Universitetet i Stavanger

Author: Ruben Eggebø

Accelerating the transition towards zero-emission long and heavy duty transport through identifying the highest potential locations for hydrogen filling stations

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AUTHOR: Ruben Hallerud Eggebø

SUPERVISOR: Homam Nikpey Somehsaraei

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List of abbreviations

BEV	Battery Electric Vehicle
CCS	Carbon capture and storage
CO2	Carbon Dioxide
E-18	Europavei 18
EU	The European Union
FCEV	Fuel Cell Electric Vehicle
MLP	Multi Level Perspective
SCC	Social Cost of carbon

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Abstract

This thesis provides an overview over what traffic distances proved the largest potential for hydrogen filling station location. It also gives insights to the level of CO2 emissions the traffic volume at given points equate to, and the potential demand for hydrogen along these distances. The traffic distances that stands out as Norway's most optimal locations based on heavy and long duty traffic data are the three main highways out of Oslo, followed by main highways from or past the three biggest cities outside of the capital, Trondheim, Bergen, Stavanger. Along with certain distances on the E-18 on the south-east of Norway, these equates to the ten most promising locations based on traffic volume.

Locating hydrogen filling stations at traffic points or distances with higher traffic volume could have major impacts in the climate and economic benefits of decarbonizing long and heavy duty transport. The impact of decarbonizing higher traffic points is significant, as CO2 emissions for the higher volume traffic points are inherently are far greater, as are the different between high volume points and medium volume points.

As the research has shown, traffic volume varies greatly, even among the highest volume distances along Norwegian highways. Securing that filling stations cover as high volumes of traffic as possible and are located as optimal as possible, could increase its decarbonizing effect and lower end cost to customers. As each station could serve higher volumes, and potentially sell more hydrogen, this makes for better business cases for private actors. For public actors and government an increase in the volume covered by each station, would provide an opportunity of being able to see greater climate emission mitigation for the money invested through policies, subsidies or incentive creation.

Foreword

While working on my thesis I have been fortunate enough to be involved with a number of enthusiastic and skilled people. First of all I would like to thank my supervisor, Homam Nikpey Somehsaraei, for excellent guidance and meeting me with the respect and smiles that he has done all the way, even in the final hours before delivering.
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1 Introduction:

1.1 Background:

The last couple of years the interest in hydrogen technology and development has seen a sharp increase. Both public and private funds have been gathering behind a variation of planned activities, ranging widely in concern of the hydrogen end use. According to Bauer, «*hydrogen is a crucial element in most strategies to achieve net zero standing, and more countries are developing hydrogen plans. In fact, over 30 countries have created such strategies on a national level, and six are drafting them*» (2021, p. 8). One of those with interest, is the European Union. The «EU Hydrogen Strategy» outlines the vast possibilities for the end use of the fuel as a reason for its increasing popularity; «*Hydrogen can be used as a feedstock, a fuel or an energy carrier and storage, and has many possible applications across industry, transport, power and buildings sectors*» (European Commission, 2020, p. 1).

The European hydrogen strategy further underlines that hydrogen has had periods of increased interest in the past, but certain developments makes for a very compelling case looking into the future; «*Today, the rapid cost decline of renewable energy, technological developments and the urgency to drastically reduce greenhouse emissions, are opening up new possibilities*» (European Commission, 2020, p.1). Both cost reduction of renewables and hydrogen technology in combination with the increasing urgency to reach goals connected to zero-emission targets, makes hydrogen based technology and its broad specter of application possibilities an important candidate going forward.

In addition, there are more to the tale of hydrogen than countries making plans. Significant investment has already been made, and the number is rapidly increasing. Bauer (2021) states that 75 countries has set net-zero carbon emission goals, and 30 of them has developed specific hydrogen strategies in hopes of reaching them. The EU, China, Australia, United States and Canada are amongst the countries backing the hydrogen development. The report further states that if all hydrogen projects come to fruition, the total investment in the hydrogen scene will exceed 300 billion USD within 2030. Also, the members organizations and businesses of the «Hydrogen Council» are planning to increase their investment in hydrogen with a factor of 6 within 2025, and with a factor of 16 within 2030, according to Bauer (2021).

While this picture painted by governmental and private backing and financial support gives no guarantees, there seems to be serious interest and determination from actors all over the world to seek a hydrogen-dependent future. As many of the bigger european energy nations has decided to increase their focus on hydrogen development and policy implementation, Norway has made steps more recently in the same direction.

Norwegian companies has a great history of producing hydrogen for industrial use, for example to make fertilizer and aluminum. From the early days of Kristian Birkeland and Samuel Eydes discoveries and developments within fertilizer production, to the more recent history with the hydrogen company Nel achieving success in their quest to produce electrolysers and hydrogen equipment. The two men's important discoveries led to an industrial adventure in Norway starting from their plant in Rjukan, Norway. Both Yara, the fertilizer company, NEL and the remained of their previous mother company, Norsk Hydro, originates from Norway. Not only were they once one single company, but hydrogen was, and still is, a common and important ingredience in all of these companies histories. As previously mentioned, hydrogen has the ability to feed a great specter of important processes in the world today, ranging from energy storage, to fueling vehicles and helping feed the world through ammonia and fertilizer products. And Norway has been responsible for a great number of developments in the last one of these areas (Yara, 2021).

As Norway, and several big companies are familiar with both hydrogen production and utilities, and development of these products and technologies, one would assume that there are business opportunities for national industrial actors to take advantage of this increased international interest in hydrogen. Adding an abundance of both hydropower and rich oil and gas fields, which are important elements of the different ways of producing sustainable hydrogen, this gives us the resources of being able to produce hydrogen with existing infrastructure. In 2020, the Norwegian government released their hydrogen strategy stating that; «*Hydrogen is an energy carrier with a significant potential for reducing local, national and global emissions, and for creating economic value for Norwegian businesses*» (Regjeringen, 2020). It further states that if hydrogen is to be a contributor to the reduction of greenhouse gases, it has to be produced using electrolysis with energy from renewable sources or extracted from natural gas combined with carbon capture and storage (CCS). While CCS has been a technological area of Norwegian interest for a long time, the production of hydrogen from natural gas combined with CCS, also called blue hydrogen, are put forward as the fastest path to hydrogen competitiveness compared to carbon intensive fuels. The report further underlines the potential Norway has within the hydrogen sector, given its gas reserves, a highly technologically advanced offshore and maritime sector and also the potential of CO2 offshore storage facilities in gas fields in the North Sea (Regjeringen, 2020).

While hydrogen seems to have many potentially commercially viable end uses, I will in this task focus on one in particular. As Norway, among many nations, has defined goals for the reduction of GHG emissions for transport, some areas of the transport sectors seems to lag behind. The battery electric vehicle (BEV) revolution in Norway has seen a sharp rise in the number of electric vehicles. However, most of the vehicles that currently run battery-electric technology are in the category of light vehicles. According to statistics from SSB, there were 340.000 electric cars in Norway at the end of 2020, translating to about 400 % increase in the last 5 years. For heavier duty transport however, the electric trucks suffer from significantly lower implementation. There were no more than a total of 37 heavy duty electric trucks in Norway by the end of 2020. While it can be hard to point out a single reason for why this segment has not seen the same development as the personal traffic, a lot of studies points out that there are several difficulties connected to the challenges of heavy and long duty transport, that are not being met sufficiently by BEV technology (Statistisk Sentralbyrå, 2021).

Similarities between BEV and fuel cell electric vehicles (FCEV) technology and its advantages, including greenhouse gas emission mitigation and local air quality improvements. While they can improve emission statistics and local air quality in dense populated areas, the different technologies comes with different demands to infrastructural changes that needs to happen in order to make the respective technologies viable in terms of market penetration. These costs may vary greatly, and its total price is also massively impacted by national conditions, leading to variations in capital costs and investments needs in every country for both alternatives. While BEV vehicles enjoys great market penetration in Norway, this is not necessarily the case for all countries. According to Robinius et. al (2018) surplus electricity from increasing renewable energy production gives convincing economic incentives to further develop the BEV and FCEV technology. Making use of this surplus energy makes for great economic and climate friendly possibilities, according to the report.

According to Robinius et. al (2018) report on infrastructural investment needs in Germany, the total cost of infrastructural development needed to support 20 million vehicles is estimated to around 51 billion euros for electric vehicle charging infrastructure, while the hydrogen alternative is estimated to the somewhat lower 40 billion euros. This gives an interesting perspective on two rather similar technologies.

Governments around the world, the EU and other organizations has long wondered how to decarbonize the transport sector. Both air-, land- and sea-transport has yet to reach this goal, and there is a lot of alternatives connected to possible technologies that could pave the way for this achievement. The hardest part of zero-emission achievements is perhaps not deciding that it is a goal, but rather how climate-economically efficient one may be in the search to be so. The personal traffic of Norwegian roads has in the last decade been world leading in implementation of electric vehicles. An astonishing growth in the sales of electric vehicles has made the world look to Norway for inspiration (Lorentzen et. al, 2017). Yet, no similar growth of zero-emission technologies has reached the long- and heavy duty-transport sector, even though it both nationally, and most places also locally, has been a stated goal. There seems to be a lack of good alternatives as the battery-electric options has not yet shown sufficient operating range or charging times to be suited for this kind of traffic. In the later years, both the EU and technology giants like Germany, South Korea, Japan and China has pushed the hydrogen technology in several technological areas, among these long- and heavy duty transport. As this technology shows results of great range and low refueling times, this sector could possibly seem like a great fit for hydrogen. Yet, infrastructural challenges among others stand in the way causing both economical and logistical challenges (Regjeringen, 2020).

For the case of hydrogen, one of the main infrastructural challenges are its high transport costs. As its energy density is very high, it takes up a lot of space (Office of energy efficiency and renewable energy, 2021). To be able to transport a lot of hydrogen at once, you would have to compress it by a great factor. This is both energy consuming and it sets huge demands to the infrastructural solutions that have to be put in place to be able to lower the transport cost of hydrogen. These solutions may not be commercially available even, at present time. As ambitious climate goals have been set both for nations and internationally, and scientists keeps pushing the fact that we do not have an abundance of time to overcome the climate challenges, this infrastructural challenge of hydrogen should be solved somehow. If we are not able to solve the transport issue itself, perhaps we can lower the need for transporting the fuel. In doing so, we could avoid costs connected to producing and delivering the fuel, possibly pushing hydrogen to an earlier commercially competitive alternative. If this is successful, the technology could enjoy a faster penetration of the market, thus leading the way to an earlier climate-solution to this segment of transportation.

In this paper I have attempted to get a statistical overview of the traffic routes in Norway, to be able to point out which existing major heavy and long duty transport lines that are the strongest candidates for hydrogen filling stations, based on the potential demand of the specific points. If we are able to determine which of our traffic points that accounts for the greatest amount of heavy and long duty transport today, we could also include this into the planning of the placements of commercial hydrogen production plants. The rational behind this is that planning these plants as close to the biggest potential sources of consumption of hydrogen, actors are able to reduce transport need, and thus also the cost, scale up their plants even more and yet again reduce costs at an even more rapid pace. This will hopefully in turn lower the cost of the fuel, while simultaneously increase the availability of it for as many as possible, due to the stations being placed near a greater amount traffic actors. In doing this we could possibly speed up the transition to a greener transport sector, while utilizing our public and private funds in a more climate-economical efficient way.

For this thesis I have aimed to provide a listing and comparable ranking of all distances along the Norwegian highways. Giving an overview over the potential that lies in decarbonizing existing long and heavy duty transport, can contribute to better planning and policy design from private and public actors. In the extension of this, I have also attempted to make a ballpark analysis of the economic damages that the current amount of traffic past each point accounts for. In addition to this, I have also sought out to calculate the potential demand for hydrogen along the top ranked national traffic points, providing private and public actors with insight as to how great of a volume these points access today, if all traffic were to be converted into hydrogen vehicles.

In the adding of all these missions, I wanted to look at what these numbers could mean for policy design and implementation for public actors, for the possible business cases in relation to private actors, and how incentivizing could take advantage of the current traffic picture to be able to optimize the efficiency of public and private spending while providing hydrogen infrastructure. The research questions for this thesis are therefore as follows:

1.2 Research questions:

Given the provided background and considering the aim of this thesis, the following research questions have been formulated to be addressed throughout my research:

1. **When ranking traffic points after total amount of long and heavy duty transport passings, which distances shows the greatest statistical potential for hosting hydrogen filling stations?**

2. **How large is the climate-economic potential of optimal placements of filling stations, and how can policy be designed to accelerate the transition towards hydrogen driven land transport?**

1.3 Structure

In this introduction, the foundation of the thesis and research questions are presented. This includes evaluation of traffic points, potential optimal placements of filling stations and the possibly areas of interest when it comes to designing policies that could enhance the transitions towards decarbonize heavy and long duty transport through hydrogen infrastructure placement.

In chapter 2, the theoretical frameworks that the research has been explained and analyzed through, are presented. Two main theories, in which originate from a common one, are being focused on throughout the text. In addition, a model of my own creation is also unveiled together with thorough explanations and walkthroughs of its calculations and results. In chapter 3 I go through the research and how it has been conducted. In this part the focus is upon the data collection, the datasets taken into use and the choices being made in the process.

In chapter 4 the results of the research are laid forward, together with results from the calculations made using the models explained in chapter 2. The results are summarized and concluded in the thesis' chapter 5, with conclusions. Here I provide an overview of the results, the theoretical framework and answer the research questions. Ending the paper, and this thesis, is chapter 6, taking a look at recommendations for future works, where I put forward reflection upon what could be the next step for hydrogen infrastructure development in Norway.

1.4 Definitions

1.4.1 Hydrogen technology

In this paper I refer to technology utilizing hydrogen in any way, as hydrogen technology. This could be fuel cell electric vehicles or other types of transport using hydrogen fuel, or industries using hydrogen for power, chemical properties or other utilities.

1.4.2 Hydrogen vehicles

Usually refers to fuel cell electric vehicles, that uses hydrogen as fuel. These vehicles stores the energy in hydrogen, running it through a fuel cell to convert it to electricity and moves forward with an electrical motor (Molloy, 2019)

1.4.3 Hydrogen filling station

Stations like traditional gas stations, where the fuel pumped or refilled is hydrogen. This is where the fuel cell electric vehicles will refill their tanks (Prince-Richard et. al, 2005)

1.4.4 Traffic point

A traffic point refers to the measuring station, that Statens Vegvesen uses to gather statistics on passing traffic A traffic point is not a distance, but a camera or sensor in which the vehicles are registered and measured (Statens vegvesen, 2020).

1.4.5 Carbon capture and storage

Carbon capture and storage refers to technology being used to capture the CO2 when burning fossil fuels or CO2 intensive material. This is then stored, either in tanks or in reservoirs (IEA, 2021).

2 Theory

2.1 Multi Level Perspective (MLP)

In the search of theories that could shed interesting light upon the different findings of my research, I quickly scoped out Frank Geels' «Multi Level Perspective». He underlines the issue of climate change as an example of «contemporary governmental problems» in which would require deep structural and systemic changes in central parts of our societies. These deep structural changes, in which he calls «socio-technical transitions» would have to have major impacts into areas like transport, energy and agriculture, for us to make progress in our battle to solve these «contemporary governmental problems» (Geels, 2011).

In the MLP, Geels also defines three main characteristics of transitions towards sustainability. The first characteristic, or problem if you would, is that private actors often lack incentives to partake in dealing with environmental challenges. Whereas historical transitions are related to businesses exploring with new technologies, Geels claims, the transition towards sustainability is a journey towards a common goal. The problem with this, according to Geels, is that it implies «prisoners dilemmas» and free riders. With this he points to the difficulty of making private actors taking on costs for the better of everybody, without the guarantee that everybody will contribute equally. Every private actor also has to trust that everyone else is going to make the same commitments and stick to their goals, and therefore risking taking more of the responsibility, and possibly cost, than others. When putting this into a competitive perspective, one could say private actors could benefit from letting others do the job of securing sustainability. With this point he underlines the importance of public goods and policy making to support green niches, change economic regulation to favor those who contribute, and to support the niches that develop green technology and solutions (Geels, 2011).

Secondly, the MLP underlines the fact that sustainable solutions often lacks the obvious user benefits that drives other historical technical advancements. It also often scores lower when comparing price to performance, Geels claims. Therefore these technologies are much more dependent on a change in economic frame conditions, according to Geels, again pointing to the importance of policy making and public funds. As innovative sustainable technology are not necessarily driven by competitiveness, political and economic changes are needed to facilitate growth in the area, in which «vested interests», or existing actors of each of the levels in the MLP, will try to resist.

The third characteristic that Geels brings about sustainability transitions, is the areas in which transitions are most needed. Examples could be energy production, agriculture and transport. The areas tend to be huge areas of common interest, that has been under development for a long, long time, and that are *«characterized by large firms (e.g., car manufacturers, electric utilities, oil companies, food processing companies, supermarkets) that possess complementary assets such as specialized manufacturing capability, experience with largescale test trials, access to distribution channels, service networks, and complementary technologies*» (Geels. 2011, p. 25).

The areas he mentions here, as examples of areas needing change if socio-technical transitions were to be made possible, are also followed and dependent upon aspects and developments within technology, markets, consumer practices, policy amongst others, according to Geels (2011). As he explains further; «*These elements are reproduced, maintained and transformed by actors such as firms and industries, policy makers and politicians, consumers, civil society, engineers and researchers. Transitions are therefore complex and long-term processes comprising multiple actors» (Geels. 2011, p. 24).* Geels points to these elements as being both a result of the actors operating at the different levels of his theory, but they are also being upheld and defended by the sheer nature of these actors and their incentives. Therefore, to be able to achieve transitions, one would have to compete against some of the mechanisms ruling within the realm of society across all levels (Geels, 2011).

The most important parts of the Multi-Level Perspective is its different analytical levels. Geels theorizes and explains the several different levels, mechanisms and workings within the development and happenings of such socio-technical transitions. He initially states that; *«The MLP views transitions as non-linear processes that results from the interplay of developments at three analytical levels: niches (the locus for radical innovations), socio-technical regimes (the locusof established practices and associated rules that stabilize existing systems), and an exogenous sociotechnical landscape» (Geels. 2011, p. 26)*. Geels explains through the MLP theory that sociopolitical environments are governed within three levels, in which different actors, mechanisms and other entities operates. This is also the areas that socio-technical transitions take place. He further explains that the three levels is both differentiated but also kept together by a set of multiple mechanisms and incentives, that both resist and motivates change. The levels are as follows:

2.1.1 Niche level:

The first of the levels in the MLP, where the transition starts, is the niche level. This level consists of thoughts, technologies, views or knowledge or that has not yet pushed its way through the niche level and became part of the of a regime. The niche actors works on innovations to get into the regime level, but meets challenges in the regime levels resistance towards transition, and the mechanisms that hold the regime in place (Geels, 2011; Eggebø, 2020, p. 7)

While the niche level tends to contain the actors driving for change, they are set to meet challenges facing actors or mechanisms from the regime and landscape level. While some parts of the other levels also incentivizes and motivates transitions, actors existing in the niche level usually fights an uphill battle. Geels further states that niche development are distinguished through three sets of processes;

- *The articulation (and adjustment) of expectations or visions, which provide guidance to the innovation activities, and aim to attract attention and funding from external actors.*
- *The building of social networks and the enrolment of more actors, which expand the resource base of niche-innovations.*
- *Learning and articulation processes on various dimensions, e.g. technical design, market demand and user preferences, infrastructure requirements, organizational issues and business models, policy instruments, symbolic meanings.*

(Geels, 2011, p. 28)

These processes all recognize developments of niches and can be used to identify niche development today. In the case of hydrogen, several of these are development characteristics that are familiar, in which has been relevant to analyze while working with this thesis.

2.1.2 Socio-technical regime:

The level above the niche level, the socio-technical regime, is made up of the currently widespread and implemented technologies and thoughts. The regime is dominated and kept in place by several lock-in mechanisms, that makes going from niche level to the regime, harder. (Eggebø, 2020, p. 7) Geels states that: "*Examples of regime rules are cognitive routines and* *shared beliefs, capabilities and competences, lifestyles and user practices, favorable institutional arrangements and regulations, and legally binding contracts"(Geels, 2011, p. 26-27).* He further states that "*The regime level is of primary interest, because transitions are defined as shifts from one regime to another regime. The niche and landscape levels can be seen as 'derived concepts', because they are defined in relation to the regime, namely as practices or technologies that deviate substantially from the existing regime, and as external environment that influences interactions between niche(s) and regime"(Geels, 2011, p. 27).* According to Geels, the other levels are exempted from the regime, making it the most influential of the levels in the MLP (Eggebø, 2020, p. 7).

The regime levels consists of currently dominating aspects of society, within several different categories or areas. Areas such as politics, science, technology and markets are dominated by their own set of dynamics, but according to Geels, they also co-evolve, being both resilient and dependent upon each other as time passes by. Changes in the one, can lead to changes in the others. While they are defined by outer borders, they are also influenced by each other by being connected through an interplay of different mechanics and themes that possibly overlap the borders of these categories, according to Geels view of transitions (Geels, 2011).

2.1.3 Socio-technical landscape:

The landscape level consists of the most stabile stage of a transitional pathway. "*The sociotechnical landscape is the wider context, which influences niche and regime dynamics"* (Geels, 2011. P. 28). It "*highlights not only the technical and material backdrop that sustains society, but also includes demographical trends, political ideologies, societal values, and macro-economic patterns"* (Eggebø, 2020, p. 7; Geels, 2011, p. 28). The landscape level consists of the slow-moving giants, that in sum creates the backdrop of society. This slow-moving landscape can potentially both resist and drive change towards transition. (Eggebø, 2020, p. 7).

According to Geels, the landscape level includes set of rules and mechanisms that niche and regime level actors can not influence short term. It takes long term development and influence for the regime or niche actors to change something in the landscape. Furthermore, Geels points

to the interplay between the levels as the driving force behind transitions. He identifies the following pattern that repeats for socio-technical transitions to happen;
«(a) niche-innovations build up internal momentum, (b) changes at the landscape level create pressure on the regime, and (c) destabilization of the regime creates windows of opportunity for niche innovations.» (Geels, 2011, p. 29). He goes on pointing out that socio-technical transitions are not dependent upon causality, or one single driver or incentive, but are rather results of processes that takes place in different levels and dimensions, reinforcing each other in a phenomenon he refers to as "circular causality".

Geels has put all of the levels into one table, in order to illustrate the placement of the different levels according to each other, and the interplay between them;

An overview of the MLP

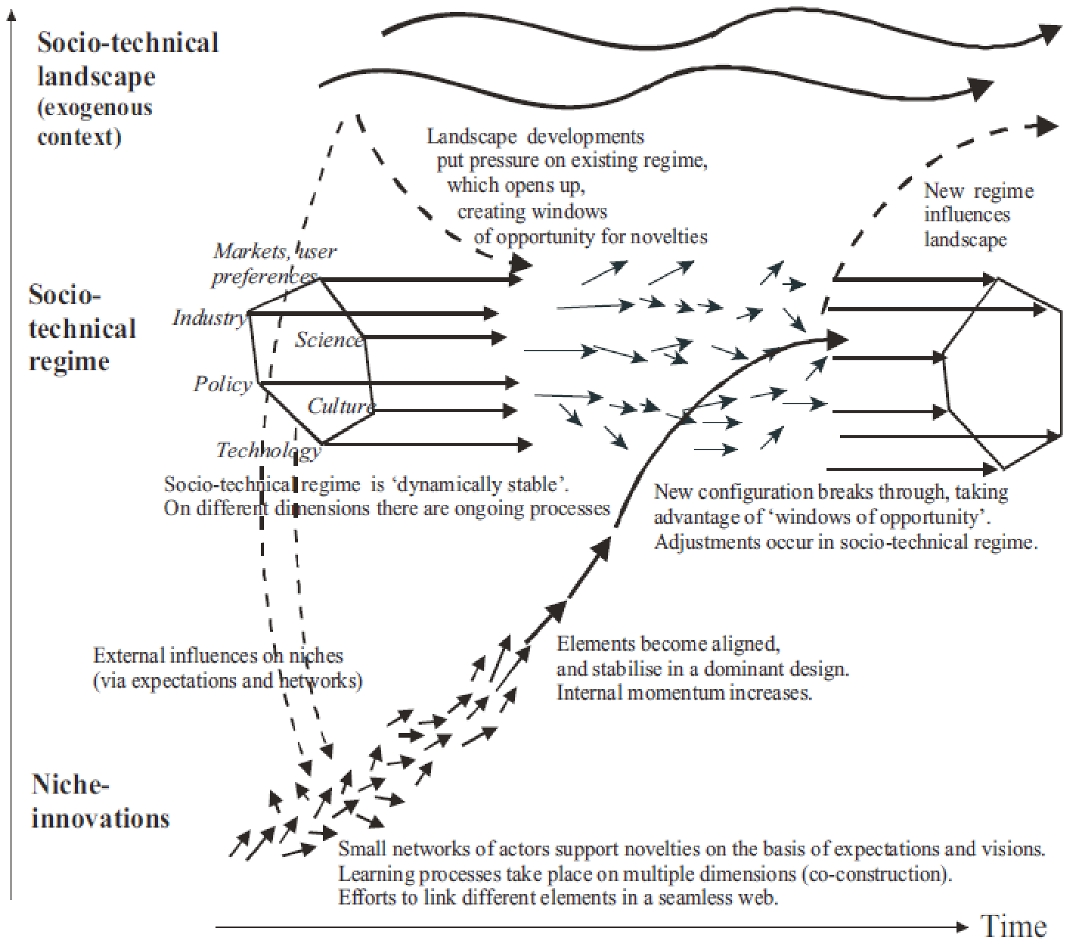

Figure 1 (Geels. 2011, p. 28)

2.2 Figenbaum and the level of governance

Erik Figenbaum uses Geels' MLP when analyzing the rapid growth of BEVs on Norwegian roads (Figenbaum, 2017). The last decade has seen a sharp increase in the number of electric vehicles. In his article he highlights a study from Nykvist and Nilson (2014). They analyzed the lack of rapid growth in BEV in Stockholm, and utilized the MLP to do so, just like Figenbaum (2017) did. While the MLPs landscape level, according to Figenbaum, is commonly used at the global level, Nykvist and Nilson (2014) lifted the «national governance network» out of the socio-technical landscape of the MLP, creating a fourth level. Figenbaum has visualized this is the following table (Figenbaum, 2017):

The MLP and Figenbaum's national governance level

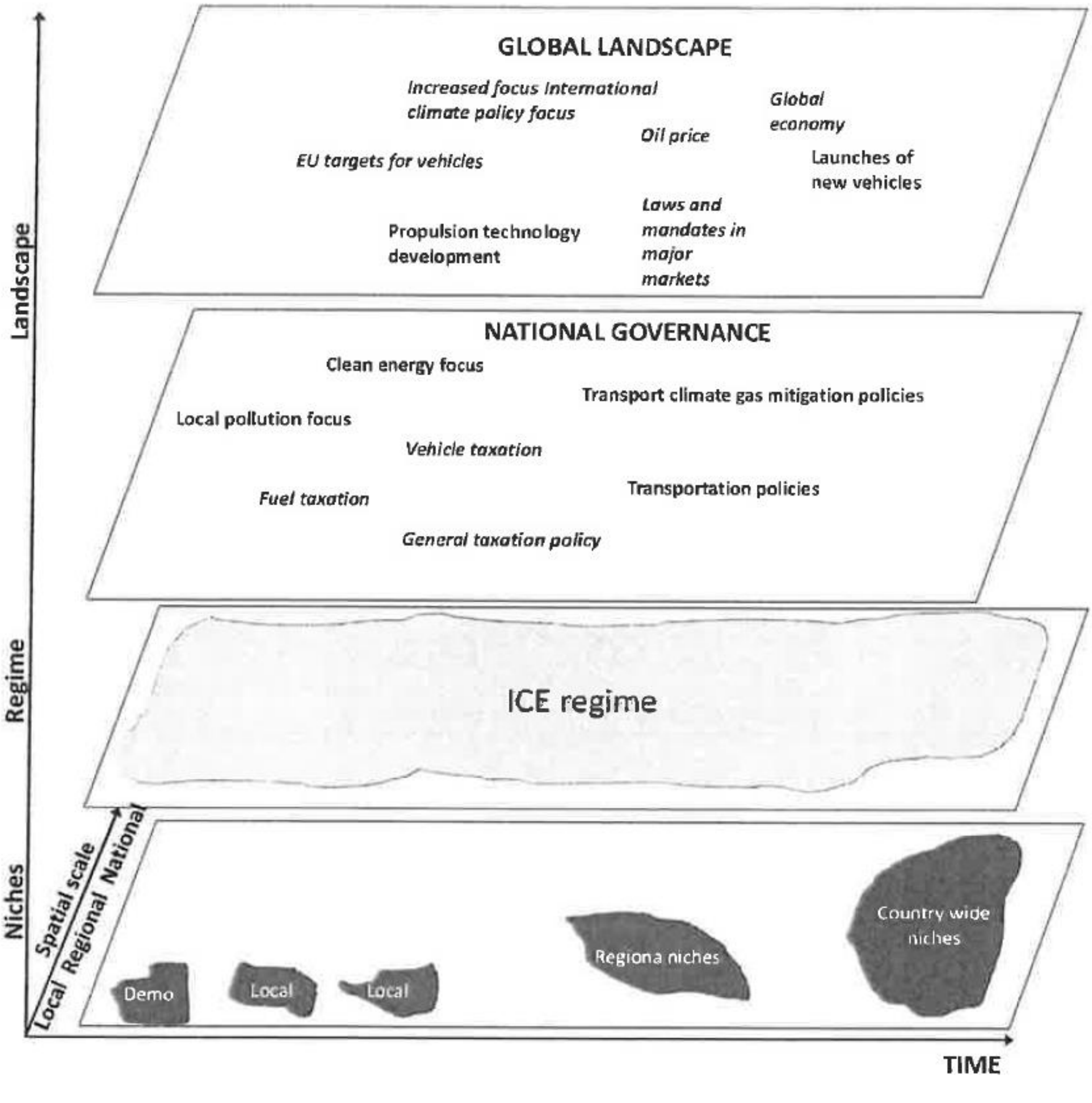

Figure 2 (Figenbaum. 2017, p. 18)

As one can see, this takes into account the MLP levels and the interplay between the levels and the actors within each level. However, it has split the socio-technical landscape into two separate levels in which impacts each other. One on the national levels, in which is impacted by the global landscape and the factors and actors that operate within. The national governance level also impacts the levels beneath it, both at the regime and niche levels. (Figenbaum, 2017).

Figenbaum further elaborates that; *«In climate policy, the national governance network will act on influences from the landscape, seeking to push the regime and support niches. Consequently, there is an argument for lifting the governance network out of the regime level»* (Figenbaum. 2017, p. 17). Figenbaums argument here is that as there is an international landscape level that is influencing the national governance level, that in turn influences both regimes and niches, one can argue that a new level has been identified. It is this new level, the national governance level, that Figenbaum points to as very important to the development of BEVs in Norway. Within this level, Figenbaum includes national policy and economic frame conditions, such as national climate goals, fuel and vehicle taxation and several other similar examples of national governance. (Figenbaum, 2017). Figenbaum's view differs from Geels' in that these are two separate levels rather than integrated parts of the same one. This allows for an analysis of what, in the case of BEVs, has made Norway such a good case for development and implementation of the technology, and why there has been such good developments in Norway compared to other nations and areas of the world. This is also something I find interesting to look at, going forward with hydrogen technology and the development and possible routes of implementation and utilization of fuel cell electric vehicles that could lie ahead.

Figenbaum specifically notes reduction of purchase price, access to bus lanes and exemption from road tolls as specific incentives created through national policy making, in which have turned out to be very effective for the BEV development from the niche level to a regime (Figenbaum, 2017). Interestingly, Figenbaum also points out that he thinks the size of the country and its population could impact how efficient a given country's governance is at creating windows of opportunity for niche activities to break into a regime. He turns the focus towards the many windows of opportunity that the created incentives has created in the history of BEVs in Norway, and claims that Norway's status as a smaller country makes it easier for the incentives to be effective, the lobby organizations to achieve results. This is because smaller countries tend to have less complicated governance structures, making the distances between levels, actors and power structures smaller (Figenbaum, 2017). This might also make the path from niche actor to regime lever shorter.

2.3 Model for climate-economic efficiency

As an additional theoretical tool, I have also implemented a model of my own creation, in which makes calculations based on the traffic past a point to be able to do a ballpark analysis of how much future economic loss the traffic past a point accounts for.

This is a model in which I engineered while working with Gjesdal Kommune. The model was first feature in the practice report (Eggebø, 2020). Here I wanted to calculate the potential level of future cost the traffic past two traffic points, basing the total amount of fuel consumption in a year and matching this with a set level of "Social cost of carbon (SCC)". The formula attempts to both find the social cost of the traffic past a point, and the total potential demand for hydrogen if all the traffic where to be converted to hydrogen fuel cell vehicles. As the model is in no shape or form meant to be a precision tool, it uses general information and averages, to be able to say something about the general level of cost a said traffic amount can end up costing society. The total cost of this traffic then depends on how high you set the level of SCC.

Using this calculation method mainly serves two important purposes for this thesis, one where I can compare traffic points to each other not only by traffic statistics, but also by climate-economic efficiency by comparing them to the needed investment connected to a filling station. Secondly, it serves an interesting purpose to be able to give a ballpark analysis on the level of economic savings one could hope to expect by decarbonizing the entire amount of traffic connected to a point. Making sure to quantify and exemplify this amount of potential climate-economic savings, helps stakeholder and policymakers to understand and evaluate the importance of each project better. Knowing the potential climate-economic savings makes us able to compare projects involving hydrogen filling stations to other climate emission mitigation projects. If we are to compare and evaluate these using realistic and relevant data, we can be more confident in the decisions made and the policies designed, while also reaching better climate-economic efficiency with projects that are put to life.

In addition to the social cost of the traffic emissions, I also wanted to calculate what the potential for hydrogen was. With this statistic I hope to show companies or stakeholders what potential lies in decarbonizing the traffic connected to the traffic points, not only from a climate perspective, but also from an economic perspective.

The calculations for this model were made as follows, with the two examples Skurve and Bjerkreim used as case studies for the model;

First I find the yearly average of daily passings accounted for by vehicles 7,6 meters long and up in the dataset. This statistic is then used to find the total amount of kilograms of fuel consumed by this traffic. This is calculated as follows:

- Average daily heavy transport passings in one year with vehicle length of 7,6m and up (Statens vegvesen, 1992)
  - This is then multiplied with the sum of annual average driving length of trucks (Stølen, 2016) divided by one year of work (235 days)
    - When multiplying the above with the average emissions per driven kilometer (0,2335 kg per km (SSB, 2016)) you get how many Kilograms of fuel are used in connection to this point.

The total amount of fuel is then used to calculate the CO2 emissions, and furthermore the social cost of the traffic passing the point in one year. This is done in the following fashion.

2.3.1 Additional calculations

- Amount of used fuel in connection to this point in kg / 0,85 (Conversion factor of kg to liter) (European Commision, 2010) = amount of fuel used in this point in liters.

- Amount of fuels used in this point in liters x CO2 emissions per liter of diesel (Thompson, 2020) = CO2 emissions connected to this point per day.

- CO2 emissions connected to this point per day x 365 = CO2 emissions connected to this point per year.

- CO2 emissions connected to this point per year x the social cost of one ton of carbon (Finansdepartementet, 2012) = how much the emissions connected to this point will end up costing society in the future at the given rate of SCC.

Using these calculations results in a number in which says something about how much societal cost is connected to the heavy or long duty traffic past a point. One could agree or disagree with the variables used, and the numbers they represent, but nonetheless it gives a comparable ground in which to base the evaluation of the traffic point on. Some could perhaps argue whether the level of SCC is the correct or realistic one, but as long as all traffic points are evaluated using the same level of SCC, we can still say something about which traffic points represents higher potential for future climate economic savings than others.

In addition, I would like to also give a ballpark figure as to how much hydrogen it would need to decarbonize all the heavy and long duty transport at a certain traffic point. This also serves as a number of how much hydrogen you can potentially sell, if all the traffic were to be converted into hydrogen trucks.

- Amount of fuels used in this point in liters / (energy density of hydrogen / energy density of diesel (Rocky Mountain Institute, 2019)) = potential demand for hydrogen at this point.

2.3.2 Mathematical setup

The calculations explained above are represented mathematically in the following:

Societal cost of traffic (vehicles from 7,6m and up) past a traffic point

$$\boldsymbol{Em_{day} = P_{day} \cdot L_{day} \cdot \frac{C_d}{\rho_d} \cdot \rho_{Em,d}}$$

$$\left(\frac{C_d}{\rho_d} = Liter\ diesel\ pr\ Km\right)$$

Where:

Em_{day} = Emission pr day $\left[\frac{Kg}{day}\right]$

P_{day} = Passings pr day $\left[\frac{1}{day}\right]$

L_{day} = Driven length pr day (average) $\left[\frac{Km}{day}\right]$

C_d = Diesel consumption $\left[\frac{Kg}{Km}\right]$

ρ_d = Diesel density $\left[\frac{Kg}{L}\right]$ $\left(\left[\frac{Kg}{m^3}\right] \text{SI} - \text{units}\right)$

$\rho_{Em,d}$ = Emission density for diesel $\left[\frac{Kg}{L}\right]$ $\left(\left[\frac{Kg}{m^3}\right] \text{SI} - \text{units}\right)$

$$\boldsymbol{SC_{year} = Em_{day} \cdot 365 \cdot SC_{Kg}}$$

Where:

SC_{year} = Social cost pr year $\left[\frac{NOK}{year}\right]$

SC_{Kg} = Social cost pr Kg $\left[\frac{NOK}{Kg}\right]$

The whole model combined:

$$\boldsymbol{SC_{year} = P_{day} \cdot L_{day} \cdot \frac{C_d}{\rho_d} \cdot \rho_{Em,d} \cdot 365 \cdot SC_{Kg}}$$

Formula for potential hydrogen demand at a point

$$\boldsymbol{C_h = C_d \cdot \frac{\mu_d}{\mu_h}}$$

$$(Derived\ from\ the\ fact\ that{:}\ C_d \cdot \mu_d = C_h \cdot \mu_h)$$

Where:

$C_h = \text{Hydrogen conusmption } \left[\frac{Kg}{Km}\right]$

$\mu_d = \text{Energy density for diesel } \left[\frac{J}{m^3}\right]$

$\mu_h = \text{Energy density for hydrogen } \left[\frac{J}{m^3}\right]$

$L_{tot} = \text{Total length driven } [Km]$

Total hydrogen demand:

$$\boldsymbol{H_{tot} = \frac{C_h}{\rho_h} \cdot L_{tot}}$$

Where:

$H_{tot} = \text{Total hydrogen demand } [L] \quad (m^3 \text{ SI} - \text{Units})$

$\rho_h = \text{Hydrogen density } \left[\frac{Kg}{L}\right] \quad \left(\left[\frac{Kg}{m^3}\right] \text{ SI} - \text{Units}\right)$

$L_{tot} = \text{total driven length } [Km]$

2.3.3 Model example 1: Skurve

The model calculates the example in the following way. The amount of daily average vehicle passings are multiplied with the average daily driving length of a truck and the average emissions per driven kilometer. This is then converted into liters using the conversion rate. Dividing by 2,6 then gives you the total amount of hydrogen at the point. Liters of fuel are multiplied by the average emission per liter of fuel to find the average daily CO2 emissions. Divided by thousand to get value in tons. This is in turn multiplied by 365 to get annual CO2 emissions. Then you end up with annual amount of CO2 emissions.

With the values for Skurve included in the calculations, it looks like this:

o Kilograms of diesel per day: 1177 x 108 (Stølen, 2016) x 0,2335 (SSB, 2016) = 29.681,568 or 29.682.

o Liters of diesel per day: 29.682 / 0,85 (European Commision, 2010) = 34.920

o Potential demand of hydrogen in kg: 29.682 / 2,6 (Molloy, 2019) = 11.416.

o CO2 emissions in relation to the point in tons per day: (34.920 x 2,68kg (Thompson, 2020)) / 1000 = 93.236 kilograms or 93.2 tons per day.

o Annual CO2 emissions in relation to the point, in tons: 93,2 x 365 = 34.018 tons per year.

o Yearly social cost of the CO2 emitted in relation to the point: 34.018 x social cost of carbon. Using the stats from the Norwegian Public Roads Administraton, the prices are fixed until and including 2015 at 210 NOK per ton, and rising equally every year, until it hits a fixed price at 800 NOK from 2030 and onwards. This gives the following prices per year:

This gives the following ballpark analysis of social cost of traffic past traffic point at Skurve:

- Until and including 2015: 34.018 x 210 NOK (Finansdepartementet, 2012) = 7.143.780 NOK per year.
- The years inbetween: Yearly equal rise from 210 NOK to 800 NOK in 15 years (Finansdepartementet, 2012).
- From 2030: 34.018 x 800 NOK (Finansdepartementet, 2012) = 27.214.400 NOK per year.

2.3.4 Model example 2: Bjerkreim

The amount of daily average vehicle passings are multiplied with the average daily driving length of a truck and the average emissions per driven kilometer. This is then converted into liters using the conversion rate. Dividing by 2,6 then gives you the total amount of hydrogen at the point. Liters of fuel are multiplied by the average emission per liter of fuel to find the average daily CO2 emissions. Divided by thousand to get value in tons. This is in turn multiplied by 365 to get annual CO2 emissions. Then you end up with annual amount of CO2 emissions.

With the values for Bjerkreim included in the calculations, it looks like this:

o Kilograms of diesel per day: 983,6 x 108 (Stølen, 2016) x 0,2335 (SSB, 2016) = 24.804

o Liters of diesel per day: 24.804,4248 x 1.15 (European Commision, 2010) = 28.525

o Potential demand for hydrogen in kg: 24.804 / 2,6 (Molloy, 2019) = 9.540

o CO2 emissions in relation to the point in tons per day: (28.525 x 2,68 (Thompson, 2020))/ 1000 = 76,2 tons

o Annual CO2 emission in relation to the point: 76,2 x 365 = 27.813 tons

This gives the following ballpark analysis of social cost of traffic past traffic point at Bjerkreim:

- Until and including 2015: 27.813 x 210 NOK (Finansdepartementet, 2012) = 5.840.730 per year
- Between 2015 and 2030: rate rising equally every year until it hits 800 in 2030 (Finansdepartementet, 2012).
- From 2030: 27.813 x 800 NOK (Finansdepartementet, 2012) = 22.250.400 per year

2.3.5 Comparison between the two points

Comparison between the two traffic points Skurve and Bjerkreim

Table 1: Comparison between the two points

Comparison	Skurve	Bjerkreim
Diesel per day (kg)	29.682	24.804
Diesel per day (liters)	34.920	28.525
Potential demand of H2 (kg)	11.416	9540
CO2 emissions per day (tons)	93,2	76,2
Annual CO2 emissions (tons)	34.018	27.813
SCC per year until and including 2015	7.143.780	5.840.730
Years between 2015 and 2030	Rising equally each year	Rising equally each year
SCC per year after 2030	27.214.400	22.250.400

3 Methodology

3.1 Data Collection

For the purpose of finding answers to the research questions in focus, I have chosen an empirical approach. I have gathered statistical data and will attempt to analyze these using existing theories and frameworks in the field of renewable transitions.

The data collection was in fact a rather simple procedure in theory. As the main objective is to statistically produce an overview of the top ranked placements for filling stations in Norway, solely based on the statistical image of traffic behaviour. This implies that much of my research indeed would have to be quantitative, as was also the case. However, a number of choices had to be made along the way, both to secure the integrity of the research, and to be able to produce the planned research within the given timeframe.

As the goal of this paper is to provide knowledge towards the road distances with the highest potential for hydrogen filling stations, the research used in this thesis was conducted through statistical analysis and gathering of relevant literature. For the theoretical frameworks, in which provides a wider context, I have looked towards relevant literature. For the quantitative demands that my research questions implies, I quickly scoped out the traffical databases of «Statens Vegvesen» as the most important source of information about the traffic points and distances around the country.

Dalland (2012), states some important criteria for quantitative research to be valid and trustworthy. Among others he mentions that data needs to be systematically categorized or chosen, and that the results needs to be accounted for in such a way that they can be reproduced or controlled by other researchers. In the following paragraphs I will in the following paragraphs account for how I have systematically chosen the data, and the choices I have made along the course of researching the questions in focus.

3.2 Choices in regards to the dataset

With respect for the time consuming effort that statistical analysis can be, I saw it necessary to make choices to reduce my statistical analytical area. Therefore, this thesis does not include every single traffic point in Norway, but focuses mainly on the highways. As this decision was made primarily with regards to the time available, however, the highways are typically the roads in which the traffic activity is the highest.

Furthermore, the database offers several different ways of comparing points to each other. You can choose either hourly traffic during the day or daily traffic over certain amounts of time. For time periods, it was possible to choose average passings in 24 hours and compare it weekly, monthly, seasonally or yearly. To be able to get a good overview over the traffic points, I chose to compare them through one full year. Therefore, I have chosen to compare the average daily traffic for 2020 at every traffic point.

As Vegvesenet offers easy access to each traffic point through their website, this information is categorized in a way where I was unable to compare all the heavy and long duty traffic at each point, However, in their databases I managed to export the statistics from all relevant traffic points, and could work with the raw materials myself. I manually picked out every traffic point on the highways in every county, and exported the data. Vegvesenet measures every vehicle that passes their traffic points, dividing them in categories based on the length of the vehicle. There are six categories; «Under 5,6m», «5,6-7,6m», «7,6-12,5m», «12,5m-16m», «16m-24m» and «Above 24m». As I needed to compare heavy and long duty transport at each traffic point, I looked at the passings of the groups consisting of vehicles of lengths from 7,6m and up. These were categories in which I had to manually combine using in the Excel-files obtained when exporting the statistics from Vegvesenets websites (Vegvesenet, 2020).

In the end, I have therefore compared the average number of passings accounted for by vehicles above 7,6 meters in 2020, at every traffic point along the Norwegian «Europaveier».

3.3 The issue of overlapping traffic and linear proximity

While statistics at each traffic points does tell the story of how many vehicles pass, it fails to identify how many traffic points each vehicle passes on any given route. Traffic points that are located near each other, certainly has overlapping traffic, meaning that vehicles that passes one point also passes others. This is of course a natural phenomenon when thinking of how traffic works, and it is very hard to design data collection methods that would account for this kind of overlapping. In reality, this means that two traffic points with 1 km between each other, along the same linear distance or road, has a lot of overlapping traffic. Practically, it would serve the same trucks if we were to put two filling stations that close to each other along the same road. Therefore, I have had to make an evaluation on how to categorize my research and analysis according to this problem (Vegvesenet, 2020).

As overlapping traffic means that it is the same vehicles that are passing, I made an assumption that the closer the points are to each other along the same road, the greater of an overlap there would be in the statistic. However, in the cases where two points are close to each other along the same road, but are divided by a city centre, or major transport hub, this overlapping might not be as significant. In these cases, more of the traffic comes in to the city or transport hub, and leaves the same way they came from, leading to less overlapping traffic shared by both points. Some few exceptions have been made during my research. One example of this is traffic points along E6 near Trondheim. Without local knowledge it was very hard to understand what part of the road that represented the southbound and northbound part of the road, compared to the city. As the strongest points along this road was placed somewhere in the middle, it was hard to decide if it was the southbound or northbound direction from Trondheim that was the strongest one. I therefore chose to the part of E6 going through Trondheim as a distance all together, and not as two different distances. Although this could be perceived as somewhat misleading compared to choices made while researching other locations, this seemed like the safest option to secure this distance being ranked appropriately (Vegvesenet, 2020)

Taking all these things into consideration, I adjusted the list of high-potential traffic points to mainly focus around distances, instead of single traffic points. I have chosen to call this «adjusting for linear proximity». In the example of some of the busy roads leading out of Oslo, a lot of strong points where located very close to each other along the same distance. To account for these changes and adjust for the linear proximity, effectively avoid close linear placements to take up the vast majority of the top national spots, and rank the distances that boasts the highest traffical statistic, highest CO2 emissions and highest hydrogen demand.

By ranking after the distances, the case of linear proximity is solved in the statistical ranking. The distances were divided into road parts that were about 50 km. As hydrogen vehicle range seems to be way, way longer than this I could have made this distance longer (Robinius et. al, 2018). However, this would lead to a less accurate statistic as road patterns does not necessarily represent equal numbers for a long distance. Especially around big cities the traffic numbers decrease significantly as you get further away from the city. Having too long range on the categorizing and adjustment for linear proximity could lead to the results assuming high traffic volumes too far from the peak traffic points along the distance. It is important that the station is located accurately, and where it can potentially serve the greatest amount of actors. In this case I found 50 km to be as accurate as one could be, without being so close that the traffical overlap is too significant.

3.4 Choices in regard to the model for calculating social cost of traffic past a traffic point

In addition to the dataset in which provided by Vegvesenets database, I also wanted to attempt to make a ballpark analysis of how much the heavy and long duty traffic past a traffic point could end up costing society. This is highly relevant in evaluating the societal value of making this part of the transport sector green. It was indeed my ambition to be able to not only compare the traffic points based on their total amount of traffic, but also on the amount of CO2 emitted. While differences in CO2 emitted at traffic points are strictly limited to the differences in the total amount of traffic, the results will clearly be linear to the total traffic passings. However, it can be of the publics interest to know how much this traffic could end up costing society in the future. In this way we could be able to better understand the value of decarbonizing this sector. Having a better public understanding of this level could also help in the evaluation of public fund spending and prioritizing.

Using calculations for «Social cost of carbon», I could then, based on the total amount of passings over 7,6 meters, attempt to calculate a «ballpark» analysis of the social cost of the traffic. As this analysis is based upon measures from trusted and scientific sources, it is hard to calculate this in a very accurate fashion. However, if every traffic point is compared using the same variables, the same level of the social cost of carbon, they are none the less comparable to each other. This insight into a possible level of social cost connected to the traffic, gives an idea of how much of a societal future expense a public or private investment could potentially avoid, if all traffic passing the point were to be made zero emission.

3.5 Research quality

In “Metode og oppgaveskriving”, Dalland underlines the importance of securing credibility and shedding light upon possible weaknesses of the research that is conducted. He states that it is also important for the data and the analysis to be able to be controlled and to conserve the ability of being done over again (Dalland, 2012). This is also important for the research performed during the production of this thesis.

In the different parts of my research I have sought to be able to cross-test as much of my research methods, results and analysis as possible. While doing the statistical research on the traffic points, I cross tested the results I got from the manual work on the dataset exported form Vegvesenets database, with the online overview of each traffic points. This was done through checking random single traffic points, as the website did not allow me to check many at once, with the same manual actions in the exported dataset. For every traffic point I tried, the result came out the equal to the manual one. This made me confident that I had indeed made the actions I wanted to do, and the results were credible and accurate. To be sure, I cross-tested 10 different points, each one with equal results (Vegvesenet, 2020).

However, in certain parts of the research, including my attempt to calculate the level of societal cost in connection to the traffic passing a traffic point in a year, it has proven hard to cross test with existing research. Although all of the variables are collected from trustworthy sources for my model, it is hard to argue that it is 100% accurate, considering the time available and also the actual objective. When looking at total amounts of emissions and societal cost, it is not sufficient to use averages and total amount of traffic and expect a finite and accurate representation of the reality on the other end. One could disagree with the reasoning and choices of levels of the variables, or even the calculation itself, but as the objective of the model was not to be as accurate as possible, but instead provide a ballpark analysis of the level of societal cost in relation to the traffic past a point, I found it to serve its purpose.

Another possible weakness of my research is that is solely depends on the total volume of traffic, and accounts for little to no other variables to be taken into account when ranking these points. This is a choice I made to be able to provide the ranking within the time available to me, but it certainly leaves important variables that needs to be addressed by both public and private actors when deciding locations for filling stations, unattended. As this was merely a statistical evaluation, the goal was to look at which distances that showed the biggest potential for hydrogen demand. The total amount of fuel spent along a distance today, provides a good statistical insight into the actual total potential, but it does not serve as a blueprint for future hydrogen filling station locations. There are a number of different variables and possibilities that could make for great business cases with huge climate-economic benefits, that not necessarily sits on top of the ranking provided based on the total number of long and heavy duty transport passings. However, with the times available and the goals of this thesis taken into account, the methods that were utilized served its intended purpose in a sufficient manner.

4 Results/Discussion

Hydrogen is one of the most abundant sources of energy in the universe. However, on earth it is rather rare to find it in its pure form. It has, as explained earlier, great qualities in terms of its ability to store energy and still stay very light. Its volume, however, can cause the transport cost to rise drastically the longer the fuel has to be transported upon production. Robinius m. fl. (2018) looks further into the challenges connected to transport challenges, and its cost-impact to the implementation and competitiveness of the technology (Robinius et. al, 2018). As several possible ways of transporting hydrogen could lower the cost compared to truck-delivery, such as pipelines, shipping and so on, there is still significant costs connected to building cost-efficient infrastructure for hydrogen transport. This can lead to difficulties in keeping the end cost low, further leading to a possibly slower implementation of the technology. Several studies has looked at hydrogen fueling infrastructure, with some even comparing it to competing technologies such as battery electric recharging infrastructure (Robinius et. al, 2018). Ribinius et. al (2018) shows, however, that hydrogen infrastructure in Germany, would actually turn out cheaper to implement than its electric recharging station network alternative. This makes for a possible good case, perhaps a surprising one, for looking towards hydrogen for cost-effective infrastructure and technology.

Even though this study implies that hydrogen infrastructure might turn out cheaper than some of its competitors, pipelines are dependent on big initial investments, requiring huge volumes of consumed hydrogen to justify it. In the niche phase of a technology, like in Geels' MLP, this is not a luxury that exists yet. Therefore one could argue that it is unrealistic to see hydrogen pipelines being justified in the niche phase of the development, as its end use will continue to stay low for a while. However, it is a fact that hydrogen competes with both present and future technologies, and transport costs are high in the niche phase (Robinius et. al, 2018). It could also be justified to claim that the end cost of hydrogen is crucial to the popularity and competitiveness of the technology. To be able to make it as popular as possible, one should seek to achieve the cheapest price for the consumers. Reducing the transport cost, which could be an issue for hydrogen infrastructure, could turn out as an effective effective way of doing this. In my research, I have sought out the geographical placements, or traffic points, of hydrogen refueling stations, based on the highest potential consumption. By knowing which traffic points stands for the greatest amounts of heavy-duty and long transport, one can let the earliest refueling stations serve the greatest amount of potential consumption, further increasing sales and thus lowering the price. Furthermore, hydrogen production plant builders could use this information in their planning of locations for their production plants, seeking out the placements where they would get as close to the highest consumption possible. This way, hydrogen producers can lower their transport cost, possibly increase their sales because of nearby higher potential demand, and hopefully being able to supply their customers with cheaper fuel. By having this information, producers could be able to further accelerate hydrogen market penetration, thus increasing the speed of the transition, like explained in Geels' MLP and in figure 1 (Geels, 2011).

For the study, I have utilized «Statens Vegvesens» databases for statistics. Through their traffic points they measure several different variables, including passages divided by vehicle information. As this paper is focused mainly on heavy and long duty transport, I have been looking into the passages that vehicles above 7,6 meters accounts for. For every traffic point along the Norwegian highways, I have gathered the average daily number of passings of vehicles above 7,6 meters in one year. So, the number in which I am comparing the traffic points to one another, is how many passings they average per day in the category of heavy and long duty transport.

From this statistic I have compared the points, gathering a list of points, ranged from the highest number of daily long and heavy duty vehicle passings, to the lowest. The goal has from the start been to be able to confidently say which traffic points boasts the highest potential demand for hydrogen, and to provide somewhat of a scale to compare possible projects to. Doing this we might be able to find common ground upon which roads should be prioritized in potential policy making and/or be subject for public and private funding. If both government and businesses could agree upon which points has the highest potential climate-economic rewards, the road towards effective policy making and public and private capital spending could indeed be shorter.

Even though this research leads to finding agreement towards which points boasts the highest climate-economic potential, several other variables would have to be taken into account before being able to decide which of the following traffic points represent the best potential in reality. Variables such as available suiting land, distance to road the filling station is supposed to cover and local clusters of transport actors wanting to convert to hydrogen. The list could be even longer. While, in respect of the time I have at my disposal to do this research, I have not included all of these variables into the evaluation of the road distances. One road distance, that represents a lower ranking position based on *potential* demand, could turn out to be a more suitable location for an actual filling station, if one of said variables speaks in the favor of this distance. Likewise, the high-ranked distances might score very low on some of these variables, making them ill suited for hosting a filling station. For example, if the road distance that is ranked number one has no suitable areas on the distance, in regard to safety regulations, it might end up being unrealistic to place a hydrogen station here.

While it is hard to include every variable that might affect a placement for a filling station, my research serves an important purpose, nonetheless. If traffic points or road distances seems more or less equally suitable for the placement of a filling station, the road distance that represents the highest potential demand should be prioritized before the others. This could make sense both to private actors as well as public ones. For private actors, higher potential demand equates to higher potential earnings, and for the suggested public spending one would wish for the highest climate rewards for the money invested. Therefor it would possibly make sense for all actors to prioritize the points that would rank higher in the following charts.

4.1 National ranking of potentially optimal placements for filling stations

I have divided the results into one list for the entire nation, and one list of the top three ranked road distances in every county. The national ranking looks as follows:

	Adjusted for linear proximity (within 50 km on same distance):		Points in connection with top placements makes for following strong distances:
1	Hvam Sør (E6 Northbound from Oslo)	7239	Distance between Oslo and Jessheim is extremely strong
2	E6 Manglerud (E6 Soutbound from Oslo)	6290	Distance between Ulven (Oslo) and Moss is very strong
3	MARITIM-510B (E-18 Soutwestbound from Oslo)	5933	Distance between Oslo and Drammen is very strong
4	Jonsten vest (E6 Southeastbound from Moss)	4124	Distance between Moss and Halden is strong
5	Kroppanbrua (E6 through Trondheim)	3797	Distance between Stjørdal and Støren is strong
6	Holmene (E18 southbound from Tønsberg)	3692	Distance between Holmestrand and Larvik
7	E39 /Somaveien (E-39 south from Stavanger)	3212	Distance between Stavanger and Vikeså
8	Eidsvågtunellen (E-39 North from Bergen before splitting with E-16)	2924	Distance between Bergen and Ostereidet
9	Fjellro (E-39 west from Kristiansand)	2726	Distance between Lillesand and Søgne
10	Lannerheia (E-39 west from Larvik)	2572	Distance between Larvik and Kragerø

Figure 3: National ranking of distances

The three main highways leading traffic out of Oslo makes for the top three distances, while the distance between Moss and Halden follows. The total amount of daily average passings is significantly reduced from first to fourth place on the list. Following further down the list are main highways out of Trondheim, Stavanger, Bergen and Kristiansand. As you can see, the number one point equates to almost three times as much traffic as number ten. This makes for rather big differences. However, this list shows the distances that covers the most long and heavy duty traffic.

4.2 Potential optimal placement for every county

4.2.1 Rogaland

Adjusted for linear proximity (within 50 km on same distance):		Points in connection with top placements makes for following strong distances:
1. E39 / Somaveien (E-39 Southbound from Stavanger)	3212	Distance between Stavanger and Ålgård
2. Finnestad (E-39 Northbound from Stavanger)	1361	Distance between Stavanger and Bokn
3. Edlandsvannet (E-39 Southeast from Ålgård)	1312	Distance between Ålgård and Helleland

4.2.2 Agder

Adjusted for linear proximity (within 50 km on same distance):		Points in connection with top placements makes for following strong distances:
1. Fjellro (E-39 Westbound from Kristiansand)	2726	Distance between Kristiansand and Mandal
2. Prestebekken/Hånes (E-18 Eastbound from Kristiansand)	2650	Distance between Kristiansand and Grimstad
3. E-18 NYE RANNEKLEIV (E-18 East from Grimstad)	1835	Distance between Grimstad and Tvedestrand

4.2.3 Oslo and Viken

(after adjusting for linear proximity, the distances are overlapping)

Adjusted for linear proximity (within 50 km on same distance):		Points in connection with top placements makes for following strong distances:
1. Hvam Sør (E-6 Northbound from Oslo)	7239	Distance between Oslo and Jessheim
2. Blommenholm (E-18 Westbound from Oslo)	5767	Distance between Oslo and Drammen
3. Årungen (E-6 Southbound from Oslo)	4816	Distance between Oslo and Moss

4.2.4 Innlandet

Adjusted for linear proximity (within 50 km on same distance):		Points in connection with top placements makes for following strong distances:
1. Vienkrysset (E-6 by Hamar)	2072	Distance between Brumunddal and Strandlykkja
2. Mjøsbrua øst (E-6 Northbound from Brumunddal)	1726	Distance between Brumunddal and Lillehammer
3. Sannom Nord (E-6 Northbound from Lillehammer)	1439	Distance between Lillehammer and Ringebu

4.2.5 Vestfold og Telemark

Adjusted for linear proximity (within 50 km on same distance):		Points in connection with top placements makes for following strong distances:
1. Holmene (E18 southbound from Tønsberg)	3692	Distance between Holmestrand and Larvik
2. Lannerheia (E-39 west from Larvik)	2572	Distance between Larvik and Kragerø
3. Spiten (E-39 through Notodden)	701	Distance between Kongsberg and Sauland

4.2.6 Vestland

Adjusted for linear proximity (within 50 km on same distance):		Points in connection with top placements makes for following strong distances:
1. Eidsvågtunnellen (E-39 Northbound from Bergen)	2924	Distance between Bergen and Ostereidet
2. Danmarks plass (E-39 southbound from Bergen)	2311	Distance between Bergen and Halhjem
3. Indre Arne (E-16 eastbound from Bergen)	1312	Distance between Bergen and Voss

4.2.7 Møre og Romsdal

Adjusted for linear proximity (Approximately within 50 km on same distance):		Points in connection with top placements makes for following strong distances:
1. BLINDHEIMSTUNNELEN (E-39 Southbound from Ålesund)	1322	Distance between Moa/Spjelkavik and Volda
2. Brusdalen (E-39 Northeastbound from Ålesund)	1090	Distance between Ålesund and Sjøholt
3. Tøndergård (E-39 Northeastbound from Molde)	867	Distance between Molde and Bergsøya

4.2.8 Nordland

Adjusted for linear proximity (within 50 km on same distance):		Points in connection with top placements makes for following strong distances:
1. Bertnes v/plantasjen (RV-80 Eastbound from Bodø)	972	Distance between Bodø and Fauske
2. Narvik Sentrum (E-6 in Narvik)	845	Distance between Ballangen and Bjerkvik
3. Jernverksbakken (E-6 in Mo i Rana)	752	Distance between Finneidfjord and Storforshei

4.2.9 Troms og Finnmark

Adjusted for linear proximity (within 50 km on same distance):		Points in connection with top placements makes for following strong distances:
1. Breivika (E-8 from Tromsø)	1439	Distance between Tromsø and Nordkjosbotn
2. Kanebogen (RV-83 from Harstad)	716	Distance between Harstad and Evenes
3. Heggelia (E-6 from Bardufoss)	561	Distance between Bardufoss and Setermoen

4.2.10 Trøndelag

Adjusted for linear proximity (within 50 km on same distance):		Points in connection with top placements makes for following strong distances:
1. Kroppanbrua (E-6 and E-39 Southbound from Trondheim)	3797	Distance between Trondheim and Hovin
2. Halsørkj mot Trondheim (E-6 Northbound from Trondheim)	2102	Distance between Trondheim and Stjørdal
3. Tangtunellen (E-6 Northbound from Stjørdal)	1762	Distance between Stjørdal and Skogn

Figure 4: County ranking

For every county, the three points with the highest potential demand for hydrogen varies more than in the national list. The total amount of traffic in a county is vastly different from one to the next, which the lists reflect. The reason I have chosen to include the best points for every county is that some of them are not represented on the national list. However, for it to be relevant for many transport actors, there needs to be better coverage geographically with a more widespread network of filling stations. Not every station can be located where it is most efficient in regards to the total amount of traffic, as a truck needs to be covered for the entire journey and not only for parts of it. Because Norway has a widespread population, and there is business all around the country, the network of filling stations needs to cover as many of the transport actors' routes as possible if we are going to be able to reach climate goals. It is not sufficient to restrain filling stations to only one end of the transport routes, as this will not make it feasible for transport actors serving longer routes to convert to hydrogen trucks. Therefor it can be anticipated that filling stations needs to be considered for peripheral placements, and cover most of our main highways for us to be able to see widespread national implementation of hydrogen transport technology. In the extension of this, filling stations in every county could seem like an expected reality if we are to roll out effective infrastructure. In deciding placement in the peripheral areas of the country, the same principal as for the national top tier locations could make sense. If points are equally practically suited for filling station placement, the points with the highest amount of long and heavy-duty transport should be preferred over the others. This links to the connection between amount of traffic, potential for higher demand for hydrogen and thus the potential for a greater climate-economic efficiency at each station. Because of this I have chosen to also list the top points of every county.

These findings are very hands on, and easy to interpret. They tell a simple truth about the amount of traffic and both the potential demand for hydrogen at the points, but also for the potential in regards to climate effect. Even though the results are strictly restricted to the *potential* of the placements at the traffic points, we are still able to make the assumption that a successful hydrogen filling station should serve the greatest amount of traffic possible, in order to obtain the greatest climate value to the public. This could serve as one of several important aspects to take into account in both policy making and public fund spending around the matter of hydrogen technology and infrastructure. If we are able to incentivize placements that could serve a greater number of trucks and actors, you could see accelerated transitional effects due to possibly lowered prices through the ability to scale up production plants and justify greater transport infrastructure investments, while at the same time decarbonizing a greater amount of the transport.

4.3 Social cost of traffic

When applying the model to the highest five placements, the calculations gives following values;

Social cost for traffic at point (in NOK)	**Hvam Sør**	**E6 Manglerud**	**MARITIM-510B**	**Jonsten Vest**	**Holmene**
Annual social cost until 2015	43 934 247	38 147 785	36 004 651	25 003 230	22 860 096
Annual social cost 2015-2030	Rising equally	Rising equally	Rising equally	Rising equally	Rising equally
Annual social cost after 2030	167 368 560	145 324 896	137 160 576	95 250 400	87 086 080

Figure 5: Social cost of traffic

As the table can tell, the top five gives rather high values as for the social cost. After 2030, as the cost is supposed to rise (Finansdepartementet, 2012), one can see a significant rise up until that point. While this is not an extremely accurate measure of the actual level of emission related damages that this traffic accounts for, it is still able to tell us something about what range the total economic damages could be in. This is in fact higher than what I would have imagined before starting this research, and it could potentially speak a strong case for a, in comparison, lower investment cost of a filling station. Compared to the economic damages of not decarbonizing this traffic, it is hard to imagine the subsidies for filling stations to reach close to this amount each year.

While the numbers are rather high, it is important to underline that these figures are based on *all* of the current heavy and long duty traffic. In reality, it is hard to imagine the implementation of hydrogen trucks to happen at a rate where you could reach the potential of 100% coverage within the timeframes researched in this case. Therefore, the figures are not comparable directly to the cost of an eventual filling stations, as a lot of variables would certainly affect the economic calculations in a incremental manner. It is however interesting to see that the potential economic savings of decarbonizing this traffic gives significant amounts of climate-economic benefits.

4.4 Potential hydrogen demand based on traffic amount

As for the hydrogen demand the best five placements gives the following amounts of potential hydrogen demand per day;

Potential hydrogen demand at point (in kg)	**Hvam Sør**	**E6 Manglerud**	**MARITIM-510B**	**Jonsten Vest**	**Holmene**
Potential hydrogen demand per day	70 208	61 075	57 536	39 956	36 531

Figure 6: Potential hydrogen demand at point top 5

Also interesting is the potential hydrogen demand at each point. If all long and heavy duty traffic were to be converted at the traffic points selected, there is serious volume to be produced. This leads to the existence of interesting business cases for a lot of actors looking to provide hydrogen. As both climate economic savings and potential demand for hydrogen seems to be high, this creates an interesting incentive situation for both the climate and the business side of sustainable transitions. While the government could potentially decarbonize the transport sector in a climate-efficient way, the actors looking to provide the fuel and infrastructure needed looks for good business cases to invest their money in. In this situation, as also mentioned earlier, this enhanced demand for hydrogen through the improved potential in increased traffic amount per station, this could also lead to a decrease in price. Hydrogen could potentially be commercially viable for transport actors at a more rapid pace. This seems to correlate with Geels' "circular causality" in the MLP, where he explains socio-technical transitions as a development happening through a set of different drivers or incentives that both interact and reinforces each other, and not through a single driver or incentive (Geels, 2011). While it is hard to determine anything as an absolute certainty, it seems promising to be able to identify the developments as happening according to the signs within Geels' theoretical framework. This could mean that there is indeed a strong case, as we have an example of several different drives that both interact and reinforce each other, leading almost to a spiraling effect where price could lower and implementation rate becomes faster. In his visual representation of the MLP model, this spiraling effect is also vividly present in his explanation of the regime actors and areas affecting each other.

Furthermore, Figenbaum’s add-on level of governance, in which he debates would be wiser to split from the landscape level, could be interesting in looking into how to further enhance sustainable transition (Figenbaum, 2017). While it is possible to identify interesting characteristics about optimal placement, and the interplay and spiraling positive effect it could create towards a transition in the transport sector, Figenbaum’s and Nykvist & Nilssons’s level of governance could potentially help us understand the possibilities of making this situation even more favorable, speeding up transition in an even more effective manner, through governance and policy making (Nykvist & Nilsson, 2014). As could be expected, filling stations represent a fixed investment cost to established. Compared to, for example, subsidizing every liter of fuel, it is a fixed and stable cost (Robinius et. al, 2018). This also means that the higher number of traffic each station could serve, the more efficient this investment would be. If policy making could provide incentives to serve the highest amount of traffic possible, this could lead to an increased climate-economic efficiency. Therefore one might argue that policy making should make incentives aimed in this direction.

As transport cost for hydrogen is high this expenditure will be an important obstacle for hydrogen producers and providers to overcome (Office of energy efficiency and renewable energy, 2021). While Norway has a widespread population and business actors follow the same widespread blueprint, there is no guarantee that hydrogen will be beneficial to produce at any location. The location of a hydrogen production plant will be dependent upon a vast number of variables, in which filling station placement will be only one of many. There is no automatic motion in production plant being located near optimal traffic points, and for many producers there could be economic incentives to place filling stations at traffic points that are nearer to be able to save transport cost. This could mean that we could miss out on the potential climate-economic benefit of serving a higher amount of trucks at each station. This could be solved in several different manners.

In fact, a goal of this thesis is that the results presented here in regards to the location of filling stations can be utilized in the planning of production facilities, so that production can be planned to save cost in relation to the points that do serve the highest amount of traffic. Doing this prior to placing the factory, saves cost for the producer and enhances their chance to sell more hydrogen in a long term perspective, and could reduce the need for public funding or policy making to incentivize optimal placement. If this is not possible, however, policy design could be made with the goal of reducing transport cost for actors according to potential traffic coverage at the filling station, so that the actors that chooses the potentially best climate-economic placements for filling stations would be able to save cost and decrease prices. This could increase implementation where there is the most amount of traffic. Another way of doing this could be for government action of public fund spending to acquire statistically strong placements for filling stations, incentivizing actors through good pricing on the land needed to place filling stations. These policy designs could be limited in time, stretching over a period of said amount of years, until the public expects the technology to be commercially viable and the demand has gotten the necessary traction to sustain itself economically. In this way the need for public spending could drastically be reduced. It is also worth mentioning that if we are able to make sure of this transition without having scaling incentive creation, subsidies that gives provides backing per kilogram of hydrogen for example, we are able to avoid the government or public cost of the policy programs being strictly connected to the successfulness of the transition. In this way we would not be able to harvest the potential that lies in effective policy making and incentive creation, in being able to save a lot of future cost for as little of present cost as possible.

4.5 Hydrogen at the niche level in MLP

According to Geels definitions of the niche level of the MLP, as described earlier, hydrogen technology and infrastructure is today a niche innovation. While hydrogen fuel cells, storage and end usage in different formats are not necessarily new technology, the hydrogen scene is looking at an unparalleled level of development, at a rate and to an extent that has not been seen before in the case of hydrogen. The processes in which Geels identifies for niche innovations can be well put into use in a study of the hydrogen technology;

- *The articulation (and adjustment) of expectations or visions, which provide guidance to the innovation activities, and aim to attract attention and funding from external actors.*
- *The building of social networks and the enrolment of more actors, which expand the resource base of niche-innovations.*

- *Learning and articulation processes on various dimensions, e.g. technical design, market demand and user preferences, infrastructure requirements, organisational issues and business models, policy instruments, symbolic meanings.*

(Geels, 2011, p. 28)

As far as niche innovation and hydrogen goes, one can clearly see the first two processes having been going on for some time. Hydrogen has, in several reports and national climate goal documents been put forward with great future promise and planned development (Olje- og energidepartementet & Klima- og miljødepartementet, 2020) (The European Commission, 2020). As for the second process that Geels describes, we have seen an enormous rise of investment levels, and several huge international and national hydrogen unions, associations and federations has been established and seen a sharp increase in member nations and industry actors. Examples of said organizations could be “Hydrogen Europe”, “Norsk Hydrogenforbund” and several other national and international organizations. As for the thirds process, which I identify hydrogen to be in as of today, my aim is that the placements of filling stations, in which has been researched and discussed in this thesis, could play a part of further developing hydrogen technology and infrastructure. As Geels points out, this third process of niche development sees learning processes throughout several areas of the technology. He specifically mentions infrastructural requirements as a category here, in which could be highly relevant in the case of hydrogen filling station placement optimalization. He also mentions “*organizational issues and business models”* and *“policy instruments”* (Geels, 2011, p. 28). As the hydrogen filling stations I have ranked using statistical research could help both create groundwork for infrastructural development and create better business models both through optimalization of location, but also through policy design, I think that this part of the MLP model is a highly relevant one for stating the potential importance of the findings presented above.

If filling stations are well placed, they have a higher chance of serving a greater amount of trucks and transport actors. This in turn would lead to further lowering emissions, while at the same time increasing the potential demand for hydrogen at every station, resulting in better business cases and in the extension of this; possibly lowering the end cost of the fuel. In a report, Prince-Richard et. al. claims that; “*The synergy with fuel cell developments and production volumes could have a noticeable impact on the capital cost of electrolyzers”* (Prince-Richard et.al, 2005) As they state, the production volumes could have major impacts of the capital cost of developing hydrogen production. Higher volumes could lower the capital needs of the electrolysers as they can produce more hydrogen for each electrolyser, leading the cost per unit to decrease, thus lowering the cost per kg of hydrogen, hopefully.

In the case of niche innovation development, as defined by Geels, the impact from the regime and landscape level could majorly impact the time it takes for niche actors and technology to break out of the niche level and into the regime. If we are able to take advantage of the possibilities that optimal placement of the hydrogen infrastructure could provide, we have the chance of significantly decreasing the time it takes for hydrogen to both break into the regime level, but also become competitive compared to traditional fuels. (Geels, 2011) Decreasing this time could lower the need for long term economic incentivizing through policy making, making the technology compete effectively on its own at an earlier stage and thus avoiding further public investment needs.

4.6 Hydrogen in relation to the regime and landscape level

Geels claims that socio-technical transitions, such as the sustainable energy transition, happens when niches move from the niche level to regime, and eventually also affect the socio-technical landscape. As previously explained, Geels defines the process in three steps, whereas niches gain traction, the regime is pressured by the landscape, which in turn creates windows of opportunities for the niches; *«(a) niche-innovations build up internal momentum, (b) changes at the landscape level create pressure on the regime, and (c) destabilisation of the regime creates windows of opportunity for niche innovations.»* (Geels, 2011, p. 29).
As for the case of hydrogen, we have seen, through examples referred to several times throughout this paper, that there is a lot of interest and serious financial backing power that is increasingly putting their money in hydrogen technology development and infrastructure.

The internal momentum seems to be getting stronger, and has seen rapid growth for several years. While we see strong changes in the landscape in regard to climate targets being implemented in the vast majority of the world's nations, combined with several industries struggling to find technologies that provide a sustainable alternative for current technologies relying on fossil fuels. Among these are several sectors within the transport sector, both on land and at sea where there are serious doubt as to whether battery-electric technologies are able to meet the requirements of range, weight limits and price to kilometer ratios (Robinius, 2018).

This can be identified as landscape developments putting stress on the regime actors and technologies. The combination of these two, the promising and fast-paced development of the hydrogen technology, the niche, and landscape pressure being put on the current regime, creates windows of opportunities for the niche actors. This is a pattern that fits the situation in a clear way, according to Geels' MLP theories.

While the landscape level are dominated by slow moving actors and aspects, the niche level is moving at a much more rapid pace. In the case of optimum placements of hydrogen stations, according to the results presented above, it could help increasing the momentum the niche builds up. With this I refer to the niches ability to compete with regime technology, on reliability, availability and price. The placement of the filling stations could in fact give positive development on all three of these aspects, thus increasing the momentum of the niche.

5 Conclusions

In regard to the first research question, it is interesting to note where the most promising placements are located geographically. The three main exits from Oslo are leading the way, showing great promise concerning both potential climate emission mitigation and potential hydrogen demand. Following, but not so closely however, are the main highways at our biggest cities outside of the capital. Trondheim, Stavanger and Bergen with their nearby and highway distances can show good numbers, and are joined by several strong distances along the E-18 in the South-east of Norway. While looking at the county-wise top ranked placements however, the numbers are significantly more spread out, and shows even more differentiation than the ones for the national ranking. Counties that contain the largest populations seems to boast the highest traffic numbers, which is no big surprise. Counties that have lower population density tends to have weaker ranked traffic points, according to the results above. However, it is worth noting that several of these counties could host industries or shipping hubs that could significantly boost the case for hydrogen production.

As for the second research question that I found worth noting is that the level of CO2 emissions that can be connected to the top traffic points, are high. This calls for the need of decarbonizing. I find it highly interesting that this also creates good incentives for hydrogen producers, as the potential demand is higher at the points that account for the highest CO2 emissions. Another interesting, and also important fact, is that the statistical spread between the points that have been analyzed in this paper are so big. The highest ranked point has almost three times the traffic of number ten on the list. This seems to underline the importance and potential there could be in placing filling stations at optimal locations, as the same fixed costs or subsidies connected to a filling stations could enable a reach of a significantly higher number of actors.

There is of course a number of ways one could imagine how to design policy to increase the climate-economic efficiency of hydrogen technology and infrastructure. In the research of this paper I have shown the potential importance of incentivizing optimal placement, and the role this can play and the impact it can have. The numbers, and the spread between the point, strongly suggest that there is traction to gain. Hopefully private actors could also implement this into the planning of not only the filling stations, but also the production facilities themselves. If this could lead to a lower cost for end users, this could also increase the speed of the transitions, just like Geels' MLP suggests. The answer to how policy design could increase the pace of the transitions and help niches break through to the regime level, could lie in

Figenbaums additional governance level of the MLP system. Because, while private actors can plan their way into lower transport cost, these costs and the cost of storage will most likely continue to be a speedbump in the road towards efficient implementation of hydrogen technology and infrastructure. As shown above, a suggestion is to be able to design policies that both incentivize planning that cut transport cost, but also some form of economic incentives that supports transporting the fuel to an optimal traffic point or distance. In this way, policy could increase the amount of filling stations located at more optimal locations, increasing the outreach, end cost and pace of transition.

6 Recommendations

As hydrogen technology seems to be on an incredible roll, showing great promise in terms of national and international attention, I would like to provide some recommendations to fellow researchers that might find it interesting to look further into locations suitable for hydrogen filling stations, and the infrastructural development of hydrogen technology. While I find production and refueling infrastructure to be vital for hydrogens chance of succeeding in decarbonizing a wide range of energy sectors, I do recommend further research on the topic.

As both my models and the research that I have conducted can give a general overview, a significant amount of variables are left to include to be able to confidently give an answer to which traffic points are the best suited for hydrogen filling station. The same goes for the calculations of the social cost of traffic at every point and the formula for hydrogen demand. My wish is that my research and results can be interesting or important enough to ignite a spark in other researchers, companies or environments, so that we in the end find ourselves with carefully calculated results that provide us with a clear path towards hydrogen infrastructure development and deployment.

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Attachment 1:

Work practice report

Menpra-2 20H

Autumn semester

Word count: 5468

Innhold

1 Part 1:

1.1 Presentation of the company

For my work practice I have been working for Gjesdal Kommune. The municipality is located in the south-east of Rogaland, with a population of about 12.000 people. Its municipality centre, Ålgård, is located 15 kilometers from Sandnes, along the highway E-39. The municipality administration is also located here, and I have been provided with an office in Storahuset, the town hall. Gjesdal employs around 900 people, meaning they are a very big employer in the region. Gjesdal has an extremely "young" population, with 35% of its inhabitants being under the age of 18. This gives them the youngest population in Norway. Gjesdal, and Ålgård, is famous for its proud traditions in hydropower. Several industries are based along the river Figgjoelva, and has for decades used hydropower to power its facilities. There are also several other rivers in Gjesdal, located in Dirdal and Frafjord, which also has facilitated industries using hydropower. Especially wool- and porcelain is connected to Gjesdal, through Gjesdal Spinneri and Figgjo Porcelain. (Gjesdal commune, 2020a)

Industry has historically played a big part of Gjesdal and Ålgårds history, and since 2000 Gjesdal municipality has seen a burst of business areas arise, especially on Skurve. Skurve is a business area located along the E-39, 10 kilometers from Ålgård sentrum. Several big business actors are located here, among the biggest are ASKO, Jæder and Spenncon. The area has formally been named regional centre for goods on road, exemplified through "Regionalplan Jæren 2050" (Tønnesen, 2020). ASKO also, asides having an area of 30.000 square meters on Skurve, operates a windmill park. It is located in close proximity to its business area, on Skurvenuten. This area is one of the most important areas for the municipality and the entire South-Rogaland, when it comes to transport (Gjesdal commune, 2020a)

Gjesdal also has a lot of focus on green energy and green solutions. They have a vision that the municipality is supposed to be greener for the future, and a leader in the region in solutions that makes the carbon footprint of its inhabitants smaller. To be able to achieve this, they have stated climate goals. By 2020, their goal is to have reduced the emissions of CO2 to a maximum of 59200 tons of CO2 equivalents. Compared to 2008, that is a reduction of 15%. Within transport, which stands for 42% of the municipalities emissions, they wish to reduce this with 6,4%. 40% of the traffic in Gjesdal consist of transport of goods and traffic going through the municipality, making this an important group to decarbonize (Gjesdal commune, 2018)

1.2 Presentation of my tasks at the company

As I was applying for work practice, I started to analyze the area of Rogaland concerning hydrogen infrastructure, as this is a huge interest of mine. My initial thoughts were that Gjesdal would be a very good placement of a hydrogen filling station, of several reasons. Both geographical placement and the mix of business actors located there was a very good match, and I wanted to look closer at this possibility. I put this forward to the municipality in our meetings prior to this work placement, and they found it very interesting. This is a project which fits great with their vision to seek reduced emissions in the transport sector.

Going forward with this, I tried to locate actors that might be interested in hydrogen in Rogaland, and quickly found out that ASKO, which already produces hydrogen through solar power in Trøndelag, was considering using their windmills on Skurve to produce hydrogen. As our dialogue continued I realized that they were holding up their decision until later this year. This led me into searching for other actors who might want to look closer at Gjesdal and hydrogen. ASKO sent me further to a company, in which had been in dialogue with them previously about providing them with hydrogen to be used in transport. As I laid forward my analysis of Gjesdal as a suited placement for a filling station, they agreed, and wanted to procede with the plans. My project has therefore been dominated by the presence of both the municipality and this hydrogen producing actor, trying to find a good way of cooperating to get this in place. Both actors agrees that there is great potential in placing this in Gjesdal.

As this is a project in which I have facilitated the municipality with both the idea and the hydrogen actor, I have been given this project, with great freedom of making my own decisions for the project, but with great help from supervisors when needed. I have had three supervisors in the head of the technical department, Trond Hansen, the head of business, Andre Andreassen, and through Ida Marie Pedersen, from the HR-department.

My first task in this project, beside facilitating the cooperation, and bringing all the pieces together in the first place, has been to lay an argumentational groundwork as to where the hydrogen in Gjesdal should be placed. The second task is to take a closer look at both opportunities and challenges for the municipality connected to a filling station in Gjesdal, and at the specific location in which I will get back to later in this paper.

1.3 How I got to use my competence through the work practice

A big part of my competence was used leading into the work practice, and the time before. I analyzed my way into locating Gjesdal as a possible placement for a hydrogen filling station, and as time went by that analysis turned out to be correct. Both the municipality, and more importantly, the hydrogen producer also agreed to my views. This showed me that my analysis had strength to it, and gave me confidence in the work that followed. Important in this is the fact that it was me who saw this first, and then drew the other actors in, using my competence and knowledge by contacting and explaining. This turned out to be an effective method, as the actors showed interest both in me and in the project.

During this work practice, I have also gotten to see several other possibilities of hydrogen use, among them an asphalt producer that use natural gas to warm the asphalt under production. I have established contact between them and the university, as I saw possibilities of these gas burners being able to be run on hydrogen instead. This hopefully leads to an EU-backed research project, in which will be a result of me seeing the possibilities and contacting actors in which I think would be able to have interest in the given case.

The competence I have earned through my studies has been very relevant for me, especially when it comes to locating such opportunities and the possibility of reducing emissions. As time has gone by, I have reached a bigger and bigger network of contacts, and have now been able to use some of these, both to be able to gain more knowledge about certain projects and technologies, but also to bring these actors together and make cooperations happen.

1.4 Summary and evaluation of my work practice through the points above.

When I started at Gjesdal, I really wanted to try to make a difference and to have some actual value for the municipality. I set myself a goal that when I leave Gjesdal, I have made an actual contribution towards an implementation of a renewable energy transition. Once I got in contact with the actor wanting to build the filling station, I saw that goal to be well within reach. Therefore, at an early stage I aimed at making something actually happening, other than just doing analyzes and reports. So, my goal has naturally been to realize the hydrogen filling station at Skurve. Although it is natural that the actual building would not start during my short stay, I feel that I have made a great contribution towards this being a reality in the future. There was nobody working with this project before, and I have been the sole leader of the project while I have been there. I can say that I am proud to have brought a development in hydrogen closer to realization, starting from scratch.

This is certainly an experience that is very relevant and extremely useful for me to have looking forward. Both for my masters, in which I have gained an industrial partner to write for, but also into my career. I feel I have mastered my tasks here at Gjesdal, even though I set some tough goals to begin with. Also, the municipality and especially Ida Marie, Trond and Andre are to be given great credit for the project, as they have supported me greatly and let me own this project myself. This would never have been what it became unless they gave their time and effort.

At the end, COVID-19 hit everybody hard and turned the working situation upside down for the last two months of the project. Because I had my own project, I was let very much alone and felt that it was hard keeping the momentum in the work. However, this became nothing more than a solvable challenge, and because I had a great degree of independence in my project from day one, this was not as big of a challenge as it could have been. The social aspect of a workplace however, was non-present for the last couple of months. But this is not to be blamed at the municipality at all, but on the restrictions of the government.

2 Part 2:

2.1 Method

The method part of this paper has been put under each relevant part of the report.

2.2 Problem statements

Gjesdals municipality plan from 2018 clearly states that it important that heavy-duty transport is electrified: *«(...) å planlegge for reduserte CO2-utslipp og støynivå, økt miljøkvalitet og for at aktiviteter i sentrum, bo- og rekreasjonsområder kan foregår på de myke trafikanters premisser. Det betyr at det skal være nullvekst i individuell bilbruk og at så mye langtransport som mulig skal elektrifiseres»* (Gjesdal kommune, 2018. s. 9).

When evaluating the potential use of hydrogen in Gjesdal, the potential for use of the fuel in heavy-duty transport made itself clear at an early stage. The E-39 highway past Ålgård, which is also being renewed, has a lot of traffic. Besides, the business area at Skurve, is determined to be regional centre for transport on road in "Regionalplan Jæren" (Tønnesen, 2020). The combination of the existing road infrastructure combined with existing policy and already established activity in the area makes for both challenges connected to climate sensitive emissions, but also potential for significant reductions.

The challenges related to the transition to emission free heavy-duty transport options are many. The actors needs strong incentives to transition to greener technologies, even though big actors in the area, among these ASKO, has shown great promise in doing exactly this. Besides, certain security risks are connected to the use and filling of hydrogen. These would have to be explored in order to secure the best possible location for the station itself. There is also significant challenges connected to making it viable for actors to change their trucks and fuel. An investment in hydrogen infrastructure involves risk if actors do not make the choices that are necessary for this transition to happen. These are all challenges I have tried to locate, and hopefully contribute to solutions to some of them.

In this work practice I have tried to both locate what is the climatic and economically best location for a hydrogen filling station, but also what are the challenges and consequences of establishing this for the municipality. My problem statements are therefore the following:

Potential use of hydrogen in Gjesdal Municipality, with a focus on transport.

1. **Placement of a filling station**
2. **Opportunities and consequences/challenges for the municipality**

2.3 Theory:

For this report I have looked specifically to Frank Geels Multi-Level Perspective, or the MLP model. This model gives insight into explains patterns in socio-technical transitions. Geels debates that transitions happen in a non-linear process, through three different levels (Geels, 2011). The levels consists of a niche level, a socio-technical regime and a socio-techinal landscape. The interplay of the development in these three levels makes the transition. Each level is unique in terms of its internal mechanisms and variables, and higher levels are more stable than lower ones, and transitions take place when there is movement from one level to another, according to Geels (2011).

2.3.1 Socio-technical regime:

The socio-technical regime consists of the currently ruling ideas, technologies or thoughts. In this level there are several lock-in mechanisms that makes it harder for niches to break through into the regime level. Geels states that: “*Examples of regime rules are cognitive routines and shared beliefs, capabilities and competences, lifestyles and user practices, favourable institutional arrangements and regulations, and legally binding contracts”(Geels, 2011. P. 26-27)* . He further states that “*The regime level is of primary interest, because transitions are defined as shifts from one regime to another regime. The niche and landscape levels can be seen as ‘derived concepts’, because they are defined in relation to the regime, namely as practices or technologies that deviate substantially from the existing regime, and as external environment that influences interactions between niche(s) and regime”(Geels, 2011. P. 27).* Geels debates that the regime level is the most important one, because the other levels are exemptions from the regime, influencing what is currently in this level.

2.3.2 Niche level:

The transition path starts at the lowest level, the niche level. This level consists of technologies or thoughts that has not yet become part of the existing regimes and become a leading, accepted or viable technology, idea or thought. The niche actors work to get their innovations into the regime level, but meets challenges in the regime levels resistance towards transition.

2.3.3 Socio-technical landscape:

The landscape level consist of the most stabile stage of a transitional pathway. "*The sociotechnical landscape is the wider context, which influences niche and regime dynamics"* (Geels, 2011. P. 28). The landscape is the backdrop of everything, and set the general rules of play and influence towards all levels in the MLP. It "*highlights not only the technical and material backdrop that sustains society, but also includes demographical trends, political ideologies, societal values, and macro-economic patterns"* (Geels, 2011. P. 28).

2.4 Placement of the hydrogen filling station

For the placement of the hydrogen station, I have chosen an interesting approach. The geographical placement of Gjesdal is ideal connected to the already existing network of filling stations in Europe. When heavy-duty transport fills in Denmark, they will have to refill once more before Bergen on their drive to the Western parts of Norway. There is approximately 650 km from the filling stations in Aalborg to the ones in Bergen. This is a stretch far too long for it to be viable to use hydrogen transport on this route. Gjesdal is placed ideally in the middle of this route. It could serve as a connection point between the existing infrastructure in Norway and Europe, connecting the two. Therefore, geographically Gjesdal points out as a good option. The areas at Skruve is also closely linked to the E-39 and would keep a station away from any city centres. Considering the road crossing infrastructure at the location it is also safe to say that the roads are very well dimentioned for this kind of traffic.

Another strong argument for Skurve is the already existing activity and actors located at the business area. With actors like ASKO, that is already producing its own hydrogen in Trøndelag using solar power, on place, cooperations and synergies in the nearby area looks very promising.

However, when looking into this I wanted to show what location would make most sense also from a climate point of view. My hypothesis was that Skurve would have a very strong potential for larger numbers of CO2 reduction than most places. As I was investigating this I also wanted to use social cost of carbon to calibrate how much it would cost society to "not" reduce any of these reductions, leaving me with a way of calculating a "justified level of investment" compared to the cost of not investing seen from a governmental point of view. Using this way of looking at CO2 emissions and the cost of them, I could be able to show what location is the best to place zero emission infrastructure also from an climate-economic point of view. I have chosen to call my model the "Eggebø-model". This uses traffic data and a number of averages to be able to point out how much CO2 is emitted in connection to a traffic point. Using the social cost of carbon, in this case a level of pricing from The Norwegian Public Roads Administration, it calculates how much the total cost of the emissions connected to the point is. For the purpose of this paper I have chosen to compare the results of Skurve and Bjerkreim separated only by 10 kilometers on E-39.

The model looks like this, with the following formulas:

2.4.1 Formulas

Total cost of emissions connected to the point:

- For total emissions past a point: Heavy transport passings from 8m and up per day (average) x (annual average driving length of trucks / 235 days (årsverk)) x average emissions per driven kilometer (0,2335 kg per km) x 1.15 (Liters per kg) = Liters of used fuel in connection to this point.
- Amount of used fuel in connection to this point in kg x 1.15 = amount of fuel used in this point in liters.
- Amount of fuels used in this point in liters / (energy density of hydrogen / energy density of diesel) = potential demand for hydrogen at this point.
- Amount of fuels used in this point in liters x CO2 emissions per liter of diesel = CO2 emissions connected to this point per day.
- CO2 emissions connected to this point per day x 365 = CO2 emissions connected to this point per year.
- CO2 emissions connected to this point per year x the social cost of one ton of carbon = how much the emissions connected to this point will end up costing society in the future. This is also a number of which will determine how much money a government could spend on the project, and end up "breaking even".

Sources for the variables: Under own section in references.

2.4.1.1 For Skurve;

- Kilograms of diesel per day: 1177 x 108 x 0,2335 = 29.681,568 or 29.682.
- Liters of diesel per day: 29.682 x 1.15 = 34.920
- Potential demand of hydrogen in kg: 29.682 / 2,6 = 11.416.
- CO2 emissions in relation to the point in tons per day: (34.920 x 2,67kg) / 1000 = 93.236 kilograms or 93.2 tons per day.
- Annual CO2 emissions in relation to the point, in tons: 93,2 x 365 = 34.018 tons per year.
- Yearly social cost of the CO2 emitted in relation to the point: 34.018 x social cost of carbon. Using the stats from the Norwegian Public Roads Administraton, the prices are fixed until and including 2015 at 210 NOK per ton, and rising equally every year, until it hits a fixed price at 800 NOK from 2030 and onwards. This gives the following prices per year:
    - Until and including 2015: 34.018 x 210 NOK = 7.143.780 NOK per year.
    - The years inbetween: Yearly equal rise from 210 NOK to 800 NOK in 15 years.
    - From 2030: 34.018 x 800 NOK = 27.214.400 NOK per year

2.4.1.2 *For Bjerkreim:*

- Kilograms of diesel per day: 983,6 x 108 x 0,2335 = 24.804
- Liters of diesel per day: 24.804,4248 x 1.15 = 28.525
- Potential demand for hydrogen in kg: 24.804 / 2,6 = 9.540
- CO_2 emissions in relation to the point in tons per day: (28.525 x 2,67) / 1000 = 76,2 tons
- Annual CO_2 emission in relation to the point: 76,2 x 365 = 27.813 tons
- Yearly social cost of the CO_2 emitted in relation to the point: Using stats from the Norwegian Public Roads Administraton, the prices are fixed until and including 2015 at 210 NOK per ton, and rising equally every year, until it hits a fixed price at 800 NOK from 2030 and onwards (NOU 2012: 16, s. 145) This gives the following prices per year:
    - Until and including 2015: 27.813 x 210 NOK = 5.840.730 per year
    - Between 2015 and 2030: rate rising equally every year until it hits 800 in 2030.
    - From 2030: 27.813 x 800 NOK = 22.250.400 per year

	Skurve	Bjerkreim
Diesel per day (kg)	29.682	24.804
Diesel per day (liters)	34.920	28.525
Potential demand of H_2 (kg)	11.416	9540
CO_2 emissions per day (tons)	93,2	76,2
Annual CO_2 emissions (tons)	34.018	27.813
SCC per year until and including 2015	7.143.780	5.840.730
Rising equally in the years between 2015 and 2030		
SCC per year after 2030	27.214.400	22.250.400

Looking at these numbers, the cost per year at the locations were surprisingly high. Over 27 million per year after 2030 is a lot of money, and more than I expected. As this model runs mainly on averages, it is mainly a “ball-park” analysis. However, it certainly provides an idea of how much we could put into such projects. This model does not say whether or not one should invest in a project, but it is able to compare projects to one another, and tell which projects gives the most reductions in total and which projects that provides the most reductions per krone invested. For the results of Skurve and Bjerkreim one could say that Skurve shows greater potential per krone invested in for example a filling station. This means that if the government were to choose between where to put a filling station costing 20 million, Skurve would be a better location. Also it shows hydrogen producers that Skurve has a higher potential annual usage of hydrogen. This model, even though it is a simple one, might have great potential in calculating costs and comparing projects that are bigger and more complicated than the example of filling stations. In a broader application it could help locate the best locations for government-supported hydrogen hubs around the country. Although I have focused on hydrogen for this task, I see a potential use of the model way broader than what is applied in this task. All renewable projects could be run through this model, giving a perception of climate damage reduction in an economic perspective, and then help decide which projects are the most optimal to support or to invest in. Helping private and public actors decide which projects deserve financing based on this model, could drastically improve the way climate-economic evaluations are done.

2.5 Opportunities, challenges and consequences for the municipality

As this task has mainly been focused around heavy-duty transport, I have first and foremost chosen to look at the opportunities connected to this application of hydrogen.

2.5.1 Opportunities:

First of all, the hydrogen production would potentially contribute to an increase in the number of workplaces in the municipality. Hydrogen is a very energy dense fuel, but has great volume. This means that every truck can only transport a limited amount of it per trip. This increases the transport cost dramatically, meaning that local productions and consumption will compete better than transported hydrogen. For Gjesdal, this could be argument as to why one should invest in local hydrogen facilities, and support local business actors in their quest to both produce and consume hydrogen. Local consumption would mean greater chance of local production facilities, as the ecosystem for hydrogen is already established. This also works the other way around, where local production would give better prices and therefore stronger incentives for local actors to use hydrogen as the preferred fuel. The idea of local produced and consumed hydrogen paves the way for the potential for a local increase of workplaces and industry based in Gjesdal. Looking into the future the municipalities could go for two different set of goals; to seek to attract production and consumption actors within hydrogen, or to depend on having the fuel transported from other places and thus letting other municipalities benefitting from Gjesdal-based actors transitioning to hydrogen. This also links to the advantage of early-movers. As the hydrogen industry, the green hydrogen production in particular, is not yet heavily established in Norway, early movers can gain bigger advantages at an early stage in the development, rather than moving to hydrogen at a later stage. Once the industry is established, and competition increases, other municipalities will also seek a more active role in attracting hydrogen actors.

Local area production and consumption also creates promising local synergies based on scaling advantages on production plants. Regjeringens hydrogenstrategi (2020) underlines the role of synergies with the following statement: *«Synergier på tvers av bruksområder kan, i tillegg til effektive verdikjeder, være en viktig bidragsyter til bedre lønnsomhet i hydrogenprosjekter. En utfordring i dag er at det kreves skala i produksjonen av hydrogen og tilstrekkelig avsettning for at det skal bli lønnsomt. Det samme gjelder for lønnsomhet i infrastruktur for fylling. Dersom potensiell etterspørsel kan samles gjennom økt samarbeid på tvers av sektorer og brukere, kan det legge til rette for bedre lønnsomhet. (…)Slike koblinger kan redusere kostnader, skape synergier og bidra til mer lønnsom produksjon»* (Olje- og energidepartementet og Klima- og miljødepartementet, 2020. p. 26). During my stay at Gjesdal, I have mapped several potential big clients for consumption of hydrogen. Green H plans to produce for the Norled hydrogen ferry at Tau. This equals an approximate daily consuming of 1500 kg of hydrogen. Velde looks into using 1200 kg a day to drive asphalt production. This gives a potential local consumption of 3,7 tons a day. Given that Skurve is less than 50 km from this gives the opportunity of taking advantage of the low transport cost and scaling advantages this gives. Based on these two factors, hydrogen delivered on Skurve could be cheaper and compete better with traditional fossil fuels, thus accelerating tranition.

Another significant advantage when it comes to synergies is the already existing development in hydrogen actors in the area. ASKO is probably the most developed hydrogen actor in Norway, if you look outside the hydrogen production industry itself. Not only are they producing their own green hydrogen in Trøndelag, but they are also consuming it through trucks and cars. Through a cooperation with Scania they have special designed several trucks to run on hydrogen. Having this actor in the area gives potential for a great early development for a hydrogen infrastructure unit on Skurve. For a producer to be able to have a big client present from the beginning is a massive attraction towards that part of the industry. For Gjesdal this means that the job of attracting production to the municipality becomes easier. It also gives the potential of a much lower price per kilogram, at an earlier stage than previously accounted for (Norsk hydrogenforum, u.å)

It would also most certainly help the municipalities climate goals, as the transport sector stands for almost 40% of the emissions in the municipality (Gjesdal commune, 2018). At the same time, an increase of zero-emission activity along the new E-39, would also help decarbonize an important traffic point that will be relevant looking far into the future.

"Regjeringens hydrogenstrategi" (2020) also states that the technology of hydrogen powered heavy-duty vehicles has a way to go, but the amount of vehicles is way lower than for example person-traffic, making it easier for big orders of hydrogenpowered vehicles to make a bit impact; *"For tyngre kjøretøy er det behov for fortsatt utvikling og uttesting før teknologien er moden for å tas i bruk. For å bidra til dette vil regjeringen fortsette å støtte utvikling og implementering av nye teknologier og løsninger gjennom Enova, Innovasjon Norge og Forskningsrådet»* (Olje- og energidepartementet og Klima- og miljødepartementet, 2020. p. 35). Gjesdal municipality could help actors looking further into the Enova, Innovasjon Norge og Forskningsrådet subsidies, motivating them to seek financial support to transition to hydrogen.

2.5.2 Challenges/Consequences:

A major challenge for the hydrogen development and market penetration, is the view upon security connected to its technology. As hydrogen is stored under great pressure, there is security concerns that has to be dealt with. The 10th of June 2019, a hydrogen filling station in Bjørvika, Oslo, exploded. While the reason turned out to be a human error as two bolts had been installed incorrectly under installation, it has majorly affected the majority's view of the security aspect of hydrogen technology. This incident also caused all hydrogen filling station in Norway to be closed for a long time, and certainly slowed down development. Uno-X, the owners of the filling station, decided to close all their stations permanently, and drop their hydrogen developments (Jensen, 2020) While we keep gas under great pressure all the time, also in traffic during transport, the pressure of stored hydrogen is under a great amount of public scepsis. For the municipality, and its politicians, voting for the construction of a filling station could be complicated. The public opinion could be influenced by such incidents, and politicians therefore has to take this into consideration when voting for or against the development of hydrogen in Gjesdal.

Availability of fitting business areas. An issue connected to the areas is the fact that companies who wants to establish filling stations would most likely want to buy as small properties as possible. Any more land than what the actually need is a waste of investments. For the business areas on Skurve it would most likely mean that some of the areas would need to be split or combined with other activities. This has both costs and time expenditure connected to it. This also comes with a challenge withing the planning and regulation department of the municipality. Splitting and regulation is strictly regulated by municipality policy, and there is generally little room for exemptions. Therefore, a discussion upon the regulation and adaptation of said business areas with the purpose of facilitating zero-emission industries should happen sooner rather than later. This could both be an administrational task, but also something that could be up for political discussion in the municipality board.

Another challenge is connected to the business areas themselves, and the cost associated with them. In the following image, two of the areas in which I have found relevant and fitting for the purpose, is marked with “1” and “2”.

Webinnsyn: (Gjesdal kommune, 2020b)

These business areas located at Skurve, has costs connected to them. Some of these are yet not fully developed. This means that for the municipality, further development requires investment before the areas are ready to be sold and used for hydrogen purposes. While the location is good and the number of acres available are sufficient, the land itself needs planning and road infrastructure. The reregulation and eventually selling of these properties would therefore also be a product of a financial discussion, as the municipality will have costs connected to the development of these areas. A process of establishing a filling station will require development of the areas, and an advanced dialogue with the filling station developers to best find the cooperation and splitting of the costs connected to area development and land use.

2.6 Conclusions:

Looking into the framework, the MLP, the development of hydrogen is certainly at the niche level. With Gjesdal municipalities role as a policy maker and instrument, they can help hydrogen accelerate its transition from the niche level towards the socio-technical regime. As I have mapped out, several opportunities arise from hydrogen development within Gjesdal. An increase in the number of workplaces for one, and secondly the well suitedness in the geographical placement of Skurve. Both the amount of traffic past the point, and its geographical location speaks for a strong ecosystem from a very early point in development. This combined with great potential in a well-developed consumption from an early stage, makes way for a better market-penetration due to lower prices. This again could increase the incentives locally, and in combination with hydrogen-focused actors already established in the area, one would have to try hard to find a more suitable location for better conditions for a transition within the heavy-duty transport sector.

At the same time, both PR-related challenges and further development and regulation of business areas needs to be attended in order to fully reach the potential of a hydrogen footprint manifesting itself within Gjesdals borders. However, if they are to set this goal, and make the right choices, all parameters seems to point in the direction of successful transition.

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