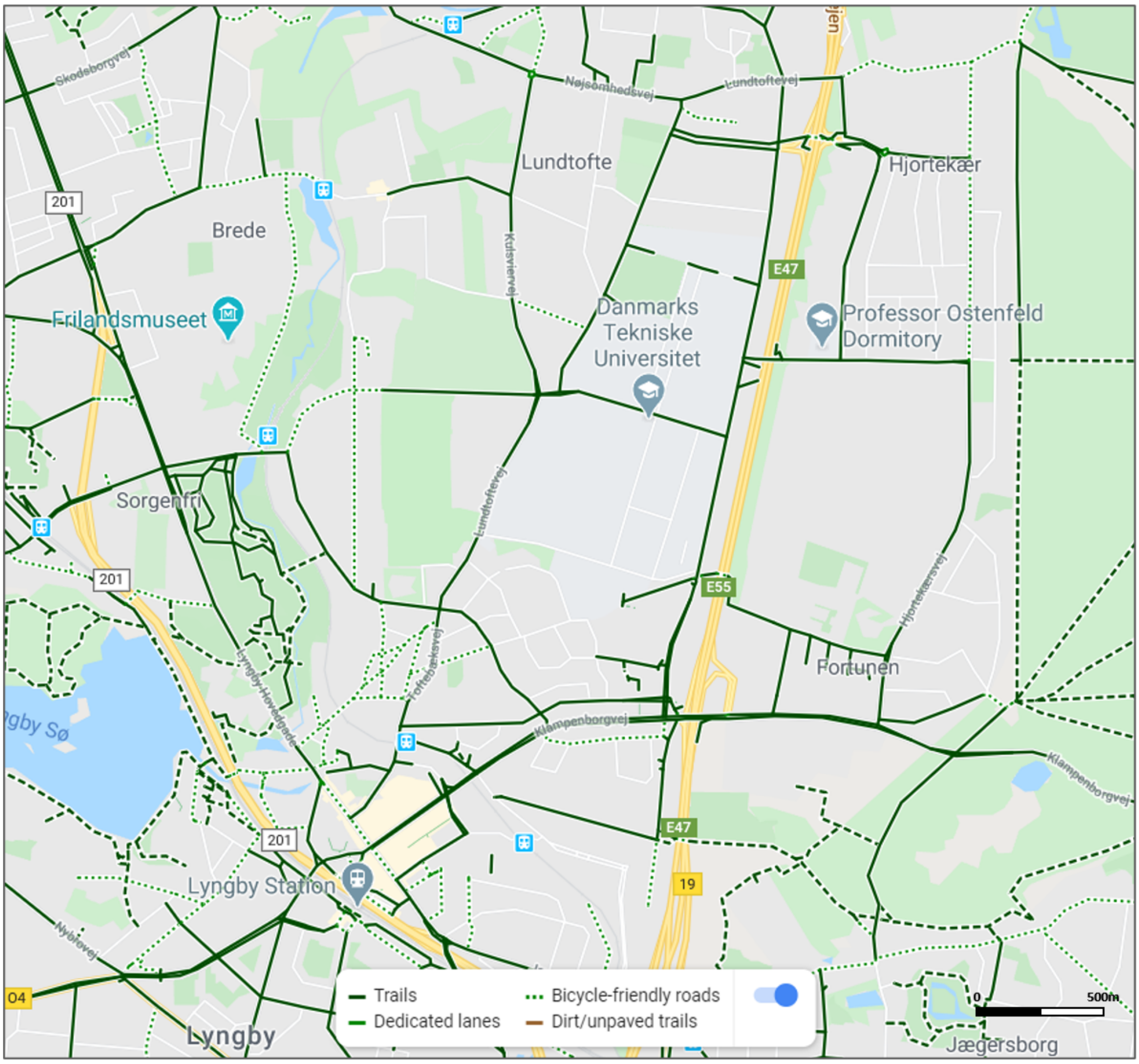



Figure D.1: Current bike lanes on campus. Source: Google maps.

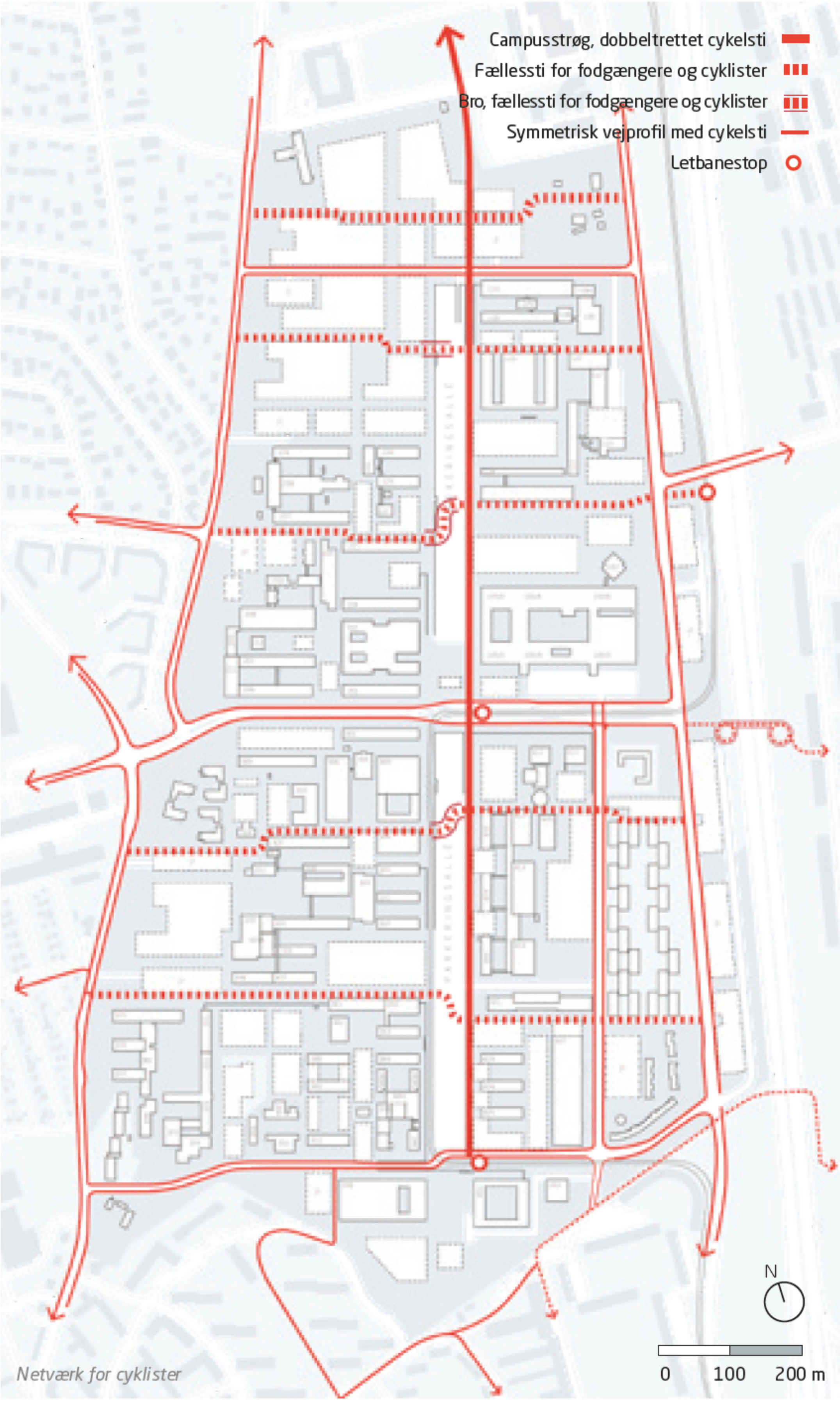



Figure D.2: Projected bike lanes on campus [Universitet 2019c]


Figure D.3: Projected bike parking on campus [Universitet 2019c]

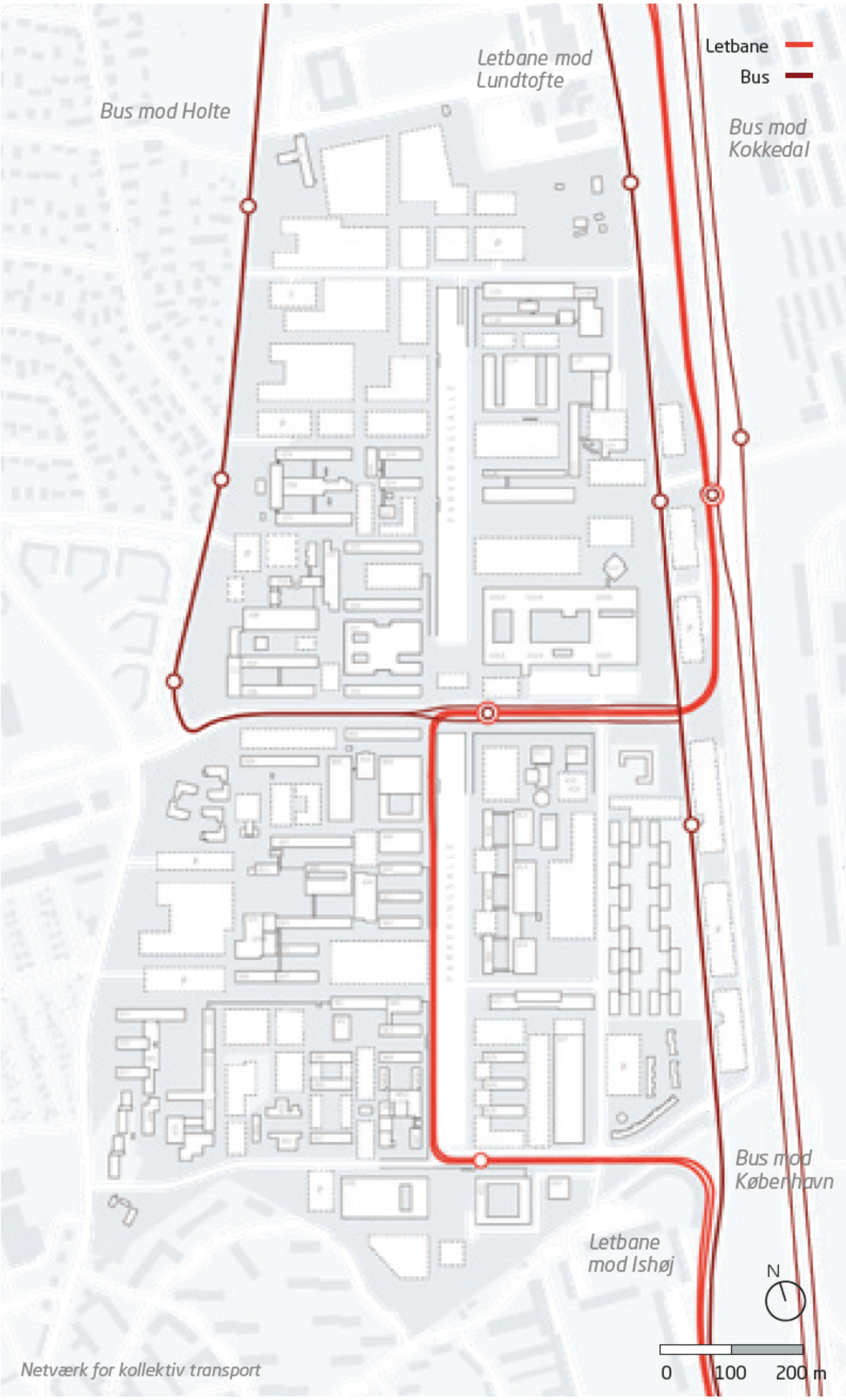



Figure D.4: Public transport lines on campus [Universitet 2019c]

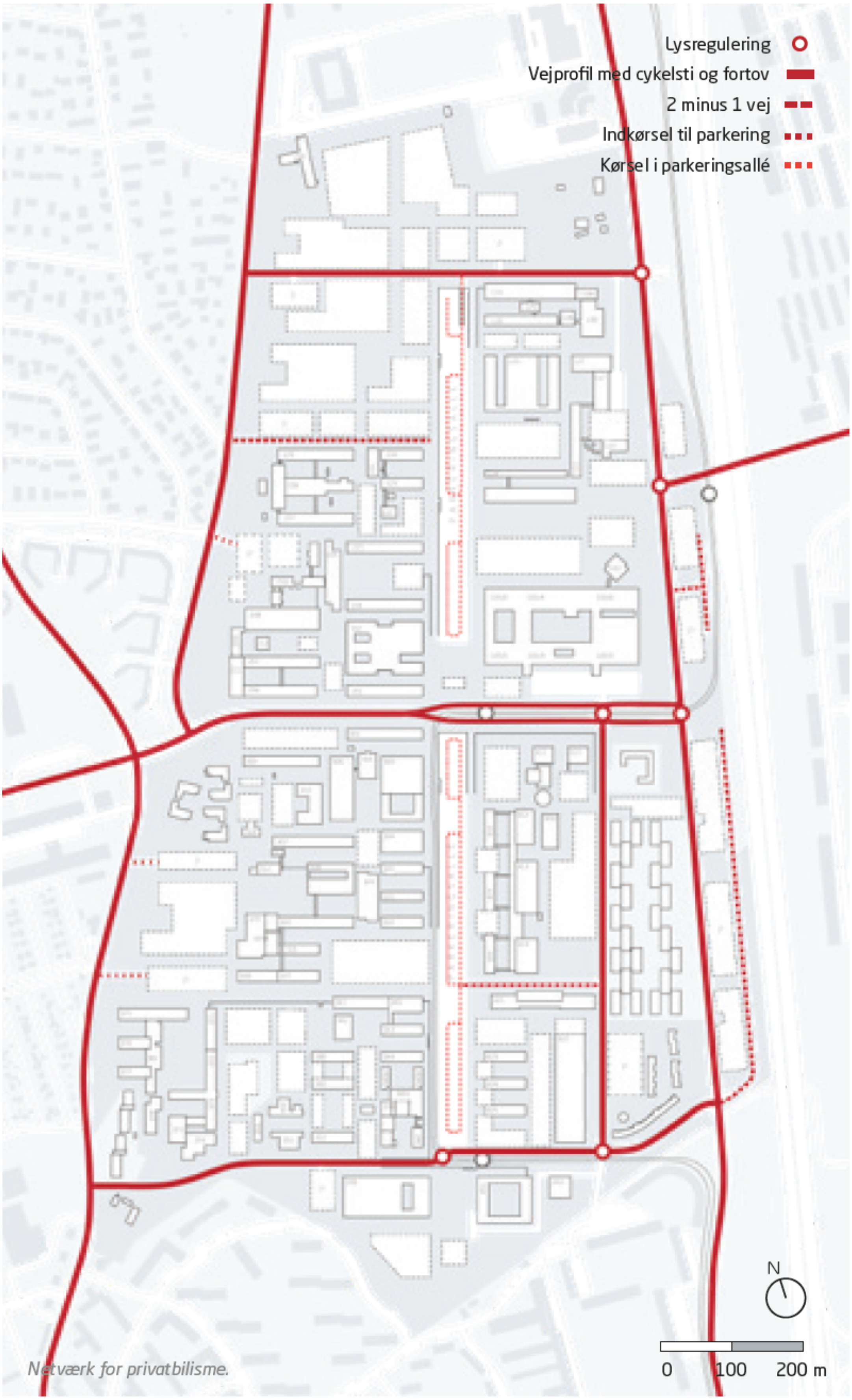



Figure D.5: Projected car network on campus [Universitet 2019c]

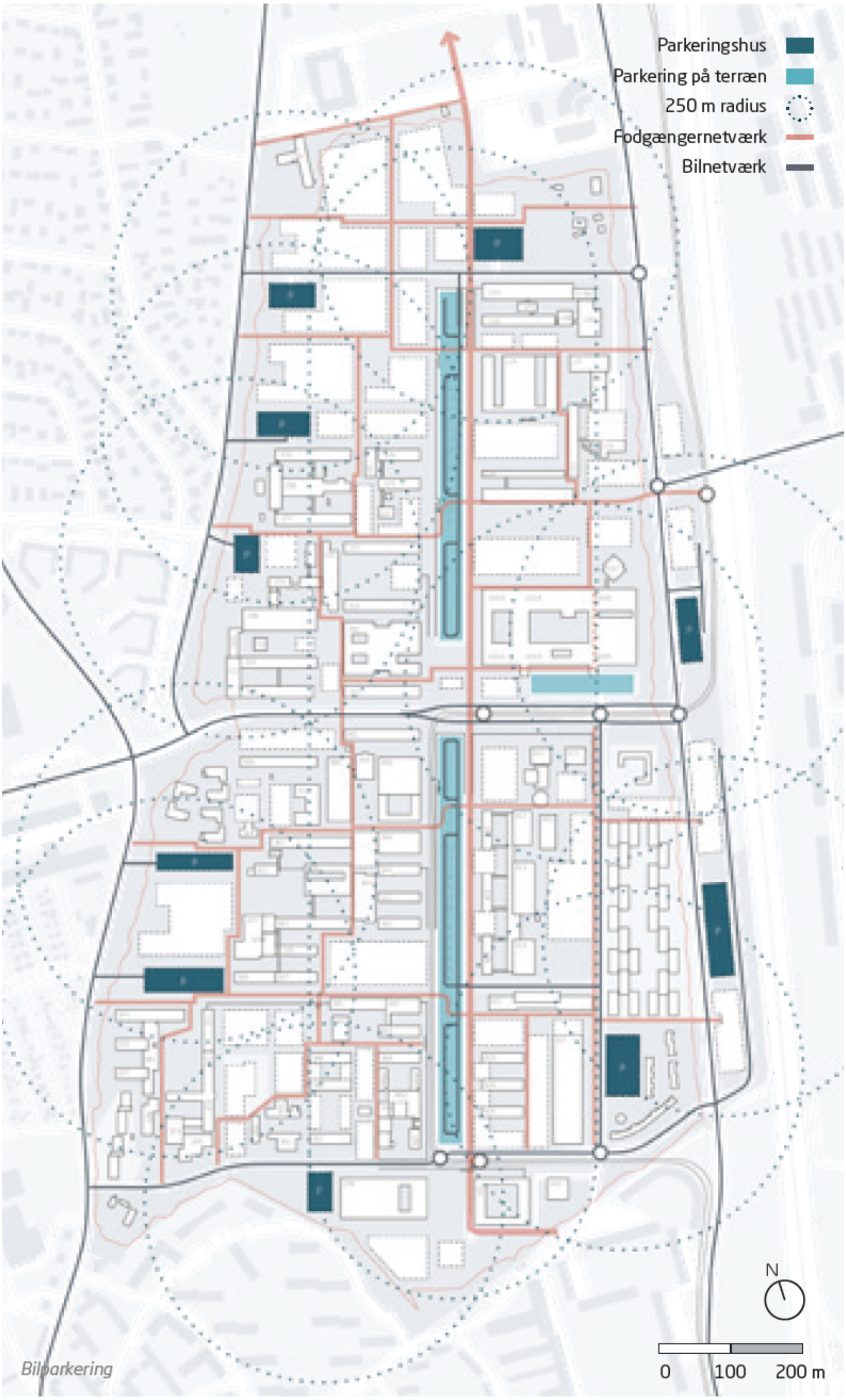



Figure D.6: Projected car parking on campus [Universitet 2019c]

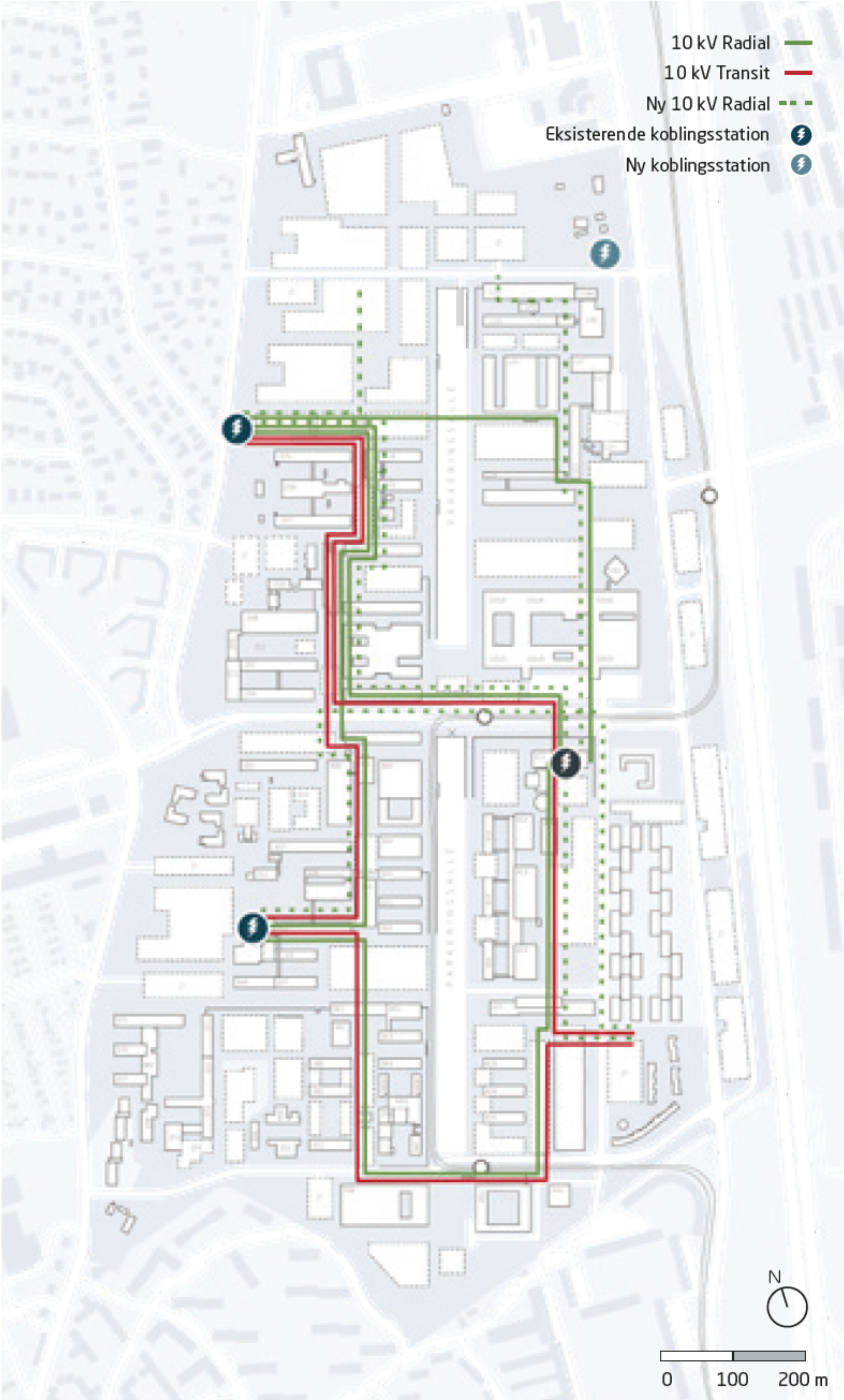



Figure D.7: Electricity network on campus [Universitet 2019c]

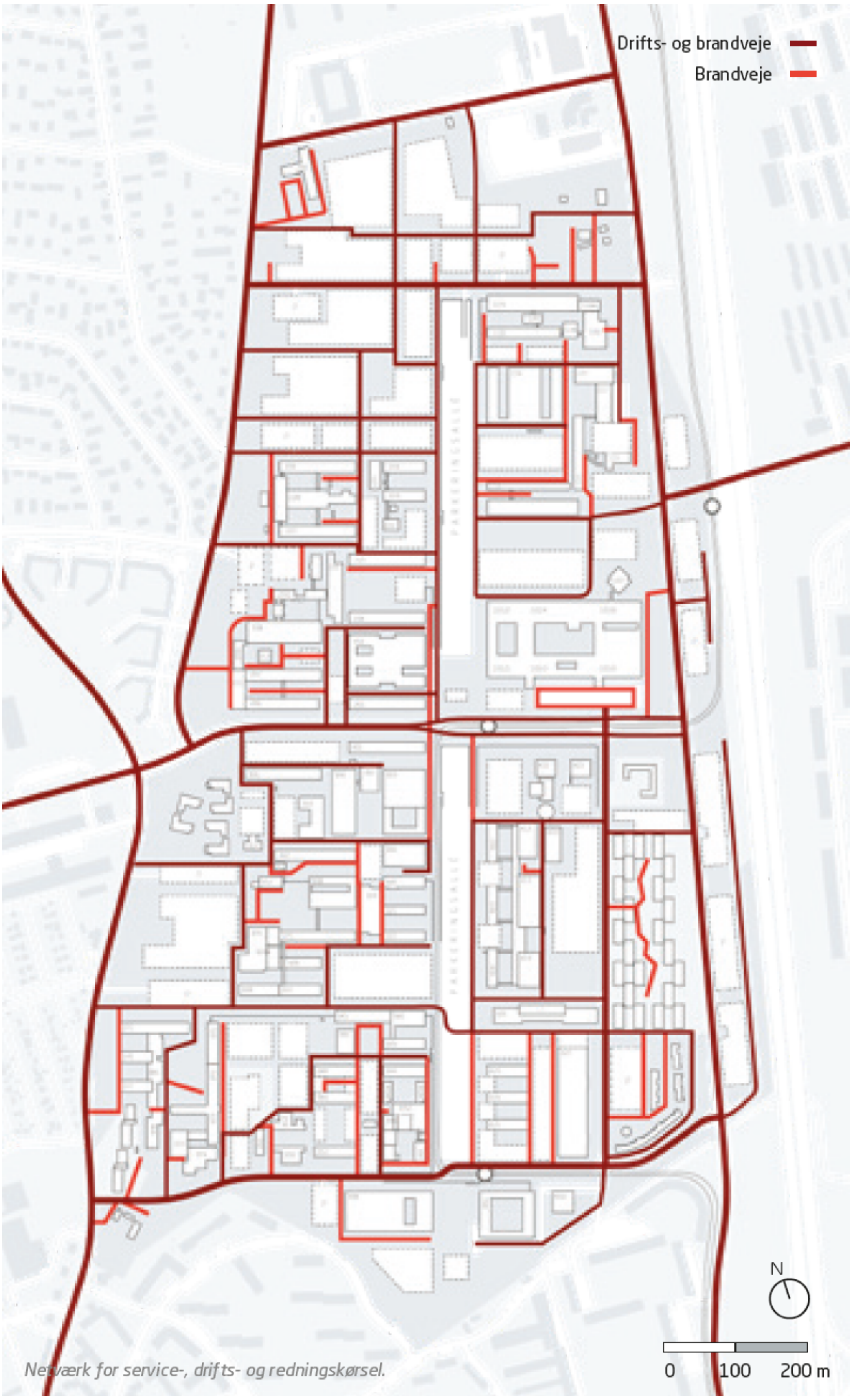
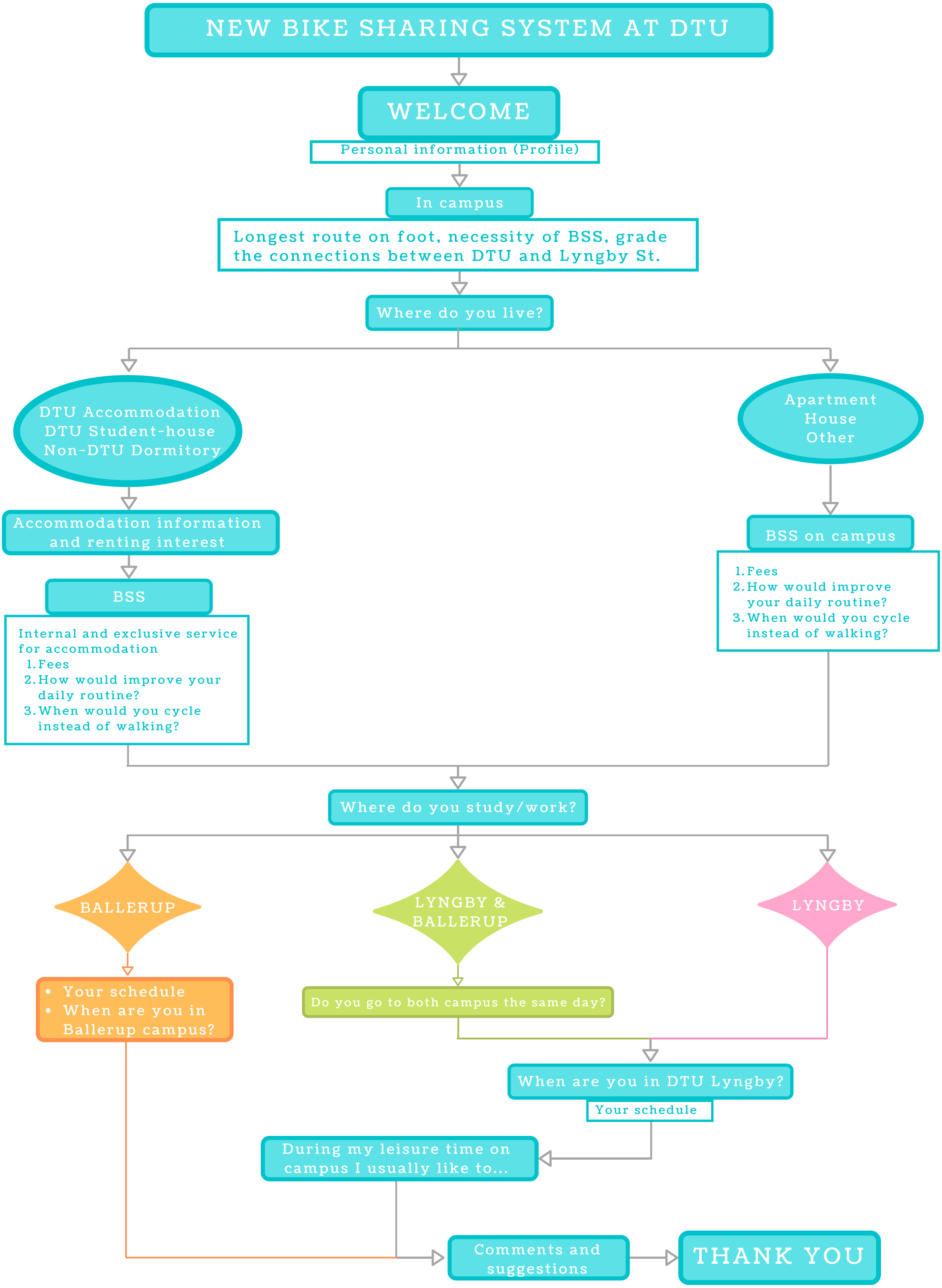



Figure D.8: Service, Operation and Rescue Network on campus [Universitet 2019c]

# E Appendix: Survey

## E.1 Main survey

**Survey path**



NEW BIKE SHARING SYSTEM AT DTU
WELCOME
Personal information (Profile)
In campus
Longest route on foot, necessity of BSS, grade the connections between DTU and Lyngby St.
Where do you live?
DTU Accommodation
DTU Student-house
Non-DTU Dormitory
Apartment
House
Other
Accommodation information and renting interest
BSS
Internal and exclusive service for accommodation
1. Fees
2. How would improve your daily routine?
3. When would you cycle instead of walking?
BSS on campus
1. Fees
2. How would improve your daily routine?
3. When would you cycle instead of walking?
Where do you study/work?
BALLERUP
LYNGBY & BALLERUP
LYNGBY
• Your schedule
• When are you in Ballerup campus?
Do you go to both campus the same day?
When are you in DTU Lyngby?
Your schedule
During my leisure time on campus I usually like to...
Comments and suggestions
THANK YOU

# New bike sharing system at DTU

Hi, my name is Helena and I am a student at DTU Lyngby.

The objective of this survey is to obtain an actual sample for a master thesis, which aims to assess the demand and feasibility of a new bike sharing system at DTU. The survey will adjust according to your answers to shorten the time. Hence it will take you less than SEVEN minutes. Feel free to consider your schedule from last year if you think it is more representative (for instance if this semester you are doing your thesis)

Bike-sharing system is a system in which bicycles are made available to people for shared use during a short period of time by paying an affordable fee.

Be aware that I am looking for an actual sample and this is just an academic study, the number of submissions won't affect the implementation. It will only influence my MSc thesis results.

Thank you for taking the time to help me and have a nice day!
*Required

## Welcome, let's introduce ourself

1. Who are you? *

*Mark only one oval.*

- Student at DTU
- Exchange student at DTU
- Professor at DTU
- Staff at DTU

2. What is your nationality?

_______________________

3. How old are you? *

*Mark only one oval.*

- 18 - 25
- 25 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- More than 60

4. Gender *

*Mark only one oval.*

- Female
- Male
- Prefer not to say

5. How far are you from DTU campus? *

*Mark only one oval.*

- 0 to 2 km
- 2 to 5 km
- 5 to 10 km
- 10 to 15 km
- more than 15 km

6. How do you get to DTU? *

*Tick all that apply.*

- [ ] Own bike
- [ ] Rented bike
- [ ] Bus
- [ ] Own car
- [ ] Shared car
- [ ] Train
- [ ] Walking

Other: [ ] ____________________

7. In case of using diverse means of transport, how do you combine them?

Examples: Bike-Train-Bike // Bike-Bus

____________________

8. How long does it take you to get to the university? *

For example: 20 minutes = 00:20

____________________

*Example: 8.30 a.m.*

9. In case you take the bus 150S, which stop do you use more frequently?

*Mark only one oval.*

( ) Rævehøjvej, DTU

( ) Klampenborgvej (Helsingørmotorvejen)

## In campus

10. How long is your longest route (on foot) on DTU campus? *

For example: 20 minutes = 00:20

____________________

*Example: 8.30 a.m.*

11. Do you consider a bike network beneficial/necessary at DTU? *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Completely disagree | ◯ | ◯ | ◯ | ◯ | ◯ | Completely agree |

12. In your opinion, how is the connection between DTU campus and Lyngby St.? *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Very bad connected | ◯ | ◯ | ◯ | ◯ | ◯ | Very well connected |

## Where do you live?

13. *

*Mark only one oval.*

- ◯ Accommodation provided by DTU *Skip to question 14*
- ◯ Student-house provided by DTU *Skip to question 14*
- ◯ Dormitory (Non-DTU) *Skip to question 14*
- ◯ Appartment *Skip to question 25*
- ◯ House *Skip to question 25*
- ◯ Other: ______________________

## Accommodation information

This section is to better understand the flow of people from accommodations to the campus.

14. How is the accommodation called? *

______________________

15. Would you rent a bike to come to the campus? *

*Mark only one oval.*

- Yes *Skip to question 18*
- No *Skip to question 25*
- Sometimes *Skip to question 18*

16. Which is the maximum distance, in kilometers, you would cycle to get to DTU? *

_______________________

17. Would you be willing to travel a greater distance if the bicycle were electric? *

*Mark only one oval.*

- Yes
- No

## New bike sharing system (BSS)

The new proposed BSS is divided into two different services:
A) Internal system at DTU campus, which will connect different buildings around the campus, as well as Lyngby St.
B) Internal and external BSS, which, in addition to characteristics from option A, will connect the campus with your accommodation.

## A) Internal bike sharing system at DTU campus

The proposed network **will connect** different **buildings** around the campus, as well as **Lyngby St**. Having different, but affordable fares depending on the use.

Main services:

- Specific parking spots that protect bikes from rain
- Easy unlock system by using your DTU card / identification

Mobile app:

- Possibility of booking within 5 minutes in advance
- Shows available parking spots
- Option to book a parking spot in your destination for a predetermined time depending on the distance

18. Which types of fares would you be interested in? *

*Tick all that apply.*

- [ ] Pay a fare per semester
- [ ] 12h or 24h renting fare
- [ ] Minute renting fare

Other: [ ] ____________________

19. If you are interested in a semester fare, how much would you be willing to pay per semester?

*Mark only one oval.*

- ( ) Up to 100 dkk
- ( ) From 100 to 150 dkk
- ( ) From 150 to 250 dkk
- ( ) More than 250 dkk

20. Would you like to have some available codes per semester for renting a bike to non-DTU guests? *

*Mark only one oval.*

- ( ) Yes
- ( ) No

21. How do you think a bike sharing system would improve your daily routine? *

*Tick all that apply.*

- [ ] It would let me choose whether I want to take the train or the bus to get to DTU.
- [ ] It would reduce my travel time on campus.
- [ ] It will allow me to go to Lyngby without using public transport.
- [ ] It will help me to be more environmentally friendly.

Other: [ ] ____________________

22. When would you consider cycling instead of walking on campus? I would cycle if the distance on foot takes me more than ... *

*Mark only one oval.*

- 5 minutes.
- 10 minutes
- 15 minutes.
- 20 minutes.
- 25 minutes.
- 30 minutes.
- I rather walk, nevermind the time.

## B) Exclusive fare for dorms

Option B **expands the service** offered in option A by **connecting DTU campus with your accommodation**. This service will allow you to use a bike during a specific period of time depending on your destination, paying a **monthly fare**.

The main advantage is that you will enjoy the service offered by the internal BSS at DTU campus plus:

- Reserved parking spots at peak hours
- Longer travel distances
- Better bike specifications (more gears)

23. Would you be interested in this specific type of renting? *

*Mark only one oval.*

- Yes
- No

24. Given that the most popular renting company offers fares around 175 dkk/month. What fare you would be willing to pay for DTU's monthly renting network (internal and external use)? *

*Mark only one oval.*

- Up to 100 dkk/month
- From 100 to 150 dkk/month
- From 150 to 200 dkk/month (as other companies)
- More than 200 dkk/month

*Skip to question 30*

## New bike sharing system (BSS) at DTU Campus

The proposed BSS **will connect** different **buildings** around the campus, as well as **Lyngby St**. Having different, but affordable fares depending on the use.

Main services:

- Specific parking spots that protect bikes from rain
- Easy unlock system by using your DTU card / identification

Mobile app:

- Possibility of booking within 5 minutes in advance
- Shows available parking spots
- Option to book a parking spot in your destination for a predetermined time depending on the distance

25. Which types of fares would you be interested in? *

*Tick all that apply.*

- [ ] Pay a fare per semester
- [ ] 12h or 24h renting fare
- [ ] Minute renting fare

Other: [ ] ____________________

26. If you are interested in a semester fare, how much would you be willing to pay per semester?

*Mark only one oval.*

- ⬭ Up to 100 dkk
- ⬭ From 100 to 150 dkk
- ⬭ From 150 to 250 dkk
- ⬭ More than 250 dkk

27. Would you like to have some available codes per semester for renting a bike to non-DTU guests? *

*Mark only one oval.*

- ⬭ Yes
- ⬭ No

28. How do you think a bike sharing system would improve your daily routine? *

*Tick all that apply.*

- [ ] It would let me choose whether I want to take the train or the bus to get to DTU.
- [ ] It would reduce my travel time on campus.
- [ ] It will allow me to go to Lyngby without using public transport.
- [ ] It will help me to be more environmentally friendly.

Other: [ ] ____________________

29. When would you consider cycling instead of walking on campus? I would cycle if the distance on foot takes me more than ... *

*Mark only one oval.*

- 5 minutes.
- 10 minutes
- 15 minutes.
- 20 minutes.
- 25 minutes.
- 30 minutes.
- I rather walk, nevermind the time.

## Where do you study/work?

30. *

*Mark only one oval.*

- Lyngby *Skip to question 35*
- Ballerup *Skip to question 31*
- Lyngby and Ballerup *Skip to question 32*

## When are you in Ballerup campus?

Remember this survey is completely anonymous.

*Required

31. My schedule is: *

M= Morning ; A=Afternoon ; E=Evening ; XX= I do not go to university

*Tick all that apply.*

| | M | A | E | XX |
|---|---|---|---|---|
| Mon | ☐ | ☐ | ☐ | ☐ |
| Tue | ☐ | ☐ | ☐ | ☐ |
| Wed | ☐ | ☐ | ☐ | ☐ |
| Thu | ☐ | ☐ | ☐ | ☐ |
| Fri | ☐ | ☐ | ☐ | ☐ |
| Sat | ☐ | ☐ | ☐ | ☐ |
| Sun | ☐ | ☐ | ☐ | ☐ |

*Skip to question 45*

Do you go to both campus the same day?

32. *

*Mark only one oval.*

- Yes
- No

**The distance between Ballerup and Lyngby is around 13 km, which takes 40-55 minutes by bus and 40-45 minutes by bike:**

33. Would you use the new bike system instead of the bus? *

*Mark only one oval.*

- Yes
- No

## When are you in DTU Ballerup?

34. My schedule is: *

M= Morning ; A=Afternoon ; E=Evening ; XX= I do not go to university

*Tick all that apply.*

| | M | A | E | XX |
|---|---|---|---|---|
| Mon | ☐ | ☐ | ☐ | ☐ |
| Tue | ☐ | ☐ | ☐ | ☐ |
| Wed | ☐ | ☐ | ☐ | ☐ |
| Thu | ☐ | ☐ | ☐ | ☐ |
| Fri | ☐ | ☐ | ☐ | ☐ |
| Sat | ☐ | ☐ | ☐ | ☐ |
| Sun | ☐ | ☐ | ☐ | ☐ |

*Skip to question 35*

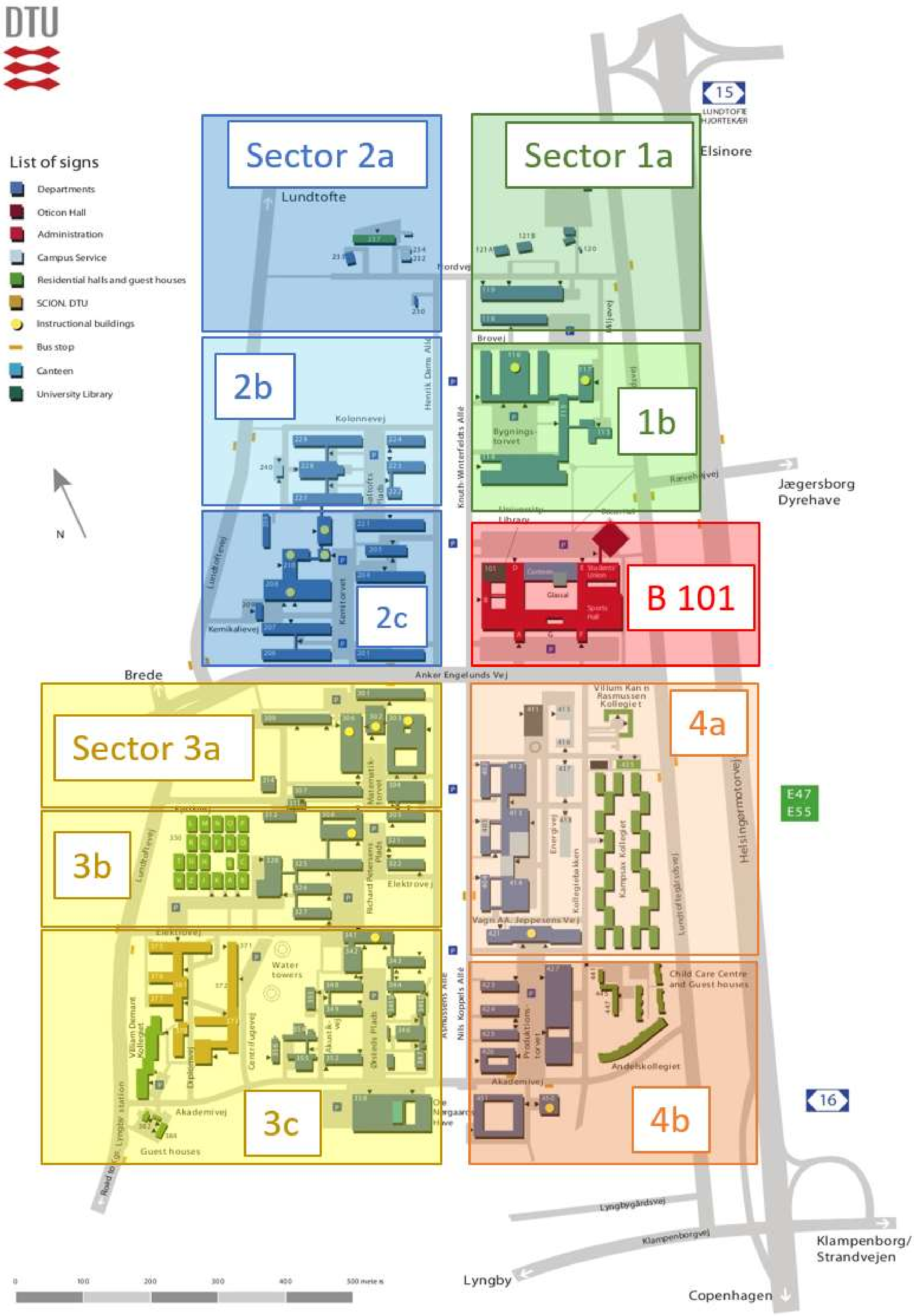
## When are you in DTU Lyngby?

Please, check the sector where you work/study in each question or check the option "I do not go to DTU".

You can use the map attached as support.

Remember this survey is completely anonymous.

DTU Sector's map



**Feel free to consider your schedule from last year instead of the current one if you think it is more representative (for instance if this semester you are doing your thesis)**

35. What schedule are you considering? *

*Mark only one oval.*

- ( ) Current schedule
- ( ) Schedule from last year
- ( ) Other: ____________________

36. Monday *

*Tick all that apply.*

| | 8-12 | 12-13 | 13-17 | 17-20 |
|---|---|---|---|---|
| I don't go to DTU | ☐ | ☐ | ☐ | ☐ |
| S 1a | ☐ | ☐ | ☐ | ☐ |
| S 1b | ☐ | ☐ | ☐ | ☐ |
| B 101 | ☐ | ☐ | ☐ | ☐ |
| S 2a | ☐ | ☐ | ☐ | ☐ |
| S 2b | ☐ | ☐ | ☐ | ☐ |
| S 2c | ☐ | ☐ | ☐ | ☐ |
| S 3a | ☐ | ☐ | ☐ | ☐ |
| S 3b | ☐ | ☐ | ☐ | ☐ |
| S 3c | ☐ | ☐ | ☐ | ☐ |
| S 4a | ☐ | ☐ | ☐ | ☐ |
| S 4b | ☐ | ☐ | ☐ | ☐ |

37. Tuesday *

*Tick all that apply.*

| | 8-12 | 12-13 | 13-17 | 17-20 |
|---|---|---|---|---|
| I don't go to DTU | ☐ | ☐ | ☐ | ☐ |
| S 1a | ☐ | ☐ | ☐ | ☐ |
| S 1b | ☐ | ☐ | ☐ | ☐ |
| B 101 | ☐ | ☐ | ☐ | ☐ |
| S 2a | ☐ | ☐ | ☐ | ☐ |
| S 2b | ☐ | ☐ | ☐ | ☐ |
| S 2c | ☐ | ☐ | ☐ | ☐ |
| S 3a | ☐ | ☐ | ☐ | ☐ |
| S 3b | ☐ | ☐ | ☐ | ☐ |
| S 3c | ☐ | ☐ | ☐ | ☐ |
| S 4a | ☐ | ☐ | ☐ | ☐ |
| S 4b | ☐ | ☐ | ☐ | ☐ |

38. Wednesday *

*Tick all that apply.*

| | 8-12 | 12-13 | 13-17 | 17-20 |
|---|---|---|---|---|
| I don't go to DTU | ☐ | ☐ | ☐ | ☐ |
| S 1a | ☐ | ☐ | ☐ | ☐ |
| S 1b | ☐ | ☐ | ☐ | ☐ |
| B 101 | ☐ | ☐ | ☐ | ☐ |
| S 2a | ☐ | ☐ | ☐ | ☐ |
| S 2b | ☐ | ☐ | ☐ | ☐ |
| S 2c | ☐ | ☐ | ☐ | ☐ |
| S 3a | ☐ | ☐ | ☐ | ☐ |
| S 3b | ☐ | ☐ | ☐ | ☐ |
| S 3c | ☐ | ☐ | ☐ | ☐ |
| S 4a | ☐ | ☐ | ☐ | ☐ |
| S 4b | ☐ | ☐ | ☐ | ☐ |

39. Thursday *

*Tick all that apply.*

| | 8-12 | 12-13 | 13-17 | 17-20 |
|---|---|---|---|---|
| I don't go to DTU | ☐ | ☐ | ☐ | ☐ |
| S 1a | ☐ | ☐ | ☐ | ☐ |
| S 1b | ☐ | ☐ | ☐ | ☐ |
| B 101 | ☐ | ☐ | ☐ | ☐ |
| S 2a | ☐ | ☐ | ☐ | ☐ |
| S 2b | ☐ | ☐ | ☐ | ☐ |
| S 2c | ☐ | ☐ | ☐ | ☐ |
| S 3a | ☐ | ☐ | ☐ | ☐ |
| S 3b | ☐ | ☐ | ☐ | ☐ |
| S 3c | ☐ | ☐ | ☐ | ☐ |
| S 4a | ☐ | ☐ | ☐ | ☐ |
| S 4b | ☐ | ☐ | ☐ | ☐ |

40. Friday *

*Tick all that apply.*

| | 8-12 | 12-13 | 13-17 | 17-20 |
|---|---|---|---|---|
| I don't go to DTU | ☐ | ☐ | ☐ | ☐ |
| S 1a | ☐ | ☐ | ☐ | ☐ |
| S 1b | ☐ | ☐ | ☐ | ☐ |
| B 101 | ☐ | ☐ | ☐ | ☐ |
| S 2a | ☐ | ☐ | ☐ | ☐ |
| S 2b | ☐ | ☐ | ☐ | ☐ |
| S 2c | ☐ | ☐ | ☐ | ☐ |
| S 3a | ☐ | ☐ | ☐ | ☐ |
| S 3b | ☐ | ☐ | ☐ | ☐ |
| S 3c | ☐ | ☐ | ☐ | ☐ |
| S 4a | ☐ | ☐ | ☐ | ☐ |
| S 4b | ☐ | ☐ | ☐ | ☐ |

41. Weekends *

*Mark only one oval.*

- ⬭ I do not go to university
- ⬭ I go to the library at 101
- ⬭ I go to another building

*Skip to question 42*

During my leisure time on campus

42. I usually like to ... *

*Tick all that apply.*

- [ ] Go home
- [ ] Visit Lyngby
- [ ] Go to Lyngby storecenter
- [ ] Watch a film at Lyngby's cinema
- [ ] Take the train and visit Copenhagen
- [ ] Go to the swimming pool

Other: [ ] ______________________

43. Would you like to get there by bike? *

*Mark only one oval.*

( ) Yes
( ) No

44. If yes, would you increase the frequency with which you go there?

*Mark only one oval.*

( ) Yes
( ) No

If you would like to help me in the next few months filling a related survey, please let me know your e-mail

45. My e-mail

______________________

Your comments and suggestions are more than welcome!

46. Comments / Suggestions

## E.2 Short survey

# Short survey: Public transport on Lyngby campus

Commute=regular traveling between locations (e.g. the path that goes from morning lecture's building to afternoon lecture's building)

On campus = inside DTU Lyngby campus (e.g. from B101 to B358)

The price of a 1 stop trip within the same sector is usually around 16 dkk.
*Required

1. Have you ever used public transport to get to DTU Lyngby campus? *

   *Mark only one oval.*

   ◯ Yes
   ◯ No

2. Have you ever needed to walk large distances on campus? *

   *Mark only one oval.*

   ◯ Yes
   ◯ No

3. Have you ever used public transport (bus) to commute on campus? *

   *Mark only one oval.*

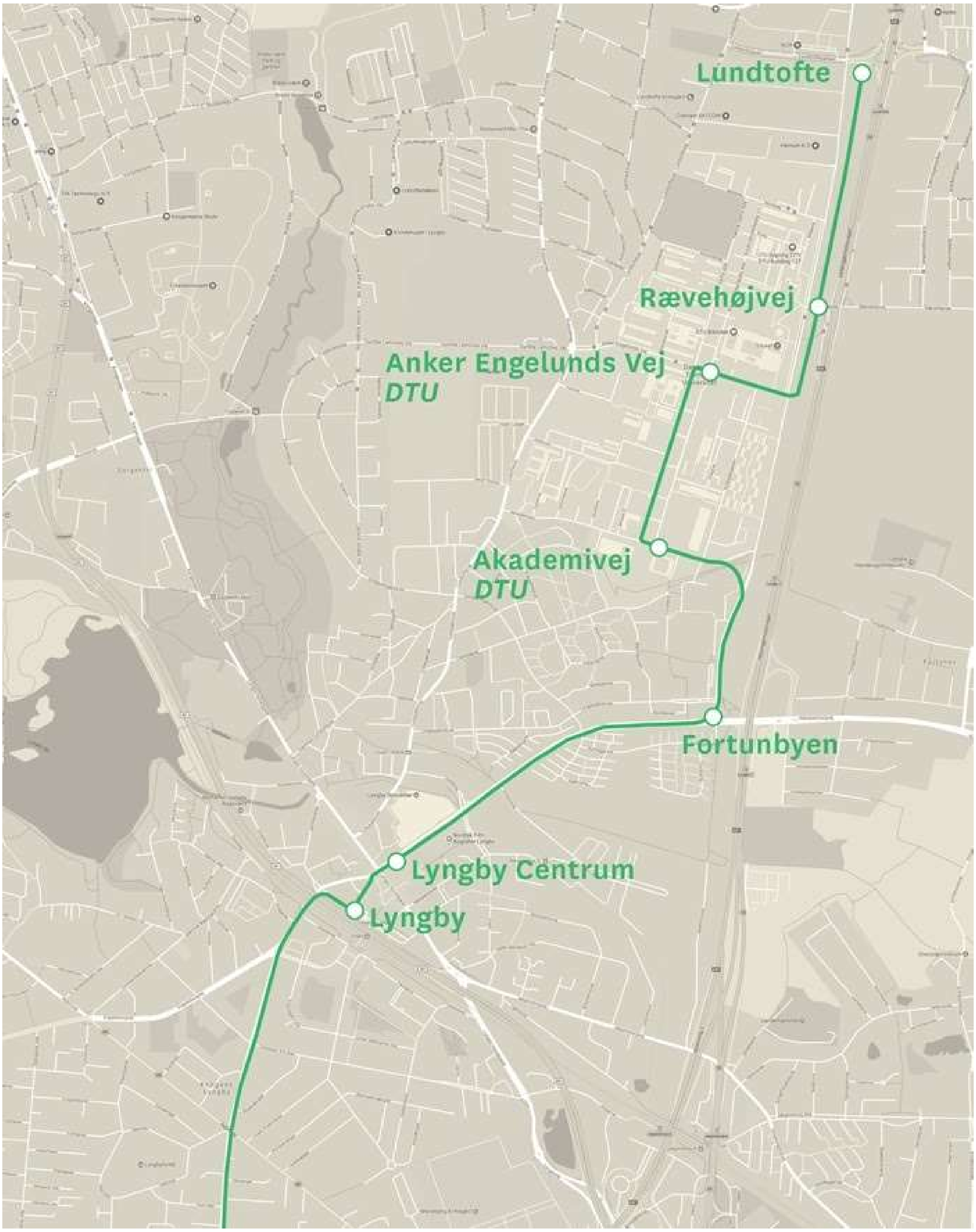
   ◯ Yes
   ◯ No

4. Light rail will arrive in 2025 and it will have three stops on campus (see picture). In case you were studying/working on DTU at that moment and considering that prices are the same as a regular s-tog, Would you use it for commute on campus? *

*Mark only one oval.*

- Yes
- No

Light rail on campus (Akademivej DTU, Anker Engelunds Vej DTU and Rævehøjvej)



5. DTU is testing a driverless bus that will connect the 29 light rail stops with the surroundings. This will include DTU campus. Prices will be similar to the current public buses. If this service would reduce your commuting time on campus, Would you use it? *

*Mark only one oval.*

- Yes
- No

6. Would you prefer another mean of transport to commute on campus? (e.g. bike-sharing system or e-scooters with more competitive and accessible prices than current public transport) *

*Mark only one oval.*

- Yes
- No

7. Comments

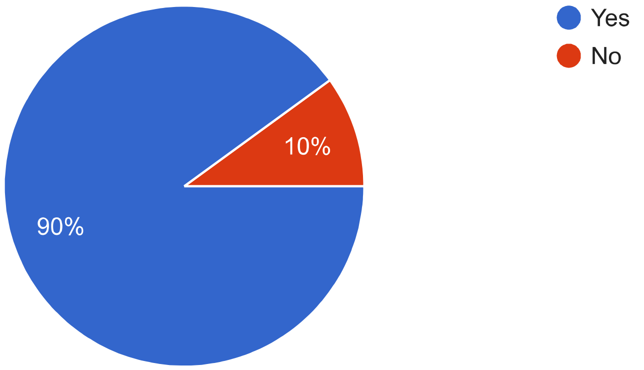
# Short survey: Public transport on Lyngby campus

10 responses

Publish analytics

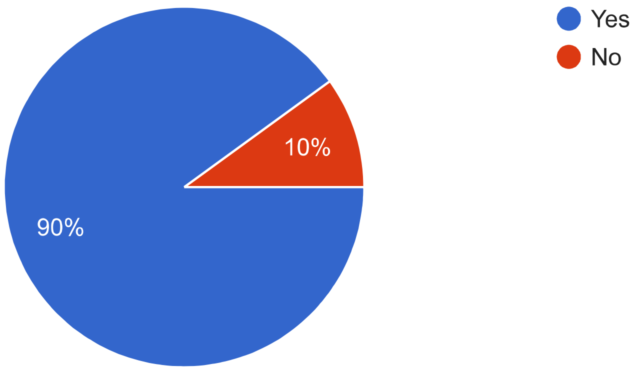
Have you ever used public transport to get to DTU Lyngby campus?

10 responses



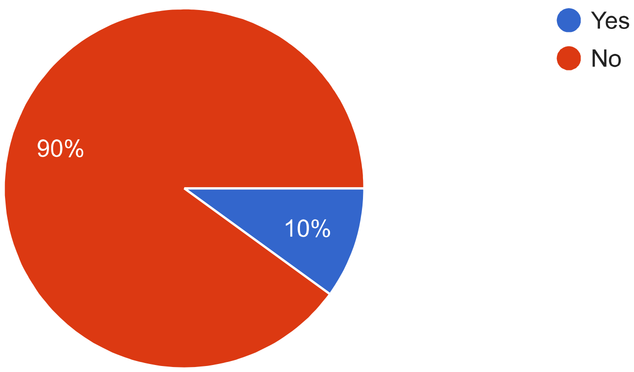

Have you ever needed to walk large distances on campus?

10 responses



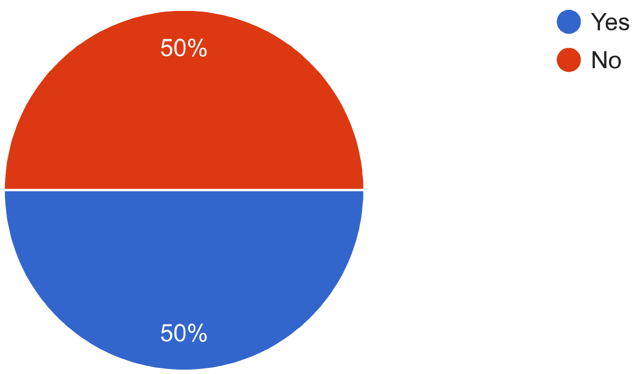
Have you ever used public transport (bus) to commute on campus?

10 responses



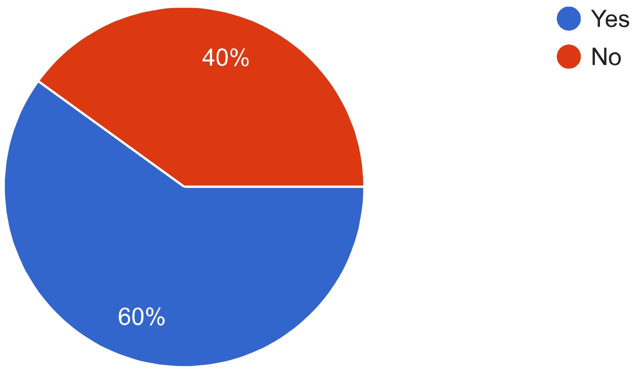

Light rail will arrive in 2025 and it will have three stops on campus (see picture). In case you were studying/working on DTU at that moment and considering that prices are the same as a regular s-tog, Would you use it for commute on campus?

10 responses



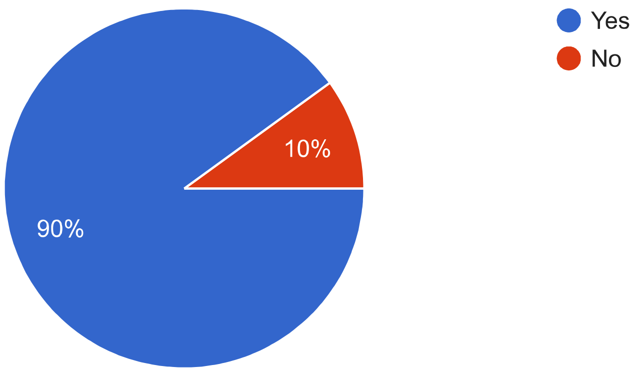
DTU is testing a driverless bus that will connect the 29 light rail stops with the surroundings. This will include DTU campus. Prices will be similar to the current public buses. If this service would reduce your commuting time on campus, Would you use it?

10 responses




Would you prefer another mean of transport to commute on campus? (e.g. bike-sharing system or e-scooters with more competitive and accessible prices than current public transport)

10 responses




Comments

2 responses

Not to depend on the schedules and for a more sustainable and optimal solution I would choose biking service before anything else

If I had ungdomskort I would use everything, if I had to pay per journey I wouldn't

# F Appendix: Design

In this appendix tables of results, processes and figures needed for the design phase in section 5.3 are going to be displayed.

## F.1 Data sets: explanation of the process

1. First of all, the primitive data has been transformed into four tables, one per time period (8-12, 12-13, 13-17, and 17-20). This is because the initial data came in tables where the respondent said at what times was at what building (Example in table F.1).

| ID Fila | Tuesday * [I don't go to DTU] | Tuesday * [S 1a] | Tuesday * [S 1b] | Tuesday * [B 101] | Tuesday * [S 2a] | Tuesday * [S 2b] |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 12-13, 13-17, 17-20 | 0 | 8-12 | 0 | 0 | 0 |

| ID Fila | Tuesday * [S 2c] | Tuesday * [S 3a] | Tuesday * [S 3b] | Tuesday * [S 3c] | Tuesday * [S 4a] | Tuesday * [S 4b] |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 8-12, 12-13, 13-17 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 |

Table F.1: Data before any treatment. Examples of profiles 1 and 7.

These new tables used Excel formulas to find the time step in the initial one, and mark it with a number in the new table (Table F.2). The formula used is the following: *IFERROR(FIND(value; INDEX(range; MATCH(value; range; exact coincidence); IFS(conditional; value)));"")*.

| | 8-12 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | XX | S1a | S1b | B101 | S2a | S2b | S2c | S3a | S3b | S3c | S4a | S4c |
| **1** | | | | | | | | | | | 1 | |
| **7** | | | 1 | | | | | | | | | |

Table F.2: Data treatment step 1. (Profiles 1 and 7 are at sectors S4a and S1b at time step 8-12 on Tuesdays respectively).

2. After creating these tables for all weekdays and time steps, it is needed to change the number to the sector name. For this, the formulas "IF, INDEX, and MATCH" have been used again to transform data from table F.2 to table F.3. The formula is the following: *IFERROR(INDEX(range; 1; MATCH(value; range; -1)); "No answer")*.

| | TUESDAY | | | |
|---|---|---|---|---|
| | **8-12** | **12-13** | **13-17** | **17-20** |
| **1** | S4a | S4a | S4a | No_answer |
| **2** | S3c | B101 | B101 | B101 |
| **3** | S3c | No_answer | No_answer | No_answer |
| **4** | S4a | B101 | B101 | S2c |
| **5** | No_answer | No_answer | No_answer | No_answer |
| **6** | XX | B101 | S3b | B101 |
| **7** | S1b | XX | XX | XX |

Table F.3: Example of the schedule after data treatment.

3. Now, the entrance and exit time to the system is needed, therefore another table is created, where Entry building, time of entry exit building and time of exit is stated. The formula used is a simple chain of ”IF”, where is asking whether there is an answer or not in table F.3. If the condition is fulfilled, that building will be the entrance one.

4. The fourth step is organizing the data in columns to create pivot tables, from where it can be obtained the number of displacements at each time step. In total 5 tables are needed for entering, 5 for the exit, and 3 for the internal commutes. The first ten tables gather the number of displacements from the mean of transport to the entrance building and vice versa. The internal commutes are collecting the displacements between buildings on campus. For instance, the appearance of the pivot table on Mondays for entering into the system at time step one, is as shown in Table F.4.

| **Entry time** | **8-12** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **S1a** | **S1b** | **B101** | **S2b** | **S2c** | **S3a** | **S3b** | **S3c** | **S4a** | **S4c** | | **Total** |
| **Klampenborgvej (Helsingørmotorvejen)** | | | | | | | 1 | 3 | 1 | 2 | 3 | **10** |
| **Lyngby St** | 2 | 4 | 5 | | 5 | 5 | 10 | 9 | 4 | 2 | 26 | **72** |
| **Rævehøjvej, DTU** | 3 | 7 | 6 | 2 | | 5 | 1 | 11 | 6 | 4 | 14 | **59** |
| **#N/D** | | | | | | | | | 5 | 6 | 240 | **251** |
| **Internal** | 5 | 6 | 2 | 5 | | 4 | 2 | 7 | 4 | 1 | 17 | **53** |
| **B101** | 1 | | | 1 | 3 | 3 | 3 | 1 | 3 | | 1 | **16** |
| **Storecenter** | | | 1 | | 4 | 3 | | 2 | 1 | | 4 | **15** |
| **Swimming pool** | | 1 | 4 | | 1 | 1 | 1 | 2 | | | 4 | **14** |
| **Cinema** | | | 1 | | | | | | | | 1 | **2** |
| **Visit Lyngby** | | 1 | 2 | | | 1 | | 1 | 1 | | 3 | **9** |
| Total | **11** | **19** | **21** | **8** | **13** | **22** | **18** | **36** | **25** | **15** | **313** | **501** |

Table F.4: Example of pivot table with the number of commutes on campus at 08:00.

5. Now is time to join all these tables into five (one per time step), remove those unnecessary movements (i.e. B101 to B101), and multiply the commutes by the percentage of the population for which is going to be designed the system.

6. Finally, this data has to be assembled in the format asked by the optimization program ”IBM CPLEX Optimization”. The formula that has been used for this purpose is *TEXTJOIN*, obtaining sets like the following one, which is representing the commutes on Monday on campus for the five time steps.

   [[[0, 0, 0, 16, 36, 41, 0, 11, 21, 51, 11, 66, 36, 21], [0, 0, 0, 6, 0, 11, 0, 0, 0, 0, 6, 26, 6, 11], [0, 0, 0, 11, 21, 26, 0, 0, 31, 31, 61, 46, 21, 11], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]] ,

   [[0, 0, 0, 0, 0, 36, 0, 0, 11, 0, 11, 6, 11, 0], [0, 0, 0, 0, 0, 6, 0, 0, 0, 0, 0, 6, 0, 0], [0, 0, 0, 6, 0, 26, 0, 0, 0, 6, 6, 6, 0, 0], [6, 0, 11, 0, 11, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 36, 0, 0, 0, 0, 0, 0, 0, 6], [0, 0, 0, 0, 0, 0, 0, 0, 6, 11, 0, 6, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 11, 0, 0, 6, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 31, 0, 0, 0, 0, 0, 0, 6, 0], [21, 0, 16, 0, 6, 31, 0, 6, 6, 0, 0, 6, 0, 0], [6, 0, 11, 0, 0, 11, 0, 0, 0, 6, 0, 0, 6, 0], [16, 0, 6, 6, 6, 41, 0, 0, 0, 0, 0, 0, 0, 0], [11, 6, 11, 0, 0, 16, 0, 0, 0, 0, 0, 0, 0, 0], [6, 0, 0, 0, 0, 6, 0, 0, 0, 0, 0, 0, 0, 0]] ,

   [[0, 0, 0, 0, 6, 0, 0, 0, 0, 11, 6, 6, 0, 0], [0, 0, 0, 0, 6, 0, 6, 0, 0, 0, 0, 0, 6, 0], [0, 0, 0,

0, 0, 0, 0, 0, 0, 16, 6, 21, 0, 0], [0, 0, 6, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 6], [0, 0, 6, 0, 0, 6, 6, 0, 0, 0, 0, 6, 0, 0], [16, 6, 11, 0, 31, 0, 21, 11, 31, 51, 16, 41, 11, 11], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [6, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [6, 0, 11, 0, 6, 0, 6, 0, 0, 0, 6, 0, 0, 0], [0, 0, 0, 0, 0, 6, 0, 0, 0, 0, 6, 0, 0, 0], [0, 0, 6, 0, 0, 0, 0, 0, 0, 6, 0, 21, 0, 0], [0, 0, 11, 0, 6, 6, 0, 0, 0, 11, 6, 0, 0, 0], [0, 0, 0, 0, 0, 6, 0, 0, 6, 0, 0, 0, 0, 0], [0, 0, 0, 0, 6, 0, 0, 0, 0, 0, 0, 6, 0, 0]] ,

[[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 6, 0, 0, 0, 0, 0, 0, 0, 0], [6, 6, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [46, 6, 11, 0, 0, 0, 0, 0, 0, 0, 6, 0, 0, 6], [36, 0, 16, 0, 0, 0, 0, 0, 0, 0, 6, 0, 6, 0], [11, 6, 0, 0, 0, 0, 0, 0, 6, 0, 0, 0, 6, 0], [6, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [16, 0, 0, 0, 0, 16, 0, 0, 0, 0, 0, 0, 6, 0], [21, 6, 41, 0, 0, 26, 6, 0, 0, 0, 0, 6, 0, 0], [11, 0, 36, 0, 0, 11, 0, 0, 6, 0, 0, 0, 0, 0], [36, 21, 51, 0, 0, 0, 6, 0, 0, 0, 16, 0, 6, 0], [21, 6, 16, 0, 0, 6, 0, 0, 0, 0, 0, 0, 0, 6], [6, 0, 6, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]] ,

[[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [6, 0, 6, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [6, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [36, 0, 31, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [6, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [11, 0, 11, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [0, 6, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [11, 6, 21, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [6, 11, 6, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [21, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0], [11, 11, 6, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]]];

## F.2 Tables of results

| | Scenario 1 | | |
|---|---|---|---|
| **y** | **All commutes** | **With reduction** | |
| **Monday** | 447 | 402 | |
| **Tuesday** | 487 | 391 | |
| **Wednesday** | 420 | 344 | |
| **Thursday** | 465 | 384 | |
| **Friday** | 345 | 288 | |
| **Maximum** | 487 | 402 | -17% |

Table F.5: Number of bikes needed obtained for each day from the mathematical model in Scenario 1

| | Scenario 2 | | |
|---|---|---|---|
| **y** | **All commutes** | **With reduction** | |
| **Monday** | 485 | 432 | |
| **Tuesday** | 506 | 406 | |
| **Wednesday** | 453 | 384 | |
| **Thursday** | 505 | 422 | |
| **Friday** | 343 | 288 | |
| **Maximum** | 506 | 432 | -15% |

Table F.6: Number of bikes needed obtained for each day from the mathematical model in Scenario 2

| | Scenario 3 | | |
|---|---|---|---|
| **y** | **All commutes** | **With reduction** | |
| **Monday** | 452 | 421 | |
| **Tuesday** | 514 | 443 | |
| **Wednesday** | 433 | 367 | |
| **Thursday** | 460 | 384 | |
| **Friday** | 337 | 206 | |
| **Maximum** | 514 | 443 | -14% |

Table F.7: Number of bikes needed obtained for each day from the mathematical model in Scenario 3

| | COMPARISON | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Rævehøjvej, DTU | Klampenborgvej | S1a | S1b | B101 | S2a | S2b | S2c | S3a | S3b | S3c | S4a | S4b |
| **1** | **Rævehøjvej, DTU** | | | -1 | -3 | -2 | | | | | | | | |
| **2** | **Klampenborgvej** | | | | | | | | | | | | | 2 |
| **4** | **S1a** | -1 | | | -3 | | 0 | 2 | | | | | | |
| **5** | **S1b** | -3 | | -3 | | 0 | -3 | -1 | 0 | | | | | |
| **6** | **B101** | -2 | | | 0 | | | 1 | 1 | 1 | | | 0 | |
| **7** | **S2a** | | | 0 | -3 | | | 1 | | | | | | |
| **8** | **S2b** | | | 2 | -1 | 1 | 1 | | -1 | | | | | |
| **9** | **S2c** | | | | 0 | 1 | | -1 | | -2 | | | 1 | |
| **10** | **S3a** | | | | | 1 | | | -2 | | -5 | | 0 | |
| **11** | **S3b** | | | | | | | | | -5 | | 0 | 0 | 3 |
| **12** | **S3c** | | | | | | | | | | 0 | | 1 | -2 |
| **13** | **S4a** | | | | | 0 | | | 1 | 0 | 0 | 1 | | 1 |
| **14** | **S4b** | | 2 | | | | | | | | 3 | -2 | 1 | |

Table F.8: Comparison between travel time on foot and by bike in minutes

| | COMPARISON | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Rævehøjvej, DTU | Klampenborgvej | S1a | S1b | B101 | S2a | S2b | S2c | S3a | S3b | S3c | S4a | S4b |
| **1** | **Rævehøjvej, DTU** | | | ON FOOT | ON FOOT | ON FOOT | | | | | | | | |
| **2** | **Klampenborgvej** | | | | | | | | | | | | | BY BIKE |
| **4** | **S1a** | ON FOOT | | | ON FOOT | | 50% | BY BIKE | | | | | | |
| **5** | **S1b** | ON FOOT | | ON FOOT | | 50% | ON FOOT | ON FOOT | 50% | | | | | |
| **6** | **B101** | ON FOOT | | | 50% | | | BY BIKE | BY BIKE | BY BIKE | | | 50% | |
| **7** | **S2a** | | | 50% | ON FOOT | | | BY BIKE | | | | | | |
| **8** | **S2b** | | | BY BIKE | ON FOOT | BY BIKE | BY BIKE | | ON FOOT | | | | | |
| **9** | **S2c** | | | | 50% | BY BIKE | | ON FOOT | | ON FOOT | | | BY BIKE | |
| **10** | **S3a** | | | | | BY BIKE | | | ON FOOT | | ON FOOT | | 50% | |
| **11** | **S3b** | | | | | | | | | ON FOOT | | 50% | 50% | BY BIKE |
| **12** | **S3c** | | | | | | | | | | 50% | | BY BIKE | ON FOOT |
| **13** | **S4a** | | | | | 50% | | | BY BIKE | 50% | 50% | BY BIKE | | BY BIKE |
| **14** | **S4b** | | BY BIKE | | | | | | | | BY BIKE | ON FOOT | BY BIKE | |

Table F.9: Conclusions of the comparison between travel time on foot and by bike in table F.8.

| | | Scenario 1 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Monday | | Tuesday | | Wednesday | | Thursday | | Friday | |
| | | All commutes | With reduction | All commutes | With reduction | All commutes | With reduction | All commutes | With reduction | All commutes | With reduction |
| **1** | **Rævehøjvej, DTU** | 263 | 157 | 261 | 159 | 221 | 98 | 236 | 137 | 166 | 58 |
| **2** | **Klampenborgvej** | 45 | 39 | 37 | 30 | 33 | 33 | 49 | 29 | 31 | 34 |
| **3** | **Lyngby St** | 125 | 158 | 172 | 164 | 161 | 170 | 170 | 157 | 143 | 135 |
| **4** | **S1a** | 12 | 11 | 35 | 22 | 11 | 6 | 18 | 12 | 11 | 11 |
| **5** | **S1b** | 43 | 21 | 44 | 28 | 37 | 16 | 68 | 32 | 48 | 27 |
| **6** | **B101** | 174 | 157 | 181 | 145 | 184 | 138 | 158 | 141 | 96 | 96 |
| **7** | **S2a** | 23 | 12 | 11 | 11 | 6 | 6 | 6 | 6 | 11 | 11 |
| **8** | **S2b** | 11 | 11 | 6 | 6 | 12 | 12 | 22 | 18 | 6 | 6 |
| **9** | **S2c** | 37 | 37 | 32 | 34 | 29 | 29 | 27 | 27 | 18 | 16 |
| **10** | **S3a** | 82 | 82 | 67 | 68 | 65 | 54 | 67 | 66 | 33 | 27 |
| **11** | **S3b** | 46 | 37 | 66 | 38 | 44 | 43 | 49 | 43 | 34 | 24 |
| **12** | **S3c** | 91 | 85 | 103 | 93 | 72 | 72 | 89 | 75 | 85 | 89 |
| **13** | **S4a** | 28 | 24 | 54 | 44 | 80 | 39 | 45 | 40 | 47 | 47 |
| **14** | **S4c** | 17 | 12 | 17 | 17 | 31 | 30 | 26 | 11 | 16 | 6 |

Table F.10: Docks needed per area in scenario 1

| | | Scenario 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Monday | | Tuesday | | Wednesday | | Thursday | | Friday | |
| | | All commutes | With reduction | All commutes | With reduction | All commutes | With reduction | All commutes | With reduction | All commutes | With reduction |
| **1** | **Rævehøjvej, DTU** | 154 | 79 | 147 | 69 | 163 | 82 | 106 | 49 | 76 | 28 |
| **2** | **Klampenborgvej** | 12 | 33 | 47 | 35 | 40 | 51 | 28 | 33 | 41 | 29 |
| **3** | **Lyngby St.** | 205 | 176 | 176 | 161 | 150 | 133 | 179 | 149 | 136 | 108 |
| **4** | **Nordvej S.R.** | 58 | 70 | 60 | 60 | 42 | 45 | 35 | 35 | 33 | 38 |
| **5** | **Linde Alle S.R.** | 23 | 28 | 18 | 33 | 18 | 19 | 38 | 25 | 17 | 24 |
| **6** | **P.O. Pedersen K.** | 6 | 6 | 6 | 6 | 5 | 5 | 9 | 12 | 0 | 0 |
| **7** | **Kampsax Kollegiet** | 6 | 6 | 12 | 7 | 12 | 6 | 12 | 6 | 6 | 6 |
| **8** | **Campus Village** | 6 | 7 | 11 | 12 | 6 | 18 | 14 | 12 | 11 | 11 |
| **9** | **P. Ostenfeld K.** | 6 | 6 | 12 | 10 | 6 | 12 | 17 | 23 | 11 | 10 |
| **10** | **Hempel Kollegiet** | 6 | 6 | 0 | 1 | 0 | 6 | 0 | 1 | 6 | 6 |
| **11** | **Poul Bergsøe K.** | 2 | 2 | 6 | 6 | 6 | 0 | 11 | 6 | 6 | 6 |
| **12** | **S1a** | 15 | 12 | 35 | 23 | 12 | 6 | 24 | 12 | 11 | 11 |
| **13** | **S1b** | 49 | 27 | 50 | 28 | 42 | 16 | 67 | 34 | 42 | 27 |
| **14** | **B101** | 181 | 170 | 198 | 164 | 190 | 144 | 187 | 168 | 85 | 81 |
| **15** | **S2a** | 12 | 12 | 11 | 11 | 6 | 6 | 6 | 6 | 11 | 11 |
| **16** | **S2b** | 15 | 11 | 6 | 6 | 18 | 12 | 22 | 12 | 8 | 6 |
| **17** | **S2c** | 37 | 37 | 32 | 34 | 29 | 29 | 27 | 27 | 18 | 16 |
| **18** | **S3a** | 100 | 94 | 65 | 58 | 79 | 54 | 52 | 52 | 39 | 33 |
| **19** | **S3b** | 46 | 34 | 75 | 50 | 51 | 50 | 49 | 43 | 35 | 24 |
| **20** | **S3c** | 86 | 85 | 103 | 93 | 79 | 79 | 93 | 81 | 76 | 76 |
| **21** | **S4a** | 33 | 26 | 54 | 44 | 69 | 44 | 45 | 40 | 47 | 47 |
| **22** | **S4c** | 17 | 12 | 23 | 23 | 23 | 31 | 47 | 23 | 16 | 6 |

Table F.11: Docks needed per area in scenario 2

| | | Scenario 3 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Monday | | Tuesday | | Wednesday | | Thursday | | Friday | |
| | | All commutes | With reduction | All commutes | With reduction | All commutes | With reduction | All commutes | With reduction | All commutes | With reduction |
| **1** | **Rævehøjvej, DTU** | 147 | 93 | 154 | 43 | 103 | 60 | 149 | 26 | 170 | 82 |
| **2** | **Klampenborgvej** | 24 | 33 | 22 | 24 | 18 | 34 | 33 | 18 | 47 | 18 |
| **3** | **Lyngby St** | 134 | 140 | 159 | 202 | 219 | 163 | 131 | 185 | 111 | 101 |
| **4** | **Visit Lyngby** | 23 | 22 | 24 | 25 | 22 | 9 | 18 | 12 | 0 | 0 |
| **5** | **Storecenter** | 30 | 34 | 85 | 70 | 34 | 46 | 48 | 45 | 0 | 0 |
| **6** | **Cinema** | 18 | 18 | 6 | 6 | 9 | 13 | 6 | 18 | 0 | 0 |
| **7** | **Swimming pool** | 41 | 30 | 20 | 23 | 17 | 12 | 46 | 35 | 0 | 0 |
| **8** | **S1a** | 22 | 11 | 35 | 29 | 12 | 12 | 18 | 6 | 11 | 11 |
| **9** | **S1b** | 49 | 33 | 50 | 33 | 56 | 16 | 68 | 36 | 37 | 6 |
| **10** | **B101** | 160 | 158 | 185 | 162 | 179 | 138 | 156 | 158 | 59 | 22 |
| **11** | **S2a** | 12 | 12 | 11 | 11 | 6 | 6 | 6 | 6 | 11 | 11 |
| **12** | **S2b** | 11 | 11 | 6 | 6 | 18 | 12 | 18 | 18 | 6 | 0 |
| **13** | **S2c** | 35 | 35 | 32 | 34 | 29 | 29 | 27 | 27 | 27 | 13 |
| **14** | **S3a** | 80 | 80 | 72 | 61 | 72 | 64 | 62 | 62 | 28 | 16 |
| **15** | **S3b** | 51 | 34 | 57 | 54 | 55 | 54 | 49 | 43 | 29 | 18 |
| **16** | **S3c** | 85 | 85 | 111 | 101 | 72 | 72 | 95 | 80 | 64 | 60 |
| **17** | **S4a** | 32 | 24 | 54 | 44 | 67 | 56 | 45 | 40 | 47 | 44 |
| **18** | **S4c** | 17 | 12 | 23 | 23 | 23 | 17 | 38 | 17 | 16 | 6 |

Table F.12: Docks needed per area in scenario 3

## F.3 Stations distribution

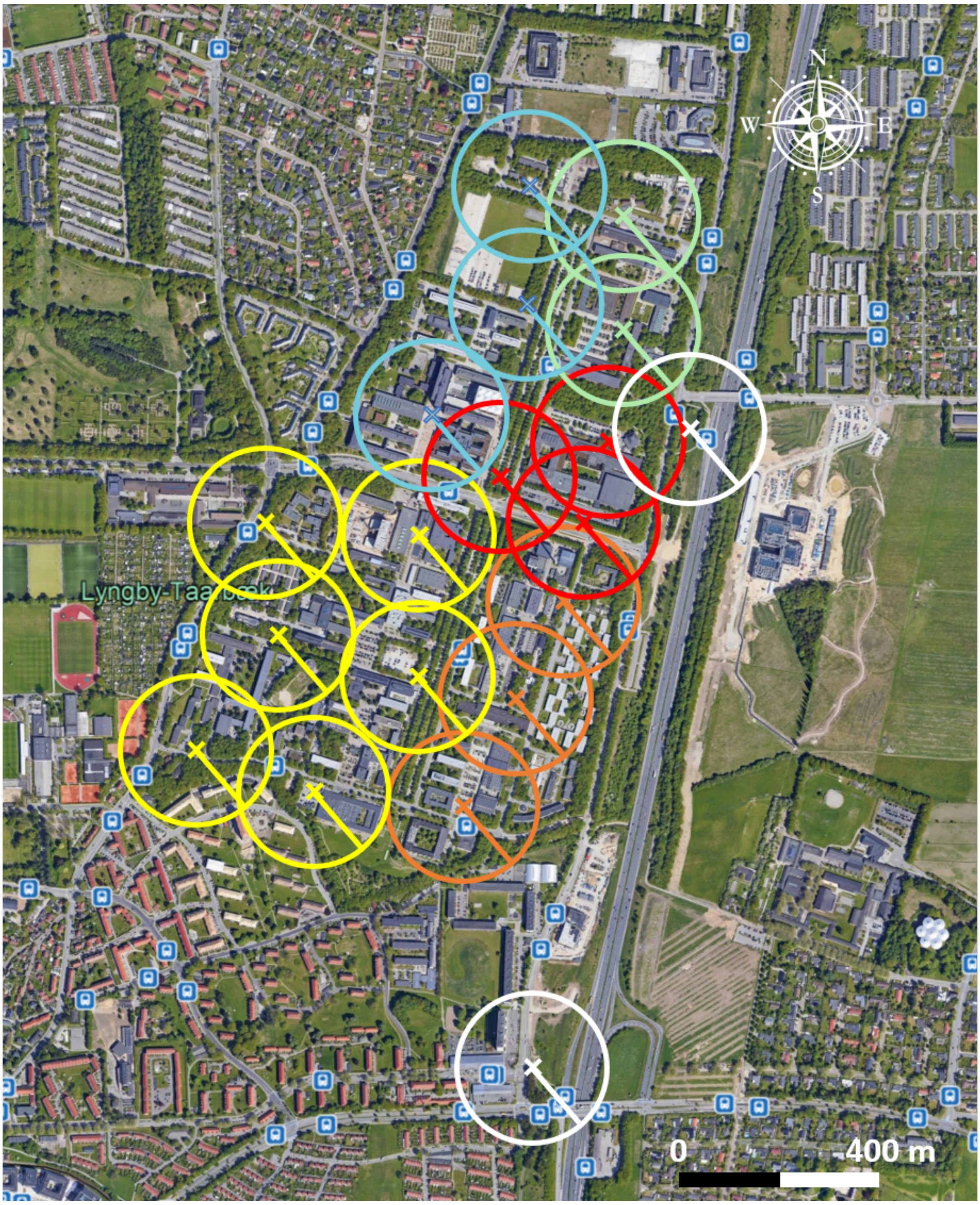



Figure F.1: Proposal of station locations on campus following recommendations in table 8.7.

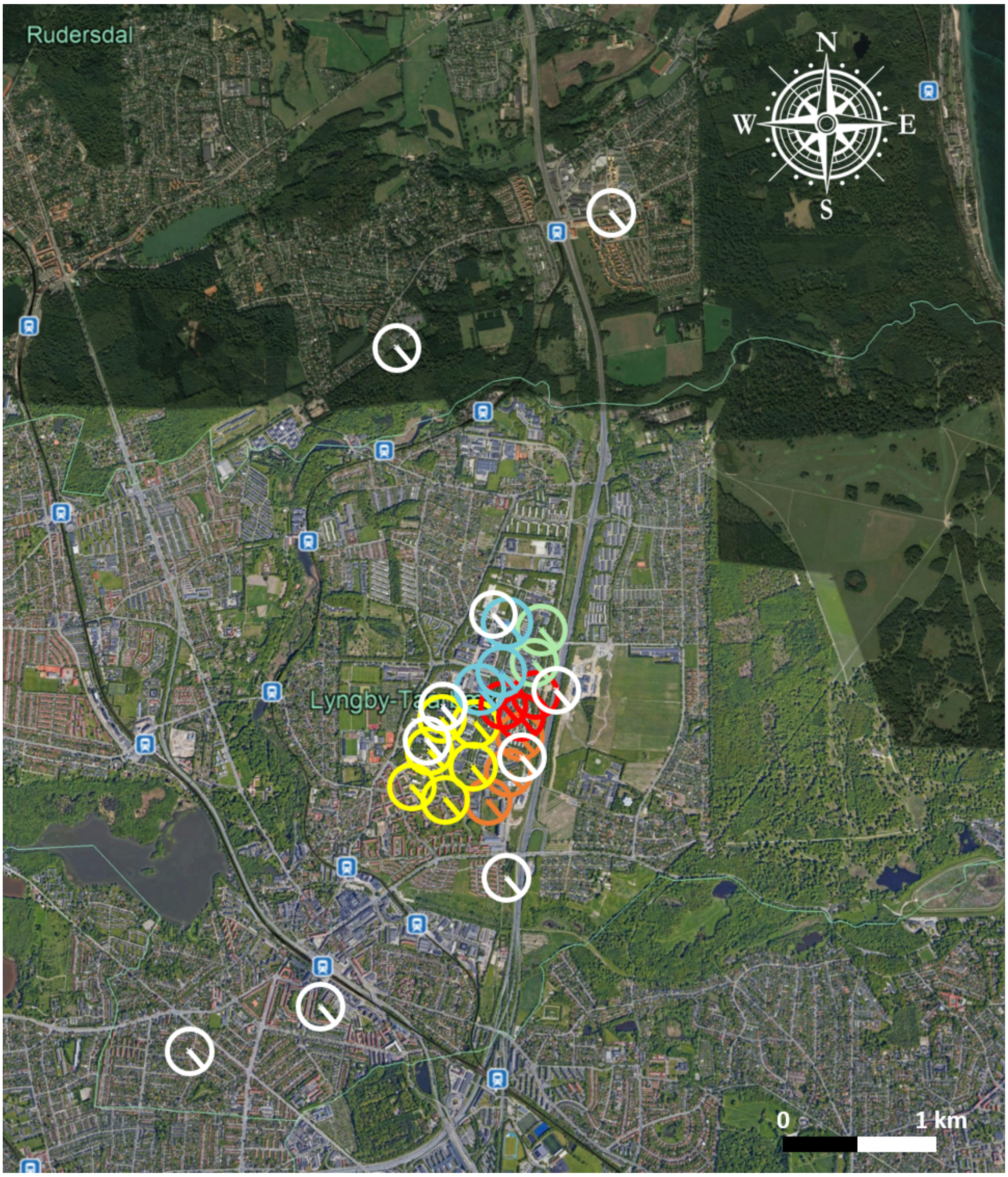



Figure F.2: Proposal of station locations on Scenario 2 following recommendations in table 8.7.

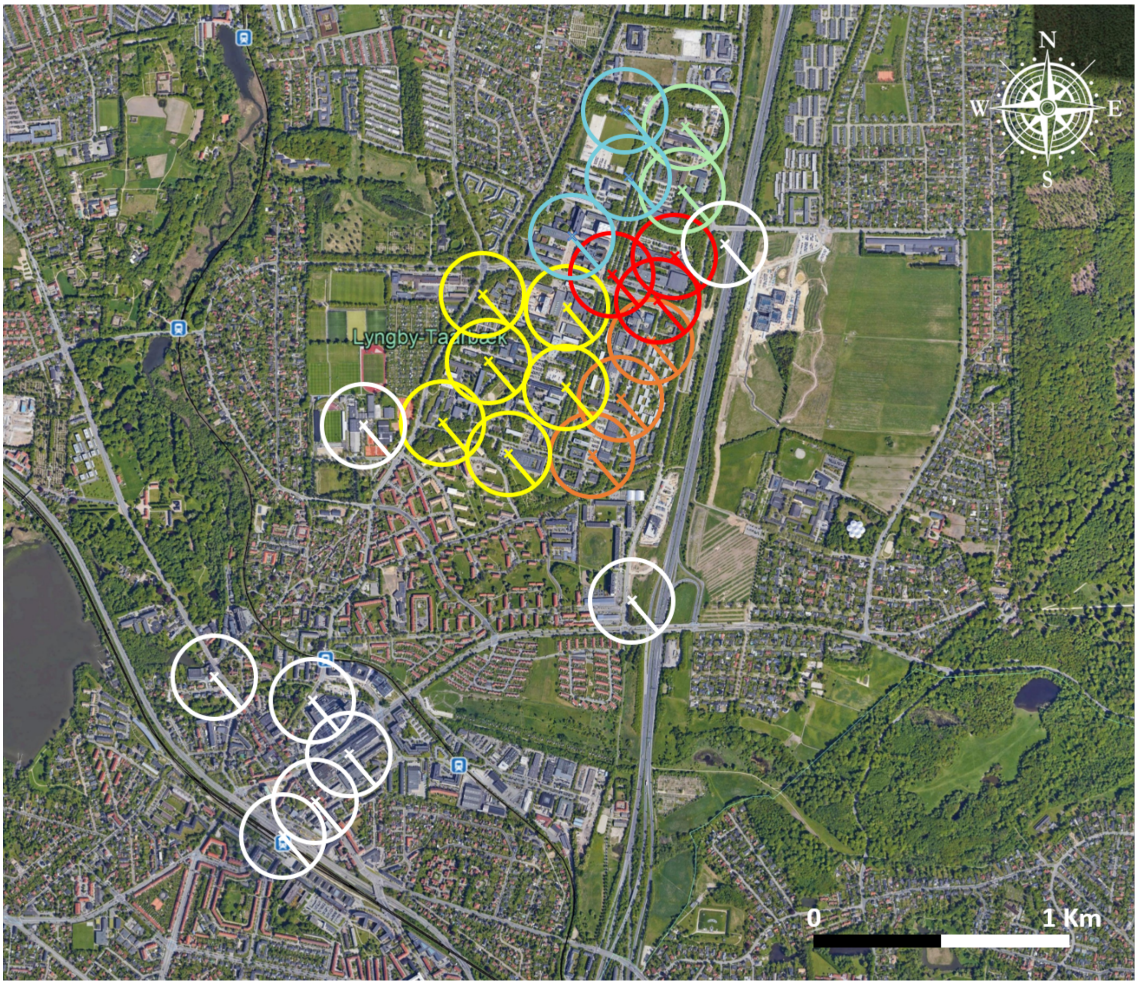



Figure F.3: Proposal of station locations on Scenario 3 following recommendations in table 8.7.

# G Appendix: Sustainability Assessment

| Buildings | By car | By bus | On foot | By light rail | By bike | Scenario 0 | Scenario X | Results |
|---|---|---|---|---|---|---|---|---|
| **101** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **113** | NO | YES | YES | YES | YES | 3 | 4 | IMPROVES |
| **114** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **115** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **116** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **117** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **118** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **119** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **120** | YES | NO | YES | NO | YES | 2 | 3 | IMPROVES |
| **121** | YES | NO | YES | NO | YES | 2 | 3 | IMPROVES |
| **122** | YES | NO | YES | NO | YES | 2 | 3 | IMPROVES |
| **201** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **204** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **205** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **206** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **207** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **208** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **209** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **210** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **221** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **222** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **223** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **224** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **227** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **228** | YES | YES | YES | NO | NO | 3 | 3 | STEADY |
| **229** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **232** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **233** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **234** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **237** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **239** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **240** | YES | YES | YES | NO | NO | 3 | 3 | STEADY |
| **301** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **302** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **303** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **304** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **305** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **306** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **307** | NO | YES | YES | YES | YES | 3 | 4 | IMPROVES |

Table for assessing indicator: Physical building connections

| Buildings | By car | By bus | On foot | By light rail | By bike | Scenario 0 | Scenario X | Results |
|---|---|---|---|---|---|---|---|---|
| **308** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **309** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **311** | NO | YES | YES | YES | YES | 3 | 4 | IMPROVES |
| **312** | NO | YES | YES | YES | YES | 3 | 4 | IMPROVES |
| **314** | NO | YES | YES | YES | YES | 3 | 4 | IMPROVES |
| **321** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **322** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **325** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **326** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **327** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **329** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **341** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **342** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **343** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **344** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **345** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **346** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **347** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **348** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **349** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **352** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **353** | YES | YES | YES | YES | NO | 4 | 4 | STEADY |
| **354** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **355** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **356** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **358** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **371** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **372** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **373** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **375** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **376** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **377** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **378** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **382** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **384** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **402** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **403** | YES | YES | YES | YES | NO | 4 | 4 | STEADY |
| **404** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **411** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **412** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **413** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **414** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **415** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **416** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **417** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **418** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **421** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **423** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **424** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **425** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **426** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **427** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **435** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **441** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **445** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **447** | YES | YES | YES | YES | NO | 4 | 4 | STEADY |
| **450** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **451** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |

Table for assessing indicator: Physical building connections

| Buildings | By car | By bus | On foot | By light rail | By bike | Scenario 0 | Scenario X | Results |
|---|---|---|---|---|---|---|---|---|
| **Campus Village** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **Hempel Kollegiet** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **Kampsax Kollegiet** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **Linde Alle S.R.** | YES | YES | NO | NO | YES | 2 | 3 | IMPROVES |
| **Nordvej S.R.** | YES | YES | YES | NO | YES | 3 | 4 | IMPROVES |
| **P. Ostenfeld K.** | YES | YES | YES | YES | YES | 4 | 5 | IMPROVES |
| **P.O. Pedersen K.** | YES | YES | NO | NO | YES | 2 | 3 | IMPROVES |
| **Poul Bergsøe K.** | YES | YES | NO | NO | YES | 2 | 3 | IMPROVES |
| **Storecenter** | YES | YES | NO | YES | YES | 3 | 4 | IMPROVES |
| **Swimming pool** | YES | YES | NO | NO | YES | 2 | 3 | IMPROVES |
| **Cinema** | YES | YES | NO | YES | YES | 3 | 4 | IMPROVES |
| **Visit Lyngby** | YES | YES | NO | YES | YES | 3 | 4 | IMPROVES |

Table G.1: Table for assessing indicator: Physical building connections


Figure G.1: Canteens, cafés and street food on DTU campus

## G.1 Universities with Bike sharing systems

Those with the provider Zagster may have closed due to the COVID impact on the business:

> Some bikeshares will be shutting down permanently due to the impact of COVID-19 on Zagster's business. If your bikeshare is impacted, you will be notified via email. [Zagster 2020]

| Worldwide ranking | Country | University | Type of system | Link | Comments |
|---|---|---|---|---|---|
| 37 | Canada | University of British Columbia, Vancouver | Bikesharing | https://students.ubc.ca/ubclife/biking-campus | |
| | India | Indian Institute of Science, Bangalore | Bikesharing | http://www.nammacycle.in/simple-technology/strategy/ | |
| | India | Birla Institute of Technology, Mesra, Ranchi | Bikesharing | https://web.archive.org/web/20151106103336/http://desiwheels.in/team.html#aboutus | Private (by students with the desire of expanding) |
| | India | Indian Institute of Technology, Bombay | Bikesharing | https://www.zoomcar.com/pedl-host-tnc | Seems to be something general not from the university |
| | Jordan | Jordan University of Science and Technology, Irbid | Bikesharing | https://www.jordantimes.com/news/local/just-turns-%E2%80%98bike-friendly%E2%80%99-self-service-bicycles-available-students | |
| | Mexico | National Autonomous University of Mexico, Mexico City | Bikesharing | https://www.dgsgm.unam.mx/bicipuma | Bicipuma |
| | United Kindom | University of Nottingham | Renting of bikes | https://www.nottingham.ac.uk/studentservices/services/bike-hire.aspx | Several cycle hire schemes in UK towns and cities overlap their university areas, e.g. the one at Stirling. Others, e.g. Leeds, offer longer-term cycle hire. Kingston University are reported to have a scheme called KU Bikes due to begin in early 2018, while Derby anticipates that Hourbike will run a scheme in Derby operating electric bikes, around the same time. |
| 1 | United States | Harvard University, Cambridge, Massachusetts | Renting of bikes | https://www.crimsonbikes.com/ | |
| 8 | United States | Yale University, New Haven, Connecticut | Bikesharing | https://news.yale.edu/2013/04/22/yale-introduces-new-bike-share-program | Provider: Zagster. May be closed dur to COVID |
| 10 | United States | University of Chicago, Chicago, Illinois | Removed on 2014 | https://www.facebook.com/ucoia/posts/718937701507245 | Bike sharing system closed. Now is complemented with Divvy's Bikes (operator in the city of Chicago) |
| 20 | United States | Pennsylvania State University, State College, Pennsylvania | BIKESHARING | https://news.psu.edu/story/621859/2020/06/01/campus-life/zagster-ends-operations-nationwide-search-underway-new-bike | Closed permanently due COVID (provider Zagster), university is looking for other providers |
| 22 | United States | Cornell College, Mount Vernon, Iowa | Renting of bikes | https://news.cornellcollege.edu/2011/05/purple-bikes-on-a-roll/ | |
| 26 | United States | New York University, New York City | BIKESHARING | https://www.nyu.edu/life/travel-and-transportation/biking-at-nyu/get-a-bike.html | From the city, university has discounts |
| 29 | United States | Duke University, Durham, North Carolina | Bikesharing | https://today.duke.edu/2014/09/zagster | Provider:Zagster. May be closed due to COVID |
| 44 | United States | Georgia Institute of Technology, Atlanta, Georgia | Bikesharing | https://pts.gatech.edu/bicycling-georgia-tech#node-312 | Provider: Relay. From the city of Atlanta |
| 50 | United States | University of North Carolina at Chapel Hill, Chapel Hill, North Carolina | Bikesharing | https://move.unc.edu/bike/bikeshare/ | |

| | | | | | |
|---|---|---|---|---|---|
| | United States | Belmont University, Nashville, Tennessee | Renting of bikes | https://news.belmont.edu/belmont-launches-bike-share-program/ | Bikes available at certain hours. Check in and out at one location on campus |
| | United States | California State University, East Bay, Hayward, California | Bikesharing | https://www.csueastbay.edu/parking/alt-trans/zagster.html | Closed permanently due COVID (provider Zagster), university is looking for other providers |
| | United States | College of Charleston, Charleston, South Carolina | Renting of bikes | http://bike.cofc.edu/bike-share-program/index.php | Bikes available at certain hours. Check in and out at one location on campus |
| | United States | Cornell University, Ithaca, New York | Bikesharing | https://bigredbikes.cornell.edu/ | Provider:Zagster. May be closed due to COVID |
| | United States | Emory University, Druid Hills, Georgia | Renting of bikes | https://transportation.emory.edu/bike-emory | Offers semester rental, year rental or summer rental. |
| | United States | Florida State University, Tallahassee, Florida | Renting of bikes | https://transportation.fsu.edu/bicycles | Semester or year rentals |
| | United States | Hamilton College, Clinton, New York | Bikesharing | https://www.hamilton.edu/news/story/golden-bicycles | Free system, bikes available without lock |
| | United States | Hampshire College, Amherst, Massachusetts | Bikesharing | http://bike.hampshire.edu/ | Free system, bikes available without lock |
| | United States | Illinois State University, Normal, Illinois | Bikesharing | https://sustainability.illinoisstate.edu/efforts/transportation/reggie_ride.php | Bikes available at certain hours. Check in and out at one location on campus |
| | United States | Keene State College, Keene, New Hampshire | Renting of bikes | https://www.keene.edu/news/stories/detail/1510671571767/ | |
| | United States | Kent State University, Kent, Ohio | Bikesharing | https://www.kent.edu/today/news/flashfleet-debuts-new-bike-share-program | |
| | United States | Northern Arizona University, Flagstaff, Arizona | Renting of bikes | https://in.nau.edu/green-nau/yellow-bike-program/ | Periods up to 7 days |
| | United States | Oakland University, Rochester, Michigan | Bikesharing | https://oaklandpostonline.com/18530/campus/bike-share-program/ | Free system, bikes available without lock. Has suffered from theft. Now they are painting the bikes to avoid students take them home. |
| | United States | Occidental College, Los Angeles, California | Renting of bikes | https://www.oxy.edu/academics/areas-study/urban-environmental-policy/our-projects/bike-share-program | Periods up to 7 days |
| | United States | Ohio State University, Columbus, Ohio | Bike shop | https://news.osu.edu/buckeye-bike-hub-to-help-keep-campus-bicycles-on-the-move/ | |
| | United States | Olin College, Needham, Massachusetts | Bikesharing | https://www.olin.edu/sites/default/files/go_bikes_info_bike_qa.pdf | |
| | United States | St. Olaf College, Northfield, Minnesota | Renting of bikes | https://www.stolaf.edu//news/index.cfm?fuseaction=NewsDetails&id=5196 | |
| | United States | Saint Xavier University, Chicago, Illinois | Bikesharing | https://www.cr80news.com/news-item/bike-rentals-are-newest-green-initiative-at-st-xavier/ | |
| | United States | Santa Clara University, Santa Clara, California | Bikesharing | https://www.scu.edu/rsfaculty/get-started/transit/ | Provider:Zagster. May be closed due to COVID |
| | United States | Southwestern University, Georgetown, Texas | Bikesharing | https://www.southwestern.edu/life-at-southwestern/pirate-bikes/ | Free system, bikes available without lock. |
| | United States | Stony Brook University, Stony Brook, New York | Bikesharing | https://www.stonybrook.edu/commcms/sustainability/transportation/_Wolf_Ride_Bike_Share/ | |

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| | United States | University of California, Irvine, Irvine, California | Bikesharing | https://parking.uci.edu/zotwheels/main.cfm | |
| | United States | University of Cincinnati, Cincinnati, Ohio | Renting of bikes | https://www.uc.edu/af/pdc/sustainability/campus_initiatives/transportation/bike_share.html | Bikes available at certain hours. Check in and out at one location on campus |
| | United States | University of Kentucky, Lexington, Kentucky | Renting of bikes | https://www.uky.edu/transportation/bike/wildcatwheels | Rental and resuse of abandoned bikes on campus |
| | United States | University of Pennsylvania, Philadelphia, Pennsylvania | Bikesharing | https://www.publicsafety.upenn.edu/penncycle-launches-pilot-bicycling-program/ | |
| | United States | University of South Florida, Tampa, Florida | Renting of bikes | https://www.usf.edu/student-affairs/campus-rec/outdoor-recreation/outdoor-resource-center-equipment-rentals.aspx | Two types of bike. Day, weekend, week, month or semester rentals |
| | United States | University of Tulsa, Tulsa, Oklahoma | Renting of bikes | https://utulsa.edu/bike-program/ | Rent for a semester |
| | United States | University of Vermont, Burlington, Vermont | Bikesharing | http://www.redstoneaptsvt.com/aptcatma.html#:~:text=The%20Bicycle%20User's%20Group%20(BUG,Center%2C%20Redstone%20and%20Trinity%20Campus. | |
| | United States | Trinity College (Connecticut), Hartford,CT | Bikesharing | https://www.trincoll.edu/news/blue-gold-and-lime/ | Lime company has some stations on campus |
| | United States | Washington State University, Pullman, Washington | Bikesharing | https://news.wsu.edu/announcement/green-bikes-back/ | Free use with university card |

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