Mobility Systems for the People in Skellefteå

AL2115 - Transdisciplinary Approaches for System Innovations

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1 Executive Summary

"A sustainable, reliable and inclusive transportation network created with the people of Skellefteå." This is the vision set out by the project group "North Stars" to transition Skellefteå's mobility systems for its people by 2050. Radical innovation towards a strong shared economy is proposed to provide a mobility system that is robust, well-connected and runs completely on renewable energy. There will also be strong citizen involvement in designing and implementing this system. The mobility system will be continuously improved to meet people's changing needs with various communication channels and feedback loops.

The municipality of Skellefteå is projected to increase its population size from 73,246 in 2021 to potentially over 89,000 by 2030, and the transportation network in the region must keep up with this rapid development. There are several social, environmental and economic challenges in the mobility system that need to be overcome. One challenge is that Skellefteå is a growing city with a large surface area that would need to be covered by the transport system. Another challenge is that currently there is limited public and shared transportation, and a large part of the population relies on private cars. The municipality has a goal of creating an inclusive and equitable transport system for the growing diversity among the citizens. Furthermore, there are plans of establishing state-of-the-art digital infrastructure to bring Skellefteå to the forefront of digitalisation. In line with Sweden's goals, Skellefteå Kraft has a goal of reaching 100% renewable energy by 2040, which would pave the way towards an environmentally sustainable mobility system.

In order to overcome these challenges and meet the needs and functions, the future mobility system has to fulfill certain criteria – connectivity, accessibility, affordability, environmental impact and safety. Indicators have been identified for each criteria to measure and assess the success of the mobility solutions. The solutions should also be resilient enough to be applicable in the face of future uncertainties such as development of technologies and diversity of the population in the future.

A pathway has been designed with several experiments designed from year 2023, to meet the objective of a citizen-owned mobility system that caters to the needs of Skellefteå's citizens by the year 2050. It starts with information campaigns about shared mobility systems to raise awareness and involve citizens in a bi-directional conversation. This is followed by the launch of an integrated digital platform that provides transportation information at the users' fingertips in real-time. A crowdfunding 'social institution' will also be established, where citizens can invest in the mobility system and gain a sense of ownership. Shared micromobility pilots will be launched; starting with electric scooters and bikes, followed by electric snowmobiles for winter. Pilot programs for autonomous mobility such as robo-taxis and shuttles will also be introduced. Upon the success of these pilots, the shared mobility solutions will be expanded and integrated into Skellefteå's transportation system by 2050. This system will be continuously improved with customer feedback through the established digital platform and social institution, ensuring a sustainable mobility system in Skellefteå that meets people's changing needs in the future.

2 Introduction

Skellefteå is a beautiful city in the north of Sweden that was established in 1845, and became industrialized in the 20th century (Javre Norbotten, 2020). Together with the remaining parts of the municipality, its current population of 73,246 inhabitant (SCB Statistiska myndigheten, 2021) is quite small compared to other areas in Sweden. However, the municipality has managed to show enormous growth in population, infrastructure and social activities in the past years. In line with the vision of Skellefteå, which is to provide a sustainable place for a better life (Skelleftea Kommun, 2022), the municipality has an overall objective to increase its population to over 80,000 inhabitants by 2030, while providing an equal opportunity for everyone moving to the city (Skellefteå Municipality, 2020*b*). In line with this vision, a research group at KTH Royal Institute of Technology, namely the project group *North Stars* has chosen to tackle one of Skellefteå's four strategy areas of its development strategy 2030: *Overcoming distance.* A more streamlined focus was put on objective 1 *easy and convenient travel*, which encompasses increase in walking and cycling, climate-neutral buses, simple and safe car travel, and on objective 3 *an accessible community, where everybody can take part*, enabling participation by all, which encompasses new and developed service solutions, and connected homes and businesses (Skellefteå Municipality, 2022*b*).

2.1 Motivation for the Focus

The research group decided to focus on this area, because mobility plays a vital role in urban development and growth, as it is the expected case in Skellefteå. In order to attract individuals and families, and satisfy needs of the entire society, be it the aged, adults or youths, from different cultures, ethnicities or religions, mobility systems need to be developed and expanded, while at the same time not putting pressure on the environment and climate.

2.2 Aim and Objectives

The aim of this project is to develop an attractive future for Skellefteå's mobility sector that will support the idea of attracting people from all stages of life; Further on, to satisfy transportation needs of the entire population of Skellefteå, and taking into account social, economic and environmental aspects.

The objectives of the project work are the following:

- Identify problem areas in Skellefteå´s mobility systems
- Describe a desired future state of its mobility system to address the problem areas accordingly, by applying the modular Participatory Backcasting (mPB) framework
- Elaborate steps and concrete examples how to realize the desired future

3 Methods

In the following, the methodology of the project work, the data collection and the modular Participatory Backcasting framework will be briefly described.

3.1 Description of Data Collection and Methods of the project work

Collection of data in relation to Skellefteå and its mobility system was mainly based on the municipality's development strategies and its traffic program, online sources of private companies and local infrastructure providers, and on scientific literature. To be precise, data were mainly obtained through the municipality's website, course literature provided by the course coordinators, through Q&A sessions with the municipality representatives and stakeholders, namely Gustav Ulander and Petter Johansson, and by using recognized scientific data bases such as Google scholar, sciencedirect or scopus.

In regards to the mPB framework, information about the approach and its implementation process were gained from the mPB manual, and through seminars and lectures as part of the course. Finally, a fundamental part of the creative process of mPB, were innumerable inspiring group discussions and brainstorming sessions.

3.2 The Modular Participatory Backcasting Framework

The principal method used in this project was the application of the modular Participatory Backcasting (mPB) framework, which is relatively new (2019). It is suitable to be applied for developing (long-term) projects having their focus on future transformations and transitions in complex socio-technical systems (Kordas et al., 2022). The mPB framework offers support in developing desired future scenarios through the following 13 modules: Problem orientation, system boundaries, current situation, stakeholder analysis, needs functions, vision criteria, drivers, solution, solution testing, pathways, action plan, and follow up.

Stakeholder involvement and participation are key elements of this approach, as the process of the mPB emphasizes a collaborative co-creation process, in order to enable a joint desirable and sustainable future (Kordas et al., 2022).

The application of the framework as part of the course terminated with module No. 11 (Pathways). The project work concluded with the elaboration of precise steps and examples (in the framework called "experiments"), how the the desired future state of Skellefteå´s mobility system can be realized.

4 Results

In the following, the results of the application of the mPB framework in regards to the future mobility system in Skellefteå will be described in detail.

4.1 Problem Orientation

As specified by Skellefteå municipality's development strategy for 2030, one of the key strategy areas is to overcome distances which is tightly connected to the mobility system (Skellefteå Municipality, 2022*b*). In Figure 1 some key sustainability challenges of the current mobility system in Skellefteå are presented in a venn diagram grounded in the three pillars of sustainability in an attempt to create a plurality of framing of the problem area in focus. All challenges, except *carbon lock-in* and *economic feasibility*, are specified in the Traffic program (2020) created by the municipality. A *growing city* and the *large surface area* of the municipality are two of the challenges which are considered to transcend all three pillars of sustainability. With a growing population in synergy with increasing numbers of housing buildings and workplaces there is also a growing need for more travel and transportation possibilities within the municipality (Skellefteå Municipality, 2020*a*). Skellefteå municiaplity is by surface area the largest costal municipality in Sweden (7 217 km^2) which creates challenges concerning long distance travels. Thus, today many people living in the rural areas are dependent on transportation by private cars (Johansson and Ulander, 2022).

Overall in the municipality the share of travels occurring by foot, biking and public transport are relatively low compared to travels by private car (Skellefteå Municipality, 2020*b*). This highlights that the *share of sustainable travels need to increase*. The *coordinated planning* challenge refers to the importance of planned interconnections between buildings and the traffic infrastructure which can help to improve availability of services and needs of the citizens (Skellefteå Municipality, 2020*b*). Another of the key challenges identified is to *decrease the transport systems negative effects on the environment and human health*. Here issues such as noise, air pollution, greenhouse gas emissions related to the traffic system are included. It is the municipality's belief that more effective vehicles and increased shares of transportation operating on renewable energy and electricity will not be sufficient measures to reach the energy and climate goals. In addition more resource-effective means of transportation (i.e. pubic transport, bike, pedestrian walks) will be required (Skellefteå Municipality, 2020*b*).

Creating an inclusive and equitable transport system in Skellefteå is also a future challenge. The municipality's goal is to create a transport system available for everyone; old people, young people, pregnant women, people with disabilities and etc (Skellefteå Municipality, 2020*b*).
Carbon lock-in (including i.e. peoples reluctance to change their driving habits) is identified as a challenge in the mobility system in Skellefteå by the authors of this report as the widespread phenomena is halting the possibility for effective and extensive systems transformation required for reducing the systems negative effects on the environment (Unruh, 2000). Furthermore, in any decision making process for complex development projects *economic feasibility* is a factor that needs to be considered. Without economic feasibility no credit can be gained and consequently, no project can be established.

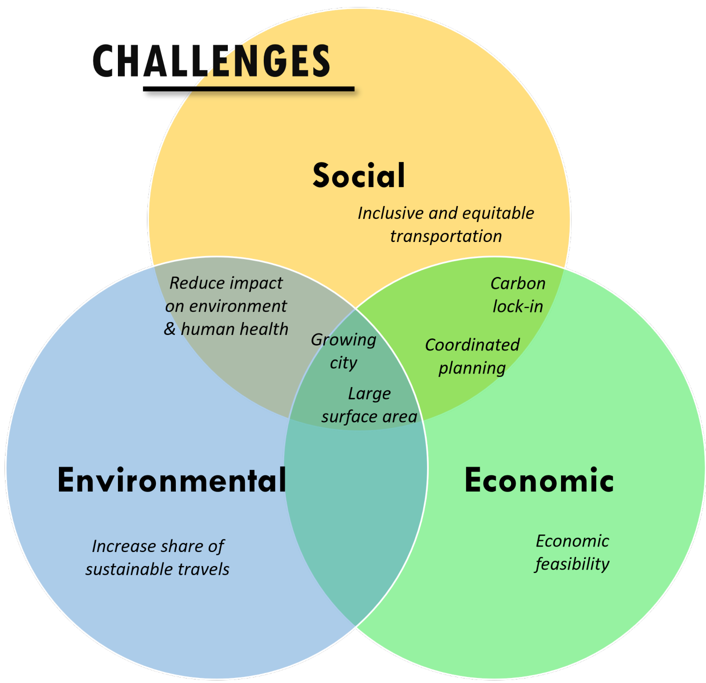

Figure 1: Identified challenges of the mobility systems within Skellefteå municipality in relation to the three pillars of sustainability.

4.2 System Boundaries

The system boundaries in this project include the whole area of Skellefteå municipality. Mobility systems existing outside the boarders of Skellefteå municipality are thus, excluded to facilitate the project work analysis. The sectorial boundaries includes the mobility system for people and excludes transport of goods. This was decided, due to the project work's limited time frame and to enable a sufficient and in depth analysis of at least one part of the mobility system. With regards to technical components of the mobility system all elements connected to the existing mobility infrastructure are included, such as mobile vehicles (both private and public), charging stations, the electric network etc. The system boundaries also encompass various social components such as any social institution, firm, citizen or person using, affecting and getting affected by the mobility system. When it comes to the temporal boundaries, the project has a time frame starting from now (2022) to year 2050, with a milestone in 2030.

4.3 Current Situation Analysis

In order to get a better understanding about the current mobility system in Skellefteå information around key system components and its functions have been gathered. The key components are elaborated below.

Population of Skellefteå

According to the Swedish statistical authority SCB the number of citizens in Skellefteå was 73 246 in June 2021 (SCB Statistiska myndigheten, 2021). Approximately 60 % of the population were in 2019 living in or around Skellefteå city, also known has Skelleftedalen (Skellefteå Municipality, 2020*a*). It is projected that the population in the municipality will increase in the near future and one possible high scenario is that by 2030 the population has increased to 89 000 (Johansson and Ulander, 2022). Today the municipality can see a new trend, where more and more people are moving to the rural areas. This makes it necessary to reopen schools, supermarkets and other services in the rural areas (Ulander, 2022).

Citizens in Skellefteå have different attitudes and interests in the transition, but some of the recurring views are openness for growth of the municipality and with regards to the transport network improvements of the train, bus, pedestrian and bike traffic systems are requested (Skellefteå Municipality, 2022*a*).

Current action plans and goals

Locally Skellefteå municipality have created a development strategy for Skellefteå 2030, including the strategy area titled overcoming distances which directly affect the mobility system(Skellefteå Municipality, 2020*b*). One of the sub-goals of the strategy area is to enable "easy travels on human terms", which imply that is should be easy to travel between rural areas and within the city center and also easy to take personal responsibility for climate, environment and health. In order to achieve the the goal three focus areas are indicated; (1) steady increase of pedestrian and bike traffic. (2) environmental friendly travels. (3) easy and safe car travels (Skellefteå Municipality, 2020*b*).

Skellefteå municipality and its mobility system also needs to live up to national climate goals. For example, according to the climate law, Sweden should not have any net emissions of greenhouse gases by 2045 at the latest (Skellefteå Municipality, 2020*b*). Furthermore, existing national goals drive for creating availability in the way the mobility system is designed, functioned and utilized and also specify that safety, environment and health are important aspects which a mobility system needs to consider (Skellefteå Municipality, 2020*b*).

Means of transport

Private cars

Currently the dominant mean of transport in Skellefteå is the private car and the existing road infrastructure is designed for supporting its functions (Skellefteå Municipality, 2020*b*).

Railway

Trafikverket is in charge of planning and developing the new railways system (Norrbotniabanan) connecting Skellefteå with other cities along the coast. Skellefteå municipality is also involved in the planning. Norrbotniabanan is not yet in service (Trafikverket, 2021).

Public transport

The municipality-owned Skellefteå bus is in charge of the public transportation in Skellefteå. They are also responsible for school busses and flight busses (Skellefteå buss, 2022). Skellefteå buss also offers a service where you can announce/book a travel within the municipality. The service is called "Ringbilen". However, the service is not widely used. It is inefficient and expensive. But there is planning for use of autonomous vehicles in rural areas for last mile access. Though, the required technology is not in place yet (Ulander, 2022).

Biking

In general the biking network is well developed in Skelleftedalen, however, some shortages exist. The largest shortages are risky intersections and stretches where cyclists and car traffic are mixed. It is also a shortcoming that cyclists and pedestrians often share the space, especially in Skellefteå center where pedestrian flows are high (Skellefteå Municipality, 2020*b*).

Pedestrian lanes
For residents and those working in rural areas, there is a need for improvements for pedestrians (also cyclists) such as safer roads to schools and bus stops (Skellefteå Municipality, 2020*b*).Accessibility adaptation of walkways with guideways, adapted passages and removal of easily remedied obstacles has begun, but there is still a lot to do before the City center is accessible and useful for everyone, regardless of functional variation (Skellefteå Municipality, 2020*a*).

Sharing vehicles
Almost nothing of sharing bikes and scooters are currently used Skellefteå. There are no public bike pools. However, it may exist semi-private or private bike pools but not in a great extent (Ulander, 2022).

Quality of existing road infrastructure
The mobility infrastructure in Skellefteå is functioning and is overall in good standard. However, there is some deficiencies in most modes of transport. A more holistic view on the system have been requested with regards to development of traffic and communications, but also more sustainable and environmental friendly solutions (Skellefteå Municipality, 2020*a*). According to the Traffic Program (2020) the public traffic today do not have the capacity to support all parts of the rural areas which makes it important that local interchanges and strategically located car parks are established (Skellefteå Municipality, 2020*b*).

The electricity network
In Skellefteå, the municpality owned company called Skellefteå kraft is responsible for operating the electricity network (Skellefteå Kraft, 2022). Skellefteå Kraft is also one of the actors that is at the forefront of developing green technology, clean energy and sustainable solutions in the Skellefteå region. Extensive work is also underway via the company Node Pole, partly owned by Skellefteå kraft, to promote the establishment of electricity-intensive industries (Skellefteå Municipality, 2020*a*) which the electricity network today is not adapted for. Since 2017 Skellefteå Kraft has invested around 250 milion SEK in projects for expanding the electricity system. The expansion is however, dependent on permits from the Energy Market Inspectorate (Ei) for each individual new line, which delays the process. Furthermore, when the system is expanded, it is important

to consider how the environment, local residents and the reindeer herding industry are affected (Skellefteå Kraft, 2022).

Skellefteå Kraft's goal is to have 100% renewable energy production by 2040. Most of the electricity and heat that is produced today comes from hydropower, wind power and biofuels (Skellefteå Kraft, 2022). In the work of phasing out fossil-fuels, establishment of charging infrastructure is also central. Planning for electricity networks and equipment for charging vehicles is today in progress (Skellefteå Municipality, 2020*a*). At the moment Skellefteå Kraft have 6 operating electric charging stations in Skellefteå in collaboration with OKQ8 (Skellefteå Kraft, 2022).

Digital infrastructure
The digital infrastructure in Skellefteå is of a good standard (Skellefteå Municipality, 2020*a*). There is good coverage of 3G, 4G and fiber for private person and companies. Coverage of 5G is also in progress (Ulander, 2022). Today there is great development in the establishment of digital information flows between society's actors, mainly through the physical infrastructure being digitally connected via wireless sensors. These connected sensors form an Internet of Things (IoT) that makes it possible to measure various environmental factors, control physical and digital processes and create a basis for decisions built on facts to design sustainable solutions (Skellefteå Municipality, 2020*a*).

4.4 Stakeholder Analysis

The key stakeholders identified in the mobility context of Skellefteå are the citizens, the municipality, corporates and local infrastructure providers. Furthermore, some specific companies such as Travikverket, Skellefteå Kraft and Node Pole have been recognized. The identified stakeholders in relation to the mobility system are elaborated below and their inter-connectivity can be seen in Figure 2.

The citizens are one of the most essential stakeholder in achieving the vision of Skellefteå and as shown in Figure 2 this is mainly because the municipality, the corporations and the local infrastructure providers are highly dependent on the citizens participation. In the end, the final consumers are the ones financing the systems and businesses in place, assuming business in this context are referred to as being local and located in the municipality of Skellefteå. Based on those insights, the dependent stakeholders should assure creating the right environment to gather citizen's needs, not only to keep flourishing, but also to invent and implement fitting solutions in the area.

Skellefteå municipality has a formal nature of power, since it has a non-profit interest and as parties representatives have been democratically elected by the people (Avelino and Wittmayer, 2016). However, their interest lies within the promotions of all the other stakeholders mentioned too. Thus, conflicts of interest might occur, where the municipality must carefully weigh the available options and have the overall satisfaction and welfare in mind.

The education and research stakeholder holder group are vital to the growth of Skellefteå and can be seen as the mind map of the city. For instance, the project group of this report North Stars can be seen as an extension of the education and research centres in Skellefteå, and this fostering of innovation and research will bring the city closer to its goals and vision. Furthermore, education and research assist in attracting young and talented minds into the university but this is highly dependent on the municipality for support and funding. For example, if Universities like Umeå and Luleå are efficiently equipped with facilities and with specific courses of interest and funding, then they will be able to attract more students to the university and these would most likely add to the population growth after studies. Thus, close collaboration between the municipality and educational institutes play an essential role in providing what is needed for a prospering environment for young talents.

The infrastructure providers (i.e Trafikverket) and Small and Medium Enterprises (SME) in the region are also major stakeholders. Especially as 65% of the employment rate comes from private companies (Smart City Sweden, 2022). Now, imagine a situation where a few companies like Northvolt decides to leave Skellefteå because of some unforeseen circumstances. This would affect the city's employment rate negatively and could tarnish the vision the city is actively trying to achieve. With this in mind the municipality should not only consider bigger corporates in the region, but also maintain close connections to SMEs and thus the employees working there.

The municipality and the infrastructure providers are highly dependent on each other as one cannot efficiently grow without the other. Together, the implementation of solutions in different regions of the city that previously have been tested and marked as efficient by the education and research group can take place. In the end, however, the success of this new transportation modes are highly dependent on citizens adoption of the solution.

Skellefteå Kraft is one of the many companies in Skellefteå working hand in hand with other stakeholders to achieve Skellefteå´s vision of 2050. One of their innovative solutions is the "Charge 100 per cent renewable" and hence completely phasing out fossil-based means of transportation with fully electric vehicles (Skellefteå Kraft, 2022). This breaks the barrier of moving to a gas station for car charge since cars can be charged at home with a charging box. While this is quite innovative, it is still highly dependent on the citizens as further development for an incremental innovation may not happen if this service is not utilized and assessed by the citizens. Looking back to the design stage, it can be seen that the education and research group had a vital role in the researching and development of the product.

A subsidiary of Skelleftea kraft is the Node Pole and their main focus is on bridging the gap between sustainable solutions and energy-intensive industries (Node Pole, 2022). However, stakeholders such as the government agencies, education and research and corporates play a vital role in achieving everything that Node Pole stands for. In the end, Node Pole's customer segments are composed of those institutions and the ambitious city development plans will need a strong commercial partner along this path.

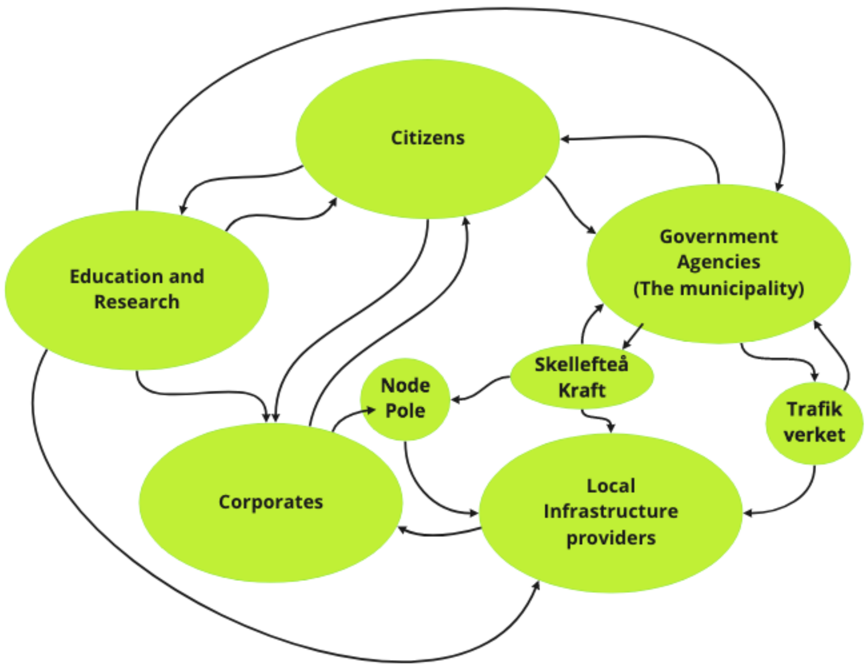

Figure 2: Inter-connectivity of some key stakeholders in the mobility system in Skellefteå.

4.5 Needs and System functions

The 5th part of the mPB framework aims to identify needs underlying the current problem situation and describe functions fulfilling the needs.

Needs
Needs may exist on various different levels, for example on the individual level of a human or citizen, on the level of a entire community, or on a district or society level. It is very important to understand the real needs of actors, which are addressed by a solution of a related problem, and not only to understand what initially seems that these actors need (Kordas, 2022). To achieve this, the "Why?"-questions technique (DesignKit.org, 2022) was applied in the context of this project (Example: "Why do citizens use transport systems?"). Gradually, various needs, applicable for most Stakeholders to the same extent, were elaborated, as demonstrated in the following:

- Need, to get from one place to another
- Need, to have access to various locations in the municipality of Skellefteå
- Need, to reach a desired destination on time
- Need, to live a certain lifestyle, which by the society is considered "sustainable"
- Need, that the mobility system can be used without huge effort, and that it is convenient

Needs may change in the future, so it is even more important, that the characteristics of an enhanced mobility systems are robust, to meet future changing needs (Kordas, 2022).

Functions
Similar to needs, functions that aim to satisfy certain needs, may change over time. Understanding how functions of a system have changed over time may also help to understand the mere dimensions of a sustainability transition, as Skellefteå aims to achieve it. Therefore, both current and future needs will be described hereafter.

Functions of the current system
As described in chapter 4.3, a very popular mean of transportation is travel by car, both in rural areas of the municipality and within the city. It can be considered as an inefficient system, because many people use the car individually, and sharing of cars is not usually considered an option. Further on, commute of the people using public transport, by bike or as a pedestrian, is relatively low. There is currently a public bus system, connecting parts of Skellefteå´s rural areas with the city, however it is operating with a rather low

frequency. To conclude, the main function of the current mobility system is on individual and flexible transportation of people, mainly fulfilled by privately owned cars. Commuting by public transport does not support this function, and is therefore not considered as a desired choice of transportation or commute by the majority of Skellefteå´s citizens.

Functions of the new system configuration

Functions of a new solution should represent a response to the underlying needs a system aims to satisfy. Considering the needs elaborated previously in this section, the following functions, as in Figure 3 can be derived:

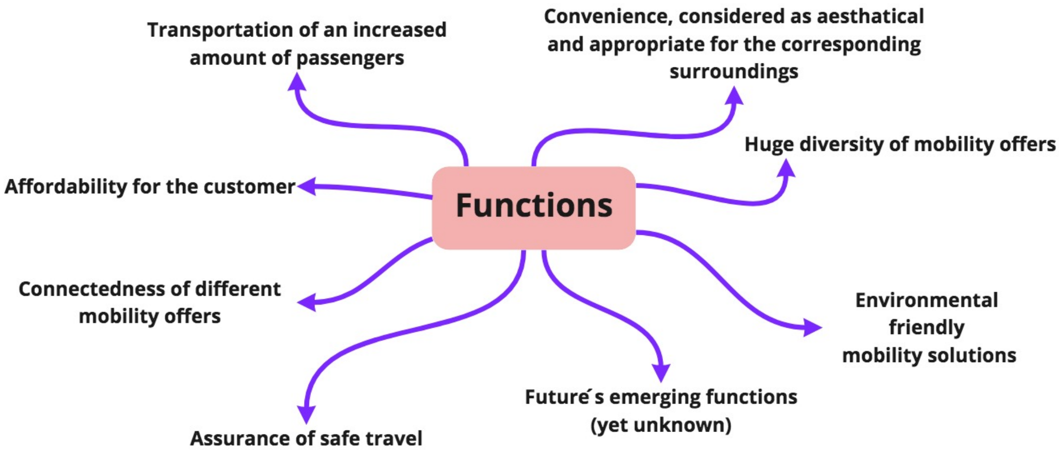

Figure 3: Functions, Skellefteå´s new mobility system shall fulfill

Besides the specific functions, new functions may emerge that are necessary to satisfy needs that are not apparent today, or not yet existent. The reason for that is, that future circumstances might affect current needs, making them irrelevant or altered, and even new functions may be necessary over time.

The variety of functions illustrate positive and promising characteristics of a new system´s configuration. Comparing these functions with the current system, the new system shall fulfill a greater number of functions, which constitute the challenges of realising Skellefteå´s objective to aim for a transition towards a more sustainable municipality.

The presented functions that the new mobility system shall fulfill, will also be represented by the future vision of Skellefteå´s mobility sector, which is introduced in the following section.

4.6 Future Vision

In this section the group aimed at creating a joint vision that incorporated needs from all stakeholders within the municipality and defines a worthwhile future where everyone can thrive towards too.

In order to achieve this ambitious goal, the team has iterated the stated vision multiple times and finally pinpointed it to the main target group of the project: the citizens. Therefore, the future development of the mobility system must integrate the citizen's needs at its core and be build around the desires previously stated in subsection 4.5, whilst also reflecting those of other stakeholders present in the city. Keeping all these aspects in mind the following vision has been defined:

A sustainable, reliable
and inclusive transportation network created
with the people of Skellefteå.

The main intention is the integration of citizens in the early decision process and come up with solutions next to concrete action measures that allow for feedback and input collection right from the start. Furthermore, the importance of the various characteristics of the future mobility system have been highlighted: *Sustainability, Reliability and Inclusiveness*, which are in line with the city's goals (Traffic program, Skellefteå Municipality (2020*b*)) and will be elaborated further in the upcoming section. Interestingly, there is existing evidence that fully accessible and inclusive mobility systems won't imply much additional costs when considered properly, but rather lead to further benefits for their users (Pojani and Baar, 2021). Last but not least, the idea was to create an iterative process allowing for constant feedback generation where issues can be addressed continuously and will be solved collaboratively.

4.7 Criteria

In order to track the defined needs and functions against benchmarks and monitor future development, corresponding criteria have been defined. On top of that, each criteria has been undermined with indicators, so proper measurement and comparisons can be drawn. Table 1 summarizes the criteria used in this report.

In this report *Affordability* directly focuses on the costs of the various mobility solutions available in the city and puts it into relation to the monthly spending per household. This approach allows for comparison over time and helps the municipality set the right prices for each mode. UN (2021) provides great reference values on how to track the affordability of a system.

In our case, *Accessibility* can be understood as the consideration of different needs among citizens within Skellefteå. Each member of the society should have equal access to the system, which will be measured and tracked by the indicators defined below this criteria. UITP (2019) defined a broad indicator framework, which incorporates several areas connected to social inclusion and thus will be used as a reference here.

Safety refers to the overall level of security within the system and aims at decreasing the amount of accidents happening in the municipality. A recent paper by UITP (2019) combined Comfort and Safety since both characteristics are closely related, however, our report mainly focuses the later one, whilst ensuring the incorporation of Public transportation as well as pedestrians.

The fourth criteria *Environmental impact* focuses on the sustainable development of the mobility system and thus not only includes the Carbon Intensity of different modes of transportation, but also tracks the performance of electric vehicles. This spot on electric vehicles is based on the latest developments in the Swedish automobile sector and the electrification of the mobility sector in general. Two of this indicators are thoroughly described in the work done by Haghshenas and Vaziri (2012), where several Urban Transport Indicators have been created in order to compare Urban Sustainability among cities on a global level.

Finally, *Connectivity* covers the physical coverage of the transportation system in place and includes mobility availability on an urban and rural level. Furthermore, the time necessary to reach a desired destination from a certain starting point will be assessed and serves as a great indicator to compare scaling of mobility solutions among different locations in the municipality.

The defined criteria serve as a benchmark for the development of the mobility system in the upcoming years and will continuously be taken into consideration throughout this report.

Table 1: Criteria and corresponding indicators for the underlying study

Criteria	Indicators	Sources
Affordability	Average price to travel	(UN, 2021)
	Share of monthly expenditure on public transportation	(UN, 2021)
Accessibility (social)	Accessibility to people with reduced physical mobility	(UITP, 2019)
	Ease of taking public transport for all ages	(UITP, 2019)
Safety	Total cost of accident reimbursements	(UITP, 2019)
	# of accidents when using PT	(UITP, 2019)
	# of safe crossings for pedestrians	(UITP, 2019)
Environmental impact	Carbon emissions (kg of (CO2+NOX) per 100 km)	(Haghshenas and Vaziri, 2012)
	Average distance travelled for 1 kWh (energy efficiency of electric vehicles)	(Haghshenas and Vaziri, 2012)
	# of trees cut down to develop transport network	-
Connectivity (physical)	Average time to travel 100 km	(UN, 2021)
	Ease of transferring from one mode of transport to another	(UITP, 2019)
	Frequency of PTs	(UITP, 2019)
	Distance from residences/workplaces/schools to PT station	(UN, 2021)

4.8 Driver Analysis

Uncertainties, its impact and its connection to Skellefteå´s mobility system. The Driver Analysis as part of the mPB framework is a tool to identify trends of the future, assess them and to define different scenarios (external scenarios), which help to predict potential futures in the context of the problem situation, specifically to the mobility system in Skellefteå municipality. Initially, several driving forces, which may shape and influence the future development of Skellefteå, were identified, through literature research, information from the municipality, brainstorming and group discussions. The uncertainty-impact matrix classifies the drivers by assessing their probability of occurrence and the impact in case of occurrence, which is illustrated in Figure 4.

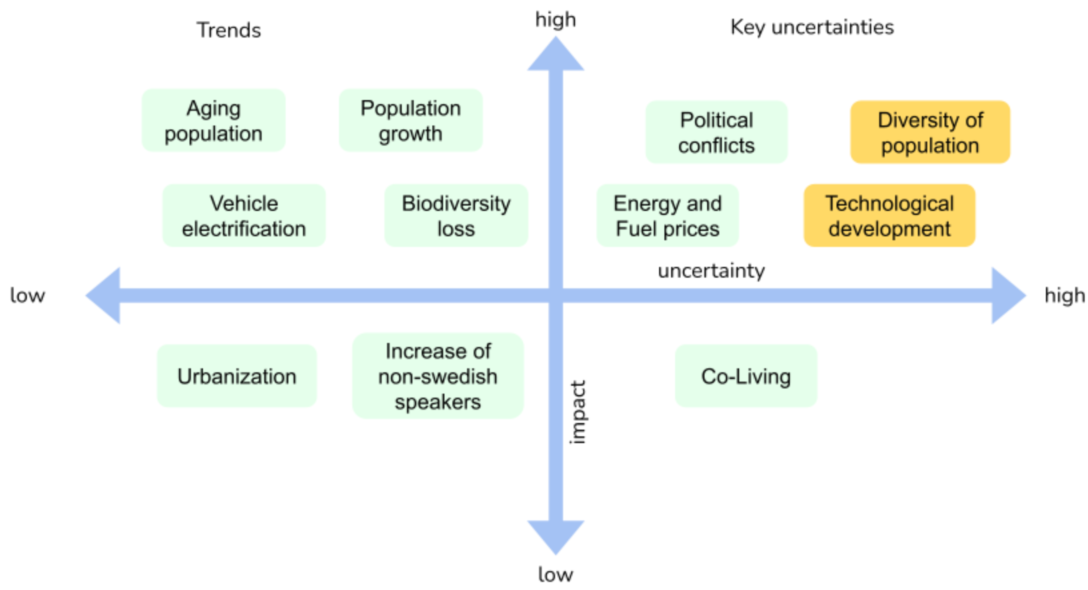

Figure 4: Impact-Uncertainty matrix of driving forces, related to the mobility system in Skellefteå

The two drivers "Diversity of population" and "Technological development" were selected as two main key drivers for further analysis, in the following called key uncertainties. Since both terms are quite broad, first of all, they will be shortly described in the following.

Diversity of population

Diversity of the population shall describe how diverse the society in Skellefteå municipality is in terms of age, cultural background, religion, ethnicity, and different income level. The population is about to significantly increase, as described in subsection 4.3. This increase is also highly related to a change of the society structure, because potentially many people not only from Sweden, but from different places from all over the world could move to Skellefteå in the near future. The municipality of Skellefteå does not have much influence on that development, but it is mainly induced by certain actors, for example companies like Northvolt (also see subsection 4.4). Besides the rather high likelihood of the occurrence, that Skellefteå will diversify its population, it remains the questions, to which extent it will happen and which consequences it implies it. For example, different cultural or religious habits may be associated with different behaviours, wishes and demands of the people. Additionally, new income structures, through the advent of many young professionals, employed at companies of different evolving industrial sectors, might result in changing what the majority of the citizen need (Wood and Landry, 2008). Same applies for the aging of the population, as it is a common trend in many countries in the 21st century: The population might become older, but it remains unsure to which extent consequences this implies, such as changing behaviours, needs to be satisfied, and functions to be fulfilled (*Travel behaviour and mobility needs of older adults in an ageing and car-dependent society*, n.d.). Through discussions within group on the basis of a literature review, many more factors are associated with the relocation of many (different) people, such as:

- Will there be many more new children in the future?
- How many will need to commute?
- To which places do they want or need to go?

Both aspects (Migration to Skellefteå and aging population) could change social structures, and the way how people live or work together, and also effect a change in the usage and adoption of the mobility system.

Technological development
Technological development in this context is used as an umbrella term, for the development of cyber physical systems, Internet of Things (IoT), autonomous driving, and digitalisation in general.

It is a relevant key uncertainty, because these technologies are a main part for the development of mobility systems. For example, the development of autonomous driving is a currently wide-known trend various countries and industries aim for. However, it remains unsure, when and to which extent this development might occur, to be illustrated by the different levels of autonomous driving (*The development of autonomous driving technology: perspectives from patent citation analysis*, n.d.). Besides that, it is relevant, because if new (significant) developments in technology take place, they can help to fulfil the variety of the functions, a new system´s configuration needs to fulfill. The authors and participants of the project group see this is as a crucial part in how the mobility systems will develop in Skellefteå.

It seems difficult and unlikely for the municipality to influence how fast technology is developing, because Skellefteå is not a hub for the described technologies. Of course, the municipality could manage and influence the extent, of how much they want to use the existing technologies. However, it is not in the position to significantly shape and co-develop future technologies.

Potential external scenarios

Subsequent to the identification of two key uncertainties, both are integrated into one matrix to define four different external future scenarios. They shall describe situations, when the different states of each key uncertainty simultaneously occur, from the combination of a low degree of technological development and diversity in society, to a high degree of technological development and population diversity.

Figure 5 illustrates the characteristics of the different external scenarios, which were mainly created based on discussions within the project team. To clarify, increase of population itself is not considered in the potential different scenarios. It is only the diversity within the population and technological development, as described above.

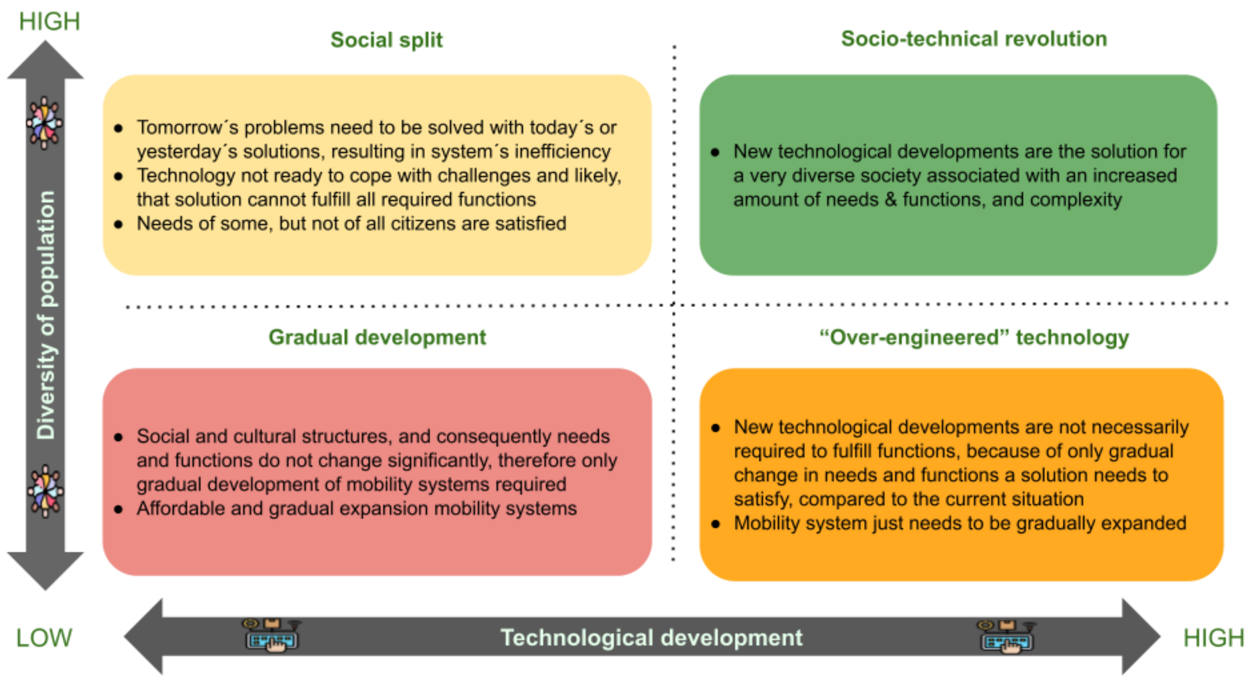

Figure 5: Potential external scenarios, illustrated with a "futures plane"

The different external scenarios play a crucial role in the modular participatory Backcasting framework, since at a later stage (see subsubsection 4.10.2) it will be assessed, to which extent the different solutions (internal scenarios) cover the different external scenarios.

The different solutions (internal scenarios) will be described in the following section.

4.9 Internal Scenarios / Solutions

In this module, the following system dimensions in the context of Skellefteå's mobility systems were identified: Transportation ownership; Energy supply; Extent of infrastructure development; Coverage of transportation system; Level of innovation. These dimensions were established as they are relevant in meeting the vision for Skellefteå. Extreme states were also identified for each dimension which would aid in forming different possible internal scenarios as seen in Table 2.

Table 2: Dimensions and their states

#	Dimension	State of Dimensions		
1	**Transportation Ownership**	**Private**	**Public**	**Shared economy**
		Everyone owns their own vehicle	Municipality owns transport system	Peer-to-peer vehicle sharing
2	**Energy Supply**	**Fossil-fuel based**	**Mixed**	**Fully renewable**
		100% fossil fuel energy used in vehicles	Mix of fossil fuel and renewables	100% renewable energy used in vehicles
3	**Extent of infrastructure development**	**Use of current infrastructure**	**Mix of current and new infrastructure**	**Completely new infrastructure**
		Mobility transitions relies on current infrastructure only	Current infrastructure used with improvements and some new additions	All transport infrastructure will be revamped
4	**Coverage of transportation system**	**Low**	**Medium**	**High**
		Only city-area is covered by transport system	Suburbs and city are connected	All rural, suburb and city areas are connected
5	**Level of innovation**	**Business as usual**	**Incremental**	**Radical**
		Current technologies continue to be used for mobility system	Slow changes to mobility systems	Drastic change to mobility systems

A morphological method was used to develop alternative configurations for internal scenarios and select the top three to be further analysed (Figure 6, Figure 7, Figure 8). The internal scenarios were chosen based on their ability to solve different areas of the mobility issues and meet the citizens' needs.

#	Dimensions	State of Dimensions		
1.	Type of Ownership	Private	Public	Shared Economy
2.	Energy supply mix	Fossil Fuel-based	Mixed	Fully renewable
3.	Extent of infrastructure development	Usage of current Infra.	Mix of current and New	Completely new infrastructure
4.	Coverage of Transportation System	Low	Medium	High
5.	Level of Innovation	Business as Usual	Incremental	Radical

Figure 6: Internal scenario / solution A: Shared future

#	Dimensions	State of Dimensions		
1.	Type of Ownership	Private	Public	Shared Economy
2.	Energy supply mix	Fossil Fuel-based	Mixed	Fully renewable
3.	Extent of infrastructure development	Usage of current Infra.	Mix of current and New	Completely new infrastructure
4.	Coverage of Transportation System	Low	Medium	High
5.	Level of Innovation	Business as Usual	Incremental	Radical

Figure 7: Internal scenario / solution B: The common new

#	Dimensions	State of Dimensions		
1.	Type of Ownership	Private	Public	Shared Economy
2.	Energy supply mix	Fossil Fuel-based	Mixed	Fully renewable
3.	Extent of infrastructure development	Usage of current Infra.	Mix of current and New	Completely new infrastructure
4.	Coverage of Transportation System	Low	Medium	High
5.	Level of Innovation	Business as Usual	Incremental	Radical

Figure 8: Internal scenario / solution C: The new old school

The first chosen scenario was "A Shared Future", where the mobility system is radically changed to only rely on a shared economy for a high transportation coverage. The second scenario was "The Common New", where the mobility system improves incrementally and includes the whole ownership spectrum (private, public and shared economy) with equal distribution among these for a high coverage. The last chosen scenario is "The New Old-school", the ownership remains similar to current scenario, of public and private, and is improved incrementally. The coverage of the transportation system of this scenario is considered to be medium as citizens in rural areas may prefer to be slightly disconnected and any mobility needs are met by private vehicles. For all three internal scenarios, the energy supply is considered to be fully renewable, which is in line with Skellefteå's goal by 2025 (Skellefteå Kommun, 2021). The extent of infrastructure development is also considered to be a mix of current and new infrastructure as some of the current infrastructure could still be used with addition of some new infrastructure when transitioning the mobility systems. These internal scenarios were further tested in the next section to develop the final scenario.

4.10 Internal Scenario Testing

The solutions, also known as internal scenarios, that have been developed should be further explored by evaluating their sensitivity and robustness in order to find a final scenario which is in alignment with the future vision.

4.10.1 Sensitivity Testing

In accordance with the mPB framework the sensitivity testing can be done by evaluating the presented internal scenarios against the defined criteria (Kordas et al., 2022). In this project the evaluation was performed by simply rating the performance of each internal scenario against each criteria, from scale 1 to 5. The lowest number (1) represented very poor performance while the highest number (5) represented very good performance. The rating was decided through discussions and consensus-building based on the current knowledge of the solution situations among the group members. In Table 3 the result of the performance rating by the group can be seen. The arithmetic mean was calculated of the performance rating for each solution to give a picture of how well each solution fulfills the defined criteria. In Table 3 it can be seen that Solution A and B both have an arithmetic mean of 4.6 while solution C has 3.8.

The motivation of the performance rating for each internal solution against the set of criteria are elaborated below.

Solution A: Shared future

In the shared future solution the criteria defined as affordability, environmental impact and connectivity were all assigned very good performance (5). It is the groups belief that a system fully built on shared economy and renewable energy will result in a decrease of expenses for the individual citizen using the mobility system. Overall it is also believed that the mobility systems environmental impact compared to today will minimize when radical innovations have the possibility to develop and as the shared economy leads to a decrease in resource use. Furthermore if the system is fully operating on renewable energy the carbon emission caused by the mobility system will decrease. As the solution includes a high coverage of the transportation system and as some new infrastructure will be built it is believed that the connectivity standard in the system will be improved.

The solutions accessibility and safety were assigned a rating of 4. The shared economy can potentially lead to that the system is a less accessible for people, as the shared economy is built on renting, sharing and borrowing of mobility vehicles. Possibly at certain times all the mobility vehicles are occupied for example. Furthermore, the shared economy can imply an increase of safety compared to private ownership, as the mobility vehicles standard and service quality is affected by more people than by a family or a single individual.

Solution B: The common new

Compared to solution A, solution B will according to the rating perform better against the accessibility and safety criteria (assigned rating 5). The solution covers a broader spectrum of transportation ownership which will offer a greater sense of freedom of choice and flexibility. Furthermore, safety measures can be more easily controlled by individuals if the ownership is private. The connectivity in solution B were also assigned a rating of 5 as the coverage of the transportation system is high and as public ownership of transportation is included, which will make it feasible to increase the frequency of public transport within the whole municipality.

The decrease of environmental impacts caused by the system when introducing solution B is assumed to be less comprehensive compared to solution A as incremental innovations will drive the development. Also affordability has been assigned a rating of 4 as the spectrum of available transportation ownership is wider, possibly causing more needs for logistics.

Solution C: The new old school

This solution only received a very good performance rating (5) against the safety criteria and is believed to be equally safe as solution B. Also here, both private and public ownership of transportation is included which in our thought process implies better management of safety measures. The solution was further assigned a rating of 4 against the affordability and environmental impact criteria as the Shared economy is excluded and as incremental innovations drives the development slowly. Due to the medium coverage of the transportation system and the exclusion of the shared economy the accessibility and connectivity of the mobility system is believed not to be of equally good standard as in solution A and B. Thus, they were assigned a rating of 3.

Table 3: Solution evaluation against all defined criteria through performance rating

#	Criteria	Indicators	Solution A: Shared future	Solution B: The common new	Solution C: The new old school
C1	Affordability	• Average price to travel • Share of monthly expenditure on public transportation	5	4	4
C2	Accessibility (social)	• Accessibility to people with reduced physical mobility • Ease of taking transport for all ages	4	5	3
C3	Safety	• Total cost of accidents reimbursement • Number of accidents when utilising PT • Number of safe crossings for pedestrians	4	5	5
C4	Environmental Impact	• Carbon emissions (kg of (CO2+NOX) per 100 km) • Average distance travelled for 1 kWh (energy efficiency of electric vehicles) • Number of trees cut down to develop transport network	5	4	4
C5	Connectivity (physical)	• Average time to travel 100 km • Ease of transferring from one mode of transport to another • Frequency of PTs • Distance from residences/workplaces/schools to PT station	5	5	3
Arithmetic mean			4.6	4.6	3.8

4.10.2 Robustness Testing

Long-term and complex planning projects such as this project can be regarded as "wicked" in its nature (Malekpour et al., 2016). There is no single solution to the problem context and there will always be unpredictable and uncontrollable consequences of any adopted solution. However, by understanding the complexities and its possible implications, such as future uncertainties, the design of the project planning can be built more robust and adaptive (Malekpour et al., 2016). As elaborated in the Driver Analysis section in this report the group members have identified two key external uncertainties towards the mobility system in Skellefteå and based on these four plausible external futures have been developed (see subsection 4.8 and Figure 5). By evaluating each solution against the four external futures the solutions robustness can be tested. If a solution is able to deal with various plausible futures the more robust the solution is considered to be (Kordas et al., 2022). Based on group discussions, Figure 9 has been created, showing the potential ability for each solution to cope with the four external futures. The more a solutions frame is covering the plausible future the better the solution is a coping well with the future situation.

For more detailed information about the internal scenarios, see subsection 4.9.

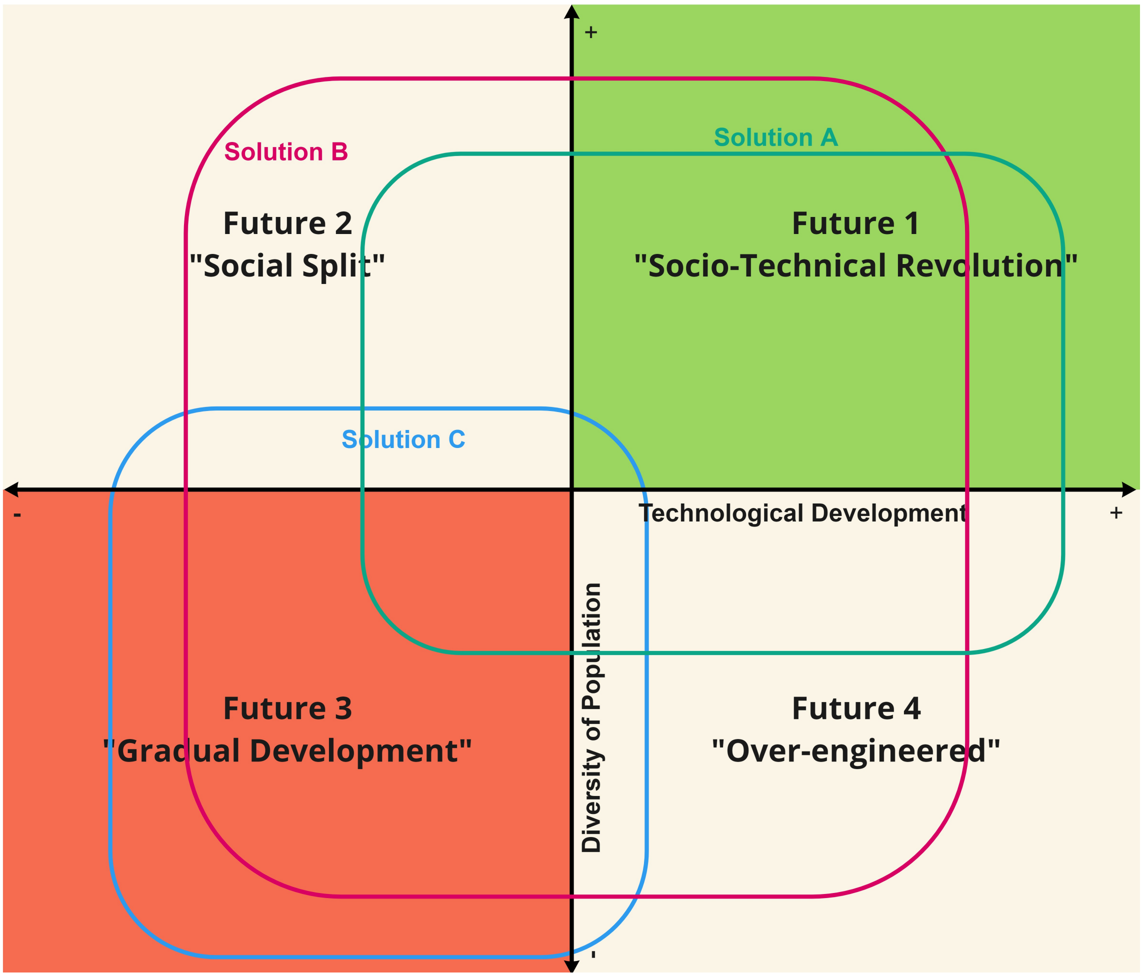

Figure 9: Robustness evaluation of each internal scenario against each of the four external futures defined.

Categorization of Internal Scenario / Solution A: "A shared future"
The Level of innovation of this scenario is radical and coverage of the mobility system high. That is the reason, why it is highly applicable for the futures one and four. In terms of technological development, it remains partly applicable also for futures two and three, since a fully renewable scenario as the energy source for transportation, and a partly development of infrastructure, relying both on existing and new infrastructure, require some technological advancement, but not as much as as for future one and four.

The sole focus on "Shared economy" as a type of ownership, might not be the solution neither for a highly diverse nor a slightly diverse population. Its adoption seems slightly more likely for a more diverse society, because people from different cultures moving to Skellefteå can be associated with different habits and attitudes, who seem more inclining towards the adoption of a shared economy. Additionally, a shared economy in the mobility sector has the potential to provide affordable solutions (Shaheen et al., 2020), which is an advantage for a diverse society, where different income levels are existent.

Categorization of Internal Scenario / solution B:"The common new"
This solution is categorized to be partly applicable for all four external scenarios, neither for upper and lower margins of both key uncertainties. The reasons in terms of diversity of population are the coverage of all three suggested ownership type and the incremental nature of innovation. Both for using solely renewable energy as a source for transporting and the objective of a high coverage for passengers, require some technological advancement, but not as much as for solution A.

Categorization of Internal Scenario / solution C: "The new old school"
This solution relies on private and public transport ownership types. Therefore, futures only with a rather low diversity in society would be applicable. For that solution, only incremental technology advancements (Level of innovation incremental, mix of current and new infrastructure, coverage of transportation system medium) would be required. As a consequence of both aspects, future three would be the only future applicable for solution C.

4.11 Final Scenario

From both the sensitivity and robustness testing, weaknesses and strengths of the created solutions have been uncovered. Based on these, a final scenario has been elaborated, to depict the optimal future mobility system in Skellefteå. In Table 4 the characteristics of the state dimensions included in the final scenario are illustrated in orange colour.

Table 4: The characteristics of the final scenario (shown in orange)

#	Dimensions	State of Dimensions		
1.	Transportation Ownership	**Private**	**Public**	***Shared Economy***
2.	Energy supply	Fossil Fuel-based	Mixed	**Fully renewable**
3.	Extent of infrastructure development	Usage of current Infrastructure	**Mix of current and new**	Completely new infrastructure
4.	Coverage of Transportation System	Low	Medium	**High**
5.	Level of Innovation	Business as Usual	Incremental	**Radical**

Essentially, the final scenario combines characteristics of the internal scenarios A and B. An outstanding element of internal scenario A is the focus on a highly technological development, which is illustrated by the focus on a radical level of innovation, and the focus on shared economy. It also relates to Skellefteå's strategy area three, "Global competitive economy", which comprises, amongst others, cutting-edge digitalisation and technology development (Skellefteå Municipality, 2022*b*).

To best possibly cover the levels of diversity in society, the coverage of all three ownership types shall be included in the final scenario, as it is part of internal solution B. The radical nature of innovation in the final scenario is strongly consistent with a shared economy in the mobility system, since it has only slightly been adopted in Skellefteå. Thus, besides the coverage of all three ownership types, the focus of the proposed final scenario lies mostly on the shared economy.

The remaining states of dimensions do not show any deviations and represent, after sensitivity and robustness, the preferred final scenario. To conclude the argumentation for a combination of both scenarios: It is the benefits regarding diversity in population (Solution B), combined with the coverage of a highly developed technology scenario (Solution A), which describe the final proposed scenario.

Through a group brainstorming, several ideas and concepts were proposed of how to realize the final scenario in the future mobility system in Skellefteå (see explanations in subsection 4.13). Imagine a future municipality where citizens can choose between different kinds of transportation modes, efficiently connecting the city center with the suburban and regional settlements. An inhabitant of Skellefteå, as part of the social institution, can (financially) profit from personally using public and shared mobility solutions, because he or she is a shareholder of the institution. Due to the availability of hydropower and the upscaling of renewable energy generation sources in the region, the mobility (Micro- and other types) fleets are fully powered by renewables. Due to radical innovations within the sector and the corresponding drastic changes in the surrounding environment, people living in the municipality will have adapted their behaviour and strongly support the concept of a shared economy, which not only includes the mobility, but will have spread to other domains as well (e.g. household equipment, leisure equipment). Due to the ongoing changes, a socio-technical revolution would have become feasible and all the new and future inhabitants that migrated to Skellefteå would have contributed to a flourishing, diverse population in the region. They have the chance to constantly communicate their needs, through representatives integrated in the municipality´s decision and development processes.

4.12 Pathway for Implementation

The defined pathway to reach a sustainable, reliable and inclusive transportation network incorporates five experiments defined by the project team and serves as a timeline to achieve this ambitious future until 2050. The following Figure 10 depicts this pathway, with defined goals and stakeholders for each stage.

Each experiment aims at aligning the development of the mobility system to meet the criteria defined throughout the project. Besides that they individually shape the society towards a sharing environment by gradually segueing into each other and paving the way for the following experiment to be implemented.The experiments will be explained in more detail in the following section.

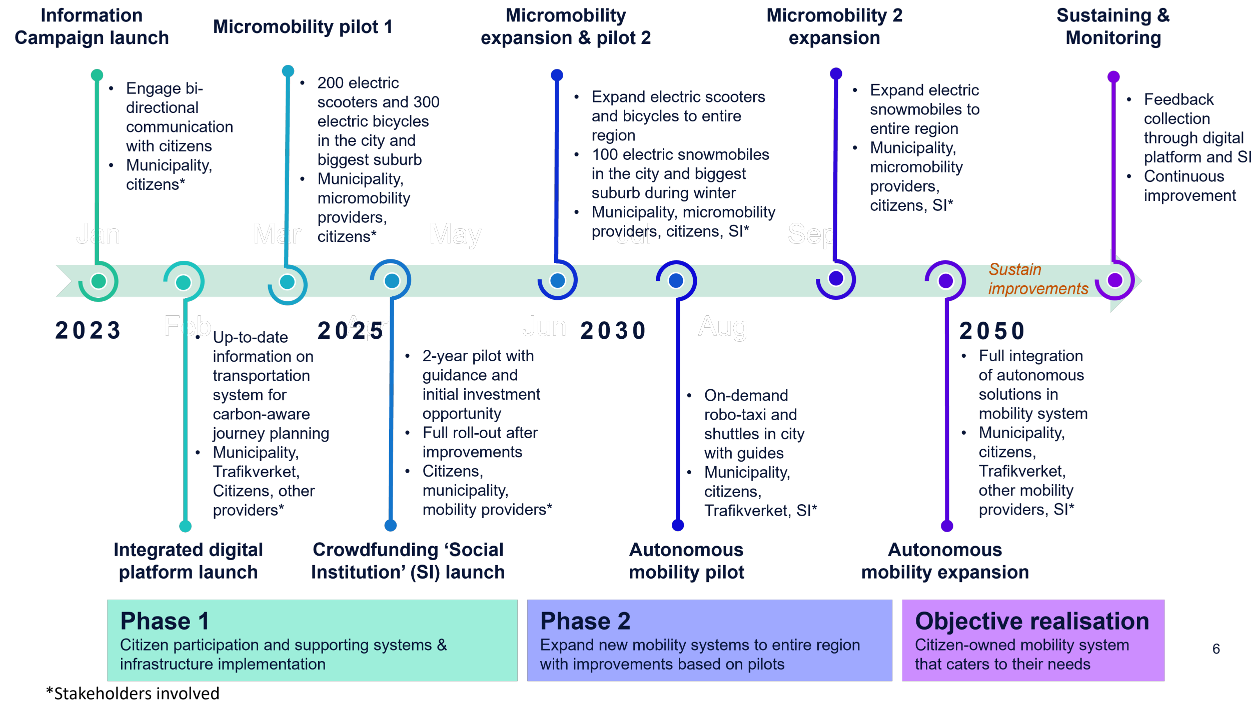

Figure 10: Pathway for implementation with defined goals and stakeholders

4.13 Experiments

Five experiments have been designed to raise awareness and implement the solutions at pilot-scale. Once success has been established in these, the solutions could be further expanded to meet the future vision. It is assumed that all vehicles will be run on 100% renewable energy in Skellefteå when implementing these solutions. In combination with the respective goals included in the pathway Figure 10, some concrete actions have been pointed out at the end of some experiments.

Information Campaign around Shared Economy

Over the last couple of years, the general concept of a *shared economy* has spread vastly over the world and multiple industries are shaping their future businesses around that approach. However, on a citizens level, the influence on their daily lives and concrete approaches for contribution may be hard to grasp. How can a single person act accordingly; which measures should be taken to support the incentive.

Thus, the first experiment will focus on raising awareness and create common understanding about what the term and lifestyle *shared economy* actually means and which benefits it brings along. By introducing a campaign aiming on the pillars of a shared economy the citizens of Skellefteå should be educated on that topic and gather concrete insights on what they can do. In order for the measure to be effective in the long-run, the project team suggests this experiment incorporates multiple levels: workshops, Social media, newspaper, discussion forums (e.g. Amsterdam by Ellen MacArthur Foundation (n.d.)). Furthermore, active participation (bi-directional) is crucial, only by experiencing the effects oneself, changes in behavioural patterns would occur. Hence, the campaign should be spread over a time-frame of 2-3 years - if not longer - to guarantee long-term success, while continuous improvement of the taken measures should be part of the following launches.

Reusing existing resources and sharing in general leads to less investment required by the municipality or the involved parties, which overall can result in a more affordable transport system for everybody. Next to that, a sharing economy can strongly decrease the environmental impact of several industries. According to Skjelvik et al. (2017) the transportation sector based on a shared economy in the Nordics has the highest potential for emission reduction, since overall less cars will be used and thus manufactured, while indirect benefits (including less congestion, air pollution etc.) would further boost this development. All in all, this initiative targets several criteria defined in Table 3.

Integrated Digital Platform for Mobility Solutions

The second experiment focuses on the integration of the various existing and future transportation modes within the city into *one, digital platform*, where all the necessary information regarding upcoming trips can simply be accessed at the users' fingertips. The authors suggest including an additional factor that sets the new app apart from existing, individual solutions: carbon emission-aware algorithms, that allow users to calculate the emissions of the chosen mode of transport for the journey and highlight the least-carbon intensive options. Furthermore, the solution will include urban as well as rural mode options and thus include the needs of all members of the society. The app moovit (https://moovit.com) serves as a great example of an Urban Mobility App that includes all options for real-time planning and purchasing in one single app. Since they offer a white-label solution, potential collaboration and the implementation of a pilot seems feasible. Continuous monitoring of the current mobility situation in the city is necessary so that new mode options are considered on an ongoing basis.

In the best case, the displayed options consider and prioritize shared modes amongst others and thus further boost the spread of these solutions. Obviously, this approach should be implemented while not discriminating other modes of transport and could be disabled by users. Another add-on should consider a purchase option within the app, so the final user does not need to install multiple apps in advance, before access to the chosen mode is finally given.

This experiment provides users with multiple benefits while always providing the most efficient option, while keeping affordability in mind. Meanwhile - if implemented correctly - the municipality could gather important feedback directly via the app, send notifications and news on malfunctions or congestion in specific areas and utilize this channel for various other points of interaction with citizens.

Crowdfunding 'Social Institution'

The third experiment aims at increasing citizen's sense of ownership within the new sharing economy. To achieve that goal, the idea of a *Social Institution* will be introduced to the people living in the municipality, where citizens can buy shares of the company and the raised funding will then be used to solve social needs and fund sustainable mobility solutions. Based on a social business model, each and every investment will be carefully evaluated on multiple criteria and then implemented potentially. At the same time the system would develop based on the requirements of the people, therefore boosting need-based connectivity. In Germany, similar Community-ownership based cooperatives have already been established for energy-related projects with wind and solar parks that are partly owned by citizens that choose to invest in them, thus strengthening citizens inclusion (Tieze, 2020). In Frankfurt, an electromobility cooperative consisting of four main founding members allows interested citizens to join the initiative with a starting investment of 500€, where in return they become a shareholder of the company while also facing reduced renting prices for the e-mobility fleet of currently 15 cars spread over the city (E-Mobilitätsgenossenschaft Frankfurtn, n.d.).

The revenue generated by those investments could either be spread among the shareholders (= citizens municipality) or ideally directly reinvested in additional activities backed by the institution's core values. Another idea regarding the revenue streams could be using them as a subsidy for the public transportation or transportation mode fees, so that citizens directly profit from their investments from the start, and hence increase the affordability of the mobility system in total.

Another advantage of that experiment would be the sense of ownership created amongst citizens. Nowadays, a lot of critique on shared mobility solutions comes in terms of damage and dirt exerted on the items in place (e.g. cars, scooters ..). Due to people owning and thus directly bearing the costs caused by these damages, they would care more about each item and thus avoid them from happening in the first place. More concretely, the project team suggests a test-phase for this experiment of about 2 years, with strong marketing and explanations up front, where citizens get educated about the concept. Similar to the Germany case, an initial investment of 5000 SEK could be required from individuals for participation. The solutions purchased with the gathered amount should include Shared Bicycles, Scooters and even the Snowmobiles. Figure 10 points out the stakeholders necessary to start this initiative.

Shared Micromobility between Suburbs and City
The fourth experiment is for the solution of establishing new shared micromobility modes of transport between the suburbs and the city of Skellefteå to meet the needs of increasing number of people living in suburbs and having to commute to the city. Micromobility is a part of the shared economy and consists of compact transportation modes like electric scooters and bicycles. Increasing the access to micromobility solutions would reduce reliance on private vehicles, especially for short-distance travels (Abduljabbar et al., 2021), hence reducing carbon emissions. If a micromobility system is integrated well within public transport, it can cover first and last mile journeys, improving the connectivity and accessibility of the mobility system (Oeschger et al., 2020). This would also reduce reliance of private vehicles, since public and shared transportation modes would be more convenient, reducing the environmental impact. Shared micromobility solutions also reduces cost of travel, making it more affordable for users (Shaheen et al., 2020).

Considering the unique climate of Skellefteå where there are many months of winter and snowfall, micromobility solutions like electric scooters would not be relevant all year. Hence, a new mode of shared micromobility could be developed - compact electric snowmobiles. These could be used by residents to travel between the suburbs and city in the months of winter, when there is heavy snowfall. It would reduce reliance on private vehicles, especially if travelling using a snowmobile reduces travel distance compared to a car as a snowmobile does not rely only on road infrastructure. A shared snowmobile could also be affordable for most, not just for those that can afford to own one.

A pilot program for implementation of shared micromobility solutions will be carried out in two stages. The first stage will be carried out in 2025, with the introduction of 200 electric scooters and 300 electric bicycles in the city and the most populated suburban area. The second stage of the pilot would be to introduce 100 electric snowmobiled in 2030 in the same areas during winter. Feedback would be collected during these pilot programs and the micromobility solutions will be expanded with improvements. Combining several micromobility solutions would improve connectivity within the dense city center, and also be applied for last mile transportation.

Autonomous Mobility

The fifth experiment is for the solution of using autonomous technologies such as robo-taxis and shuttles for the mobility systems, including public transportation in Skellefteå, ride-sharing, and vehicle-sharing. Shared autonomous vehicles are known to be more efficient and operating costs are predicted to be lower than driver-based mobility (Krueger et al., 2016). They could make transportation solutions like on-demand public transport a reality while keeping them well-connected and affordable. Use of autonomous vehicles for vehicle-sharing is also beneficial as it makes the vehicles more accessible since users would not have to travel to the vehicles to use them; the vehicles could be available at the user's doorstep (Fagnant and Kockelman, 2014). Furthermore, electric autonomous vehicles would have lower carbon emissions than driver-based vehicles, lowering the environmental impact of the mobility system. Per a study by Fagnant and Kockelman (2014), one shared autonomous vehicle could replace approximately eleven traditional driver-based vehicles. As autonomous technologies have been developed to be very robust, they would be safe for implementation and use as well. Overall, use of autonomous vehicle technologies could meet the criteria for the future vision.

For the experiment, a pilot program for shared autonomous vehicles and autonomous public transportation could be carried out in Skellefteå city area to assess its success from 2030. It is proposed that the pilot would include shared autonomous vehicles for citizens to rent, and autonomous buses as public transport. Before the pilot is started, supporting infrastructure such as compatible road networks would be constructed. During the pilot, on-demand autonomous buses could be run, where people would indicate their daily commute route, and buses would run on these routes. Carbon emissions-aware algorithms would be used to ensure that people along similar routes are grouped together to minimise carbon emissions of these buses. During this pilot, a human could be present on-board to explain how it works, and answer any questions.This would help to ease in the users, as they would feel more comfortable with having someone knowledgeable onboard while the technology is still new. Once its success is established in the city, it could be expanded out to the suburbs, where the population is expected to increase in the coming years. By 2050, the autonomous mobility solutions would be fully integrated into Skellefteå's mobility system.

Integrating the experiments

Synergy is present among the experiments as they support the implementation of each other. For example, having information and campaigns for a shared economy would aid in understanding the user needs and encourage users to adopt new mobility systems such as shared micromobility and autonomous vehicles. An integrated digital platform would combine the different transportation modes to make them more accessible and connected. Additionally, applying the experiments in coordination would address the human behavioural needs of using a shared economy. These include affordability, safety and availability (Heineke et al., 2021). Availability of vehicles is especially important for the success of shared economy as a replacement for privately-owned vehicles as one of the most attractive factors of having private-owned vehicles is that it is easily available (ibid).

An action plan is essential to facilitate learning from the experiments. For each of the experiments, clear objectives, timeline and target group should be set. This will allow a clear understanding of implementing the experiments and assessing their success. It is also essential to collect feedback for the experiments during and after implementation. Workshops could be held for stakeholders such as the citizens of Skellefteå with focused group discussions and surveys to gather their feedback on the pilot programs. The data collected from these workshops can be evaluated to find points for improvement in the different mobility solutions and implemented when expanding the solutions to a larger scale. It is especially important to involve the citizens in all the processes, from solution design, implementation and long-term sustenance processes, as it would ensure that their needs are addressed and they have a sense of ownership of the mobility systems. This would in turn encourage their adoption of the new transportation modes.

The success of these experiments in transitioning the mobility system successfully can be assessed using the identified criteria. The indicators of each criteria can be used to monitor the experiments, which would be deemed to be successful if they meet the set requirements. Once the requirements are met, the system can be further transitioned to the rest of Skellefteå. It is also important to integrate the different solutions well for a smooth-running mobility system that is easy to use and well-connected.

5 Discussion

The discussion section of this final report reflects first of all about challenges in relation the implementation of the mPB framework. Secondly, the iterative process of the mPB framework will be examined, and where the project group (needed to) diverge and converge from it. The third section of the discussion focuses on limitations of the nature of the framework *itself*, related to the specific project area (Mobility systems for the people in Skellefteå), but not regarding the implementation of the framework (contrast to the first aspect of the discussion). The discussion concludes by briefly summarizing the main outcomes of the project work for mobility systems in Skelleftea.

5.1 Challenges related to the implementation of the mPB framework

Without having previous experience of working with the mPB framework, the beginning of the implementation of the modules in relation to Skellefteå was a bit confusing. In addition to that, it was also challenging to understand the bigger picture about the deliverables and requirements as part of the course. The project group North Stars decided early in the process to focus on mobility solutions in Skellefteå, mainly based on input from the introduction presentation of Skellefteå municipality.

Challenges, the project team experienced during the implementation of the mPB framework were the overwhelming and not easy to understand nature of the framework, the lack of commitment for decision making (also as a result of the first aspect), and the complexity of transitioning a mobility system in general, but also in relation to the specific case of Skellefteå. All of this resulted in unnecessary challenges and long discussions, but also the way towards the determination of the final focus area.

Besides that, lack of clarity and difficulties in data collection (possibly to the fact, that those were not available for the project group) lead to a misleading focus of the problem area (Involvement of citizens to enhance the mobility system). However, the focus on citizens involvement related rather to a way of achieving elaborated solutions, not to be a solution itself. This focus area was too much concentrated on a single actor (the citizens), thus too narrow for a focusing area, which is against the nature of the mPB framework. Eventually the project group understood and was convinced, that for creating and realising future sustainable solutions, the participation and consensus of all relevant actors are key. This kind of co-creation opens up many opportunities to successfully achieve sustainable system transitions (Kordas et al., 2022).

Regarding the needs and functions module, some difficulties evolved while trying to grasp and phrase both needs and functions of the underlying problem. Potentially a lot of confusion around this module was created because of the erroneous focus area at that time. Once the focused area had been changed to the final state, the identified needs of the mobility system in Skellefteå became more open and more focused on mobility itself, i.e. questions such as "Why do people us the mobility system" were formulated to reveal fundamental underlying needs. A lot of misconceptions emerged around the difference between functions and criteria. This was mainly the case, since the group had difficulties with understanding the definition of system functions. At some point, the project group mastered to sharply distinguish between criteria and functions, without putting value on criteria, but developing functions which clearly satisfy fundamental needs related to the focus area. Even though resources such as the (Skellefteå Municipality, 2020*b*) of the municipality were available, it was difficult to collect data to fully understand the current situations of mobility systems in Skellefteå. The physical distance not to be present on the spot, for example to directly collect information through surveys, interviews or observations, made it challenging to develop functions of the desired system. An additional challenge when applying the mPB framework was the identification of key external uncertainties to the system and the development of the 4 potential external futures, mainly caused by a partly misconception of how much actors could have influence on those.

As it is natural while working in groups, and especially since various decisions, for example regarding criteria or the morphological table, where taken based on group discussion and consensus-building, the different views of the group members lead to rather long discussions. In addition, it may be mentioned, that some group members did not know each other at all, which made it challenging to best possibly distribute and assign tasks for everybody, particularly having in the mind the very short time frame of the entire project (mid of January 2022 - mid of March 2022). However, the dynamics of the group enabled exciting collaboration amongst each other, which inspired us to thoroughly work on creating sustainable future scenarios and solutions for the mobility systems in Skellefteå.

One of the easier modules to implement in relation to mobility system in Skellefteå was the future vision. The future sustainability aims and goals for year 2030 regarding the transport system are clearly stated in the (Skellefteå Municipality, 2020*b*) made by Skellefteå municipality. Combining those with the determined criteria, needs and functions, where no major challenges in regard of the vision. After the final scenario had been identified, the group experienced great brainstorming sessions, were several different potential experiments were recognized to depict and illustrate the final scenario. This step in the mPB framework was one of the easiest and most exciting during the entire working process. Perhaps, it had been the only step of the mPB framework, where no concerns regarding applicability and suitability were present.

To conclude this section: besides lots of exciting working sessions in the solution finding process as part of the project group, it was the short time frame and huge intensity of applying the framework itself, which were identified as key challenges on the way to successfully accomplish the project.

5.2 The iterative process of the mPB framework: Divergences and Convergences

In Figure 11 the linear process in the seminars which also reflects the order of presented mPB modules are shown together with the project works iterative process back and forth between the modules. Below some numbered working steps which required a change of approach is further elaborated.

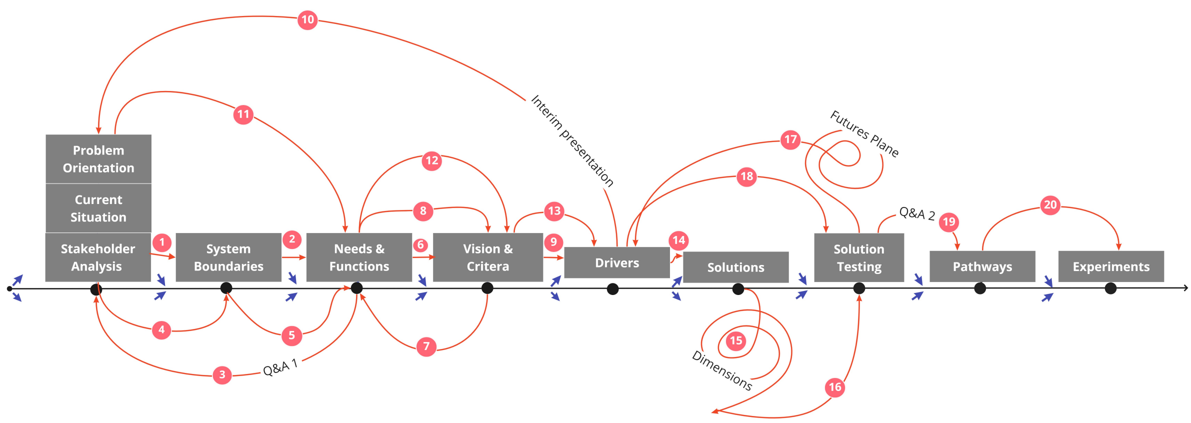

Figure 11: The iterative process of the project work when following the mPB framework and the convergence/divergence points in the process (in blue).

10) Around the time of the interim presentation the group came to know, from a feedback session, that the mPB framework was not suited for being applied on the focus area the group had at the time; citizens involvement to enhance the mobility system. The group realized that the previous modules had not been fully understood and that a new approach for implementing the mPB framework to the project work was needed. Thus, the group went back to the problem orientation and started again to apply each modules concepts to develop a more solid base of information to elaborate a strong vision. Overall this made the group realize that the nature of mPB require continuously adjustments and refinements when new perspectives and information are revealed.

15) A lot of time and effort were spent on identifying relevant dimensions and associated extreme states (the final result is seen in Table 2). In the beginning the group discussion did not result in anything concrete. First the definition of dimensions were not clear to us and secondly when it was, identifying relevant dimensions for the system in focus was a challenge. Multiple key qualitative or quantitative characteristics of the mobility system in Skellefteå were brought up during discussion, but deciding on a limited set of the most relevant dimensions was difficult. Especially, as the people mobility system is a complex system with many interrelated components. However, after consultation and inspiration from other groups in the course 5 different dimensions were jointly selected by the group members.

17) When it came to the robustness testing, the main problem was the first identified key uncertainties. As mentioned before these key uncertainties were not fully external factors which made the futures plane unsuitable for the robustness testing. Thus, the key uncertainties needed a refinement before the robustness testing could be useful for the final scenario. Once again the group needed the question whether they had interpreted the previous modules concepts right.

In Figure 11 small blue arrows is also displayed between each module. These represent where in the process of applying the mPB framework in relation to our project work, the group members understand that the process have entered a convergence versus a divergence state.

The apprehension among the group members is that when entering the system boundaries module from the more broad problem analysis, the work process entered a convergent state as the problem context needed a more clear focus. Continuously, the problem context became more and more focused (more convergent) as more specific components and its functions in the system were identified. The convergent state continued all the way until the vision was elaborated. At this point, the working process once again started to diverge as the team had to begin more brainstorming sessions to enable more reflection on potential alternatives. The working approach continued to diverge when the solutions were developed. At this stage, all the group members knowledge base and potential input to the future solutions were considered. In general there are no right or wrong proposals for the pathway to the desired future and thus, all suggested alternative were valuable. While working on the remaining modules the process returned to the state of convergence as the testing excluded undesirable alternatives and as in the end more concrete and specific suggestions for a way forward were required.

5.3 Limitations of the mPB framework itself and recommendations

Limitations of the mPB framework related to the focus of the project group specific area (Mobility systems with the people in Skellefteå) and partly to the focus area of this course (Sustainability transition of Skellefteå) were derived to be data quality, data availability, and further minor miscellaneous aspects, as derived in the following.

Considering data quality, the nature of the mPB framework to require creative input, for example through applying the morphological analysis of the solution development, might lead to potential wrong results. Of course, group discussions and brainstorming are based on a former scientific research, however also demand a lot of intellectual property, to introduce by the participants, who might be subject of cognitive biases. Another example of the mPB framework to generate results subjectively is the performance rating of the internal scenarios against the set of criteria.

Lack of data availability might be existent by applying the framework, however is strongly depending on the role and their access to information sources. In context of the project group specific focus area, because of our position as (mainly) non-Swedish students, not living in Skellefteå, important data could have been missed, which potentially led to the development of not having achieved the most suitable results for Skellefteå. Another aspect is the open-end character of the mPB framework on the one hand offering a vary broad range of methods to be applied, and on the other hand if the formulation of the challenges to be solved is quite broad, as the context of the course illustrates it. Both aspects provide a lot of flexibility and room for creative unfolding. Evidently, it is important to dedicate a lot of time on understanding the current situation, problem area, needs and functions, etc., but it can also lead to a certain degree of confusion and demotivation, and delays in the progress. Finally, it is the role of a student group, which may limit the application of the framework. It can be related to lack of data availability, taking the example of this project specific focus, that students hardly have access to information from industry or societal institutions. It also illustrates the concern of subjectivity and cognitive biases, because students may belong to the same "bubble", potentially following similar mindsets and habits. Having in mind all these challenges related to the framework, the project group North Stars derived three main areas of recommendation:

1. Consolidated guidance and streamlining of project area
2. Increased involvement of stakeholders
3. Creation of diverse or alternative groups to apply the mPB framework

Consolidating guidance by professionals along the process of applying the mPB framework or streamlining the focus area may reduce levels of confusion and demotivation, increase efficiency of the work, and altogether increase the quality of the results.

Increased involvement of the stakeholders may increase the availability and quality of data. Naturally, stakeholder involvement and participation is a method in realising solutions, for example through co-creation workshops. However, by involving stakeholders also in the data collection process, for example through surveys or interviews, facilitated by the municipality, data accuracy and correctness could be ensured, and the quality of them increased.

As described above, the role of student groups being the actor to apply the framework, limit it as well. It can be of interest to create mixed groups consisting of both students, but also of people being in the leading position to steer transitions, for example at governmental institutions. This would likely create an environment of bringing together both different mindsets, different perspectives about problems, but also enhance the accessibility to different sources of information (Science through students and primary data through actors directly involved in the transition). This general idea would have been also applicable for the project context of Skellefteå and its sustainability transition. Finally, it can be of interest for institutions steering transitions, to adopt and use certain modules and activities of the mPB framework, for example by elaborating needs and functions, or the methods of the solution testing. The application of those could lay the foundation for further innovative development, without going into much depth into the framework, which could be associated with utilization of many resources.

5.4 Conclusion

An essential aim of this project has been the development of potential scenarios on how the municipality of Skellefteå can reach their ambitious goal of a future-proven transportation system while rapidly increasing in population size over the upcoming decades. To guarantee active involvement of citizens along this development process, the vision for 2050 is defined as creating a sustainable, reliable and inclusive transportation network in cooperation with the people of Skellefteå. The validation of this process will be conducted on the base of several criteria closely related to various social, economical and environmental factors. Conducive to realizing this vision a clear pathway consisting of several experiments has been elaborated and presented to municipality representatives. The positive feedback on the creativity, while being reasonable at the same time, of the suggested solutions and advancements of the mobility system, strongly supports the feasibility of these wild ideas. Thus, the proposed measures are in line with today's targets and could potentially be implemented in real life. Especially the idea of a Shared Institution could provide multiple benefits, since a common sense of ownership and responsibility is the perfect base for a shared economy. Even though the idea of Robo-Taxis or completely autonomous vehicles in the region sounds more like a movie today, the initial goal of the mPB method has been achieved. That is, defining a radical vision of the future based on crucial problems within defined boundaries. Summarized, this project highlights ways to achieve the final solution in 2050 and provides great insights for further investigation by local authorities.

6 Teamwork and Organisation

At the first group meeting on zoom a project group agreement was developed based on all group members input. This activity helped to get a sense of each group members expectations and ideal working process which also contributed to a more relaxed atmosphere in the group. The group members agreed on that meetings in person was important for most sufficient and fun collaboration and thus, a majority of the group meetings occurred physically.

A shared google drive folder with a meeting project log was also created and used from the beginning of the group work which facilitated the collaboration and the control of the working process. A key measure which made the group meetings more efficient was that each meeting had a designated meeting leader and scribe. Furthermore, consensus-building has been a prioritised throughout the project which has helped to create a good working atmosphere.

Possibly, the team could have planned the project work better in order to avoid time pressure in the end of the project work. However, as the mPB framework and its iterative nature was new for all group members the planning of the project work was challenging.

Using more digital tools like Miro has been useful throughout the project work as it has aid the creative collaboration and communication. The tool has also supported a structured documentation of our work process and lines of thoughts.

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