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Multiple Imaginaries of the Fossil Fuel Free Future

Biogas and Electricity in Swedish Urban Transport

Amelia Mutter

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UNIVERSITY

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The Department of Thematic Studies - Technology and Social Change

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TABLE OF CONTENTS:

LIST OF ARTICLES:	I
CHAPTER 1. INTRODUCTION	1
1.1 RESEARCH PROBLEM	2
1.2 AIM AND RESEARCH QUESTIONS	3
1.3 ORGANIZATION OF THE THESIS	4
CHAPTER 2. BACKGROUND	5
2.1 TARGETS FOR A FOSSIL FUEL FREE TRANSPORT SYSTEM	5
2.2 RENEWABLE FUELS IN SWEDISH TRANSPORT	6
2.2.1 BIOGAS	7
2.2.2 ELECTRICITY AND ELECTRIFICATION	10
2.3 SWEDISH TRANSPORT GOVERNANCE	11
2.3.1 NATIONAL POLICY MAKING	12
2.3.2 SWEDISH REGIONS AS TRANSPORTATION PROVIDERS	14
2.3.3 TRANSPORT GOVERNANCE IN MUNICIPALITIES	14
CHAPTER 3. THEORETICAL PERSPECTIVES - SOCIOTECHNICAL IMAGINARIES OF THE FOSSIL FREE FUTURE	17
3.1 SOCIOTECHNICAL ENSEMBLES	17
3.2 CHANGE AND OBDURACY IN TRANSPORT ENSEMBLES	18
3.3 IMAGINARIES OF THE DESIRABLE FUTURE	21
3.3.1 SOCIOTECHNICAL IMAGINARIES - FOUR DIMENSIONS	23
3.3.2 UNDEREXPLORED THEMES	25
3.4 CONCLUDING REFLECTIONS	27
CHAPTER 4. METHODS & MATERIALS	29
4.1 PROJECT TIMELINE	29
4.2 MUNICIPAL CASE STUDIES	30
4.2.1 LINKÖPING	31
4.2.2 MALMÖ	32
4.2.3 CASE STUDY INTERVIEWS	33
4.2.4 CASE STUDY DOCUMENTS	36
4.3 NATIONAL IMAGINARIES OF BIOGAS AND ELECTRIC VEHICLES	37
4.3.1 DOCUMENT ANALYSIS - THE FFF-INVESTIGATION	38
4.3.2 INTERVIEWS	38
4.3.3 ADDITIONAL DOCUMENTS	39
4.4 ANALYSIS AND WRITING	40

CHAPTER 5. ARTICLE SUMMARIES	43
5.1 ARTICLE I	43
5.2 ARTICLE II	44
5.3 ARTICLE III	45
5.4 ARTICLE IV	46
CHAPTER 6. DISCUSSION	49
6.1 IMAGINARIES OF BIOGAS AND ELECTRIC VEHICLES	49
6.2 INTERACTIONS BETWEEN IMAGINARIES OF THE FOSSIL FREE FUTURE	51
6.3 OBDURACY AND CHANGE	52
CHAPTER 7. CONCLUDING REFLECTIONS	55
7.1 CONTESTED VISIONS OF THE FOSSIL FUEL FREE FUTURE	55
7.2 SOCIOTECHNICAL IMAGINARIES OF ELECTRICITY AND BIOGAS	56
7.3 FUTURE RESEARCH	58
REFERENCES	61

LIST OF ARTICLES:

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Article IV:

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CHAPTER 1. INTRODUCTION

Today we use 100 million barrels of oil every day. [...] There are no rules to keep that oil in the ground. So we can't save the world by playing by the rules. Because the rules have to be changed. Everything needs to change. And it has to start today.

Greta Thunberg - Extinction Rebellion - London - October 31, 2018

In the last two years, 17-year-old Greta Thunberg has gained worldwide renown for her climate activism. Thunberg's movement, which calls for immediate and aggressive action to stop climate change, started in August 2018 on the steps of the Swedish parliament, calling attention to the role of this small Nordic nation within the global epidemic. "Fridays for future" has grown dramatically in the past year, leading to hundreds of thousands of events in 226 different countries (Fridays for Future 2019). Above, Thunberg calls for changing the rules in an attempt to curb oil consumption. This thesis focuses on on-going attempts to do just that in Thunberg's home country of Sweden. Here, national policy has set ambitious goals for achieving this fossil fuel free future, particularly in the transport sector which currently is heavily dependent upon fossil fuels. Nearly two-thirds of the 107 TWh of fossil fuels used in the country were used for domestic transportation in 2017 (66TWh) (Energimyndigheten 2019a). Currently there is a strong policy focus on achieving fossil fuel independence in transportation, contributing to targets of reducing greenhouse gases from the transport sector by 70% by 2030 and achieving net zero greenhouse gas emissions by 2045 (Sveriges Riksdags Trafikutskottet 2018). These targets suggest a national intention to achieve the fossil fuel free future quickly. This ambition is often reiterated by current prime minister Stefan Löfven who calls for Sweden to become "the world's first fossil fuel free welfare state" (Löfven 2019).

Achieving such a widespread shift away from fossil fuels, however, is not an easy task. As Geels et al. (2012) suggest, the transport system and especially automobility might be the "hardest case" in the realm of sustainability, particularly considering the role of stabilizing mechanisms that move towards more rather than less car-based transportation. The fossil fuel transport sector has been built up over more than a century, resulting in a complex sociotechnical system around these fuels and the vehicles that use them for propulsion. As Jasanoff and Kim (2013, 189) explain, "new energy futures will need to reconfigure the physical deep structures of civilization - grids and pipelines, seashores and pastoral landscapes, and suburbs and cities - that were shaped by the energy choices of the past." As this perspective exemplifies, energy systems are deeply embedded in the developments of the past, particularly because of the enormous timescales that it takes for fossil fuels to be generated. Changing the fossil fuel-based system, therefore, is not just a matter of physical infrastructures and systems, but also includes changing sociocultural practices and ideas of the future.

Furthermore, there are multiple possible pathways for achieving such a change. As a result of growing concern about climate change, many alternative approaches and structures have emerged for reducing the volume of fossil fuels used in the transport sector: increased use of alternative fuels in vehicles (e.g. biofuels, fuel cells, electricity), mobility management, and reducing transport demand. Although there is a potential for many of these alternatives to contribute to the fossil fuel free future on a societal level, conflicts may emerge between them on local levels, as much transport planning, particularly in Sweden, occurs within cities, municipalities and regions. This situation can lead to potential conflicts between national level policy setting (as with the goals for fossil fuel independence) and local and regional preferences, practices and traditions.

In particular, this situation sets visions of electric vehicles and biogas as alternative vehicle fuels in Swedish transport against each other. While initial use of electric vehicles in Sweden has been limited, accounting for only 1.35% of all personal vehicles in 2018, some actors suggest that electrification within the transport sector will continue rapidly, even dominating the personal vehicle market as early as 2026 (Andersson & Kuhlén 2019). In addition to personal vehicles, public transport buses in urban settings are another sector where electrification is considered a promising alternative. The predictability of routes and limited ranges of these vehicles contribute to conditions that are favorable to electrification (Aldenius et al. 2016; Magnusson & Berggren 2017).

In Sweden, this potential indicates one specific realm for possible competition between electric vehicles and biofuels, particularly because 86% of public transport bus kilometers were driven by biofuels as of 2017 (Svensk Kollektivtrafik 2018). Although public transport is the area of transport where the most renewable fuels are used, the percentage of biofuels used in all road transportation is also high at 22% due primarily to the usage of drop-in biofuels, where liquid biofuels are mixed into diesel and gasoline stocks (Energimyndigheten 2019a). These statistics set Sweden far ahead of the global average when it comes to biofuels in transportation. Local systems of biogas production and use have developed in many cities and regions of Sweden, where public transport buses account for a large percentage of total biofuel use as a result of decisions by public actors (Palm & Fallde 2016; Ericsson et al. 2013). In several of these cities, this usage is so widespread that the bus system is primarily or entirely supplied by biogas (Vernay et al. 2013; Fallde 2011).

1.1 RESEARCH PROBLEM

This thesis focuses on the interaction between visions of biogas and electric vehicles within the Swedish fossil fuel free future. These two fuels were chosen as the focus for analysis not only due to the important role each can possibly play within the future transport sector, but also because of their potential for conflicts as competitive fuels, particularly as Swedish public transport providers might look to replace biogas city buses with electric vehicles. These two fuels also share a number of dynamics which make them particularly interesting to study alongside each other. While the majority of liquid biofuels are imported, both biogas and electricity are largely produced in Sweden, contributing to the perception that using these fuels improves Swedish energy security. Furthermore, unlike liquid biofuels such as ethanol and biodiesel, both the biogas and electric vehicle systems require specific types of vehicles, infrastructures, and maintenance procedures. This means that the inclusion of these fuels in the fossil free future is complicated by the need to transform the connected material structures.

The role of competing alternatives in sociotechnical change has been studied in recent social science literature, for example by Markard and Hoffman (2016), who suggest a framework to study the role of this dynamic in transitions. The competition and complementarity between biogas and electricity in heavy vehicles has additionally been the subject of a more detailed analysis by Magnusson and Berggren (2017). This thesis seeks to build on this previous literature by emphasizing the role that future visions play in these interactions. By considering these visions, I will analyze how actors understand the ability of these fuels to help contribute to a better future. There are multiple ways of conceptualizing such future visions, however, I will primarily conceptualize these as "sociotechnical imaginaries", a theoretical perspective which emphasizes the way that sociotechnical futures become collectively held and institutionally stabilized (Jasanoff & Kim 2009, 2015). Sociotechnical imaginaries have been widely used as a way of studying visions of energy futures (Tidwell & Tidwell 2018; Korsnes 2016; Karhunmaa 2018; Kuchler 2014).

The thesis explores the interactions between the two sociotechnical imaginaries of biogas and vehicle fuels, showing how actors' inclusion of each of these fuels in the fossil free future is influenced by imaginaries of the other. Also, these imaginaries play out on different geographic scales. The empirical material of the thesis is taken from two case studies of urban public transport in the Swedish cities of Linköping and Malmö, as well as a study of emergent transport policy on a national level. In addition to sociotechnical imaginaries, the thesis also engages with theoretical perspectives on obduracy and change to consider how incumbent fuel systems become stabilized or remain open to adaptation within the greater shift towards renewable fuels.

1.2 AIM AND RESEARCH QUESTIONS

The aim of this thesis is to explore visions of biogas and electric vehicles within a transformation of Swedish urban transport to a fossil fuel free future. With this aim in mind, I address the following research questions:

1. What are the visions of local and national actors concerning the future of biogas and electricity as fuels in urban transport in Sweden?
2. How do these visions of biogas and electric vehicles interact with each other and how do these interactions vary on different geographic scales?
3. What factors contribute to obduracy or change in configurations of biogas and electric vehicles in different local contexts?

In pursuit of these questions, I consider visions of these alternative fuels in two urban contexts and on the national level. Biogas has become a prominent fuel in many public transport systems, while electric buses are emerging as a desirable alternative in many of these areas. This leads to an interesting dynamic where the two fuels sometimes interact within visions of the future public transport system in many municipalities. To explore these interactions further, I utilize case studies of two municipalities with incumbent biogas urban bus systems to understand how actors in these locations understand the role of biogas and electric vehicles. The Swedish cities of Linköping and Malmö were chosen to provide contrasting examples of one municipality where biogas is currently used extensively but where electrification is under consideration and one where electric vehicles are already being implemented. My understanding of visions is largely drawn from interviews with key actors in both cases, as well as local planning documents. These case studies work to answer the research questions by emphasizing both the role of visions on local scales and how these are influenced by national

imaginaries. Finally, as the biogas bus system is relatively stable in the Linköping case but undergoing significant change in the Malmö case, these two examples provide interesting counterpoints for exploring issues related to obduracy and change in such systems.

In addition to the municipal case studies, I have also explored visions of biogas and electric vehicles on the Swedish national level. This part of the study interacts more directly with national targets for fossil fuel independence by studying policy documents that explicate the way that biogas and electricity are viewed as contributing to these policy goals. Much of this analysis focuses on one main policy document, a 2013 Swedish government official report that outlines the possibilities for achieving fossil fuel independence. By examining the way that biogas and electric vehicles are discussed in this document and the following consultation process, I identified commonly held visions that suggest what role these fuels will play in the future transport system. The analysis is supplemented by interviews with national level actors and analysis of additional policy documents. This part of the thesis addresses the research questions by determining the existence of national level visions of biogas and electricity that can be compared with the local case studies to address research questions 1 and 2.

1.3 ORGANIZATION OF THE THESIS

The thesis is composed of four articles and an introductory essay. The introductory essay consists of seven chapters, of which this text is Chapter 1. Chapter 2 of the essay will present a more thorough background to the empirical study of the thesis. This chapter will provide context on Swedish policy making and the goals for the fossil fuel free future, as well as an overview of biogas and electricity in Swedish energy. Additionally, the chapter will explain the different levels of transport governance in the country. Chapter 3 will explain the theoretical perspectives that are used in the thesis, including how systems of fuel provision are understood as sociotechnical ensembles, how I conceptualize processes of obduracy and change, and how the perspective of sociotechnical imaginaries is employed to understand visions of the future. Chapter 4 will introduce the methodology used in the thesis and explain the materials that have been used in the analysis. Chapter 5 will briefly introduce the four articles that make up the thesis and will summarize the main perspectives and conclusions from each paper. Chapter 6 will then tie together the analysis from these papers in a discussion surrounding the research questions. Finally, Chapter 7 will discuss overarching conclusions from the work.

CHAPTER 2. BACKGROUND

In this chapter I present a relevant background for understanding the role of biogas and electricity within the Swedish transportation sector. This chapter consists of three sections. In the first section I outline the renewable energy and greenhouse gas emission targets that are core components of current Swedish energy and environmental policy. In the second section I describe the current use of renewable fuels in transport with a focus on biogas and electricity, and in the third section I provide a short orientation on Swedish transport governance.

2.1 TARGETS FOR A FOSSIL FUEL FREE TRANSPORT SYSTEM

As a member of the European Union, Sweden is required to comply with EU policies, including the renewable energy directive (RED). This directive is an agreement among members of the union to increase the share of renewable energy fuels in order to reach certain targets over time. The first version of the RED recommended the goal that 20% of energy from the transport sector should be renewable by 2020 (Sveriges Riksdags Trafikutskottet 2018). A new version (RED II) came into force in 2018, setting a target of 32% renewable fuels by 2030 (The European Parliament and the Council of the European Union 2018). One important aspect of the RED is that it sets limitations on certain types of fuels, including the percentage of fuels that can originate from energy crops (at 7%), as well as a ban on palm oil based biofuels from 2021 (Sveriges Riksdags Trafikutskottet 2018).

In addition to European targets, Sweden has also set its own, more ambitious goals for achieving a fossil fuel free future. These goals originated in a 2009 government bill which called for a 40% reduction of greenhouse gas emissions by 2020 (compared with 1990 levels), setting additional goals of a "fossil fuel independent vehicle fleet by 2030" and a "sustainable and resource efficient energy supply with net zero emissions of greenhouse gases" by 2050 (Regeringskansliet 2009). With these goals, often referred to together as the 2050-vision, the government placed the fossil fuel free future centrally on the political agenda, going beyond the targets set by the Kyoto protocol and EU agreements. However, some of these goals are vague, particularly the goal of a fossil fuel independent vehicle fleet, where the outcome depends on how "a fossil fuel independent vehicle fleet" is defined. This goal is the focus of the 2013 official government report *Fossil fuel freedom on the road - A report of the investigation on fossil free vehicle traffic* (sometimes referred to as the FFF-investigation), which was written with the directive of mapping possible pathways towards achieving the aforementioned 2030 and 2050 targets.

The FFF-investigation provides additional clarity on these targets, for example by defining a fossil fuel independent vehicle fleet as "a road transport system whose vehicles are primarily driven with biofuels or electricity" (Regeringskansliet 2013, 36). This definition opens up the notion of a fossil fuel free future to a variety of alternative fuels, and even leaves the possibility for some percentage of fossil fuels to remain (as long as they are used in hybrid applications). With such a shift to a fossil fuel independent vehicle fleet, the FFF-investigation claims that a reduction of greenhouse gas emissions of 80% should be possible by 2030 (in comparison with 2010 levels) (Regeringskansliet 2013). This target was reduced later in 2017 by another Parliamentary decision called *A climate political framework for Sweden* (Sveriges regering 2017), which formally reduced the national target to a 70% reduction of greenhouse

gas emissions from domestic transportation by 2030 (also in comparison with 2010 levels and excluding air traffic). For most of the thesis, I focus on visions concerning the progress towards the fossil fuel independent vehicle fleet, but greenhouse gas reduction goals are also important as part of the motivation to shift to renewable fuels within the climate change agenda.

2.2 RENEWABLE FUELS IN SWEDISH TRANSPORT

The Swedish transport system had a total energy use of 126 TWh in 2017, of which 88 TWh or almost 70% were used for domestic road transportation (Energimyndigheten 2019a). The majority of this energy comes from fossil fuels, although 19 TWh (22%) comes from biofuels and 3 TWh (3%) from electricity. The most commonly used biofuel in transport to date is biodiesel, followed by ethanol and biogas. Both biodiesel and ethanol are used in high and low blend forms, often denoted by the percentage of biofuel. For example, E5, E85 and ED95 are all types of ethanol that are mixed in amounts of 5%, 85% and 95% with gasoline respectively. However, while the amount of ethanol used in Sweden has been decreasing, use of biodiesels such as FAME (Fatty Acid Methyl Ester) and especially HVO (hydrogenated vegetable oil) have been increasing (Energimyndigheten 2017b). These fuels are mostly used as so-called “drop in fuels” mixed into the diesel stock. Of these two fuels, HVO is the more widely used, perhaps because of its chemical similarity to diesel which allows it to be used in higher percentage mixes. Biogas and electricity are also increasingly used in the transport sector and will be elaborated upon in the following section.

Biogas and electricity have different attributes, different origins, and can be made from different fuel stocks. Table 1 compares the relevant fuels with regards to energy efficiency, greenhouse gas emissions, and the percent GHG emissions saved, three measures considered especially important for the potential to achieve a fossil free road transportation system.

Table 1. Environmental Impact of Fuels¹

Fuel	Energy efficiency kWh/km	GHG Emission gCO ₂ eqv/kWh	Percent GHG Emissions reduction compared to Gasoline
Diesel MK1	0.55	290	12%
Gasoline MK1	0.73	329	0%
FAME	0.55	116	65%
HVO	0.55	50	85%
E 85	0.69	184	44%
Vehicle Gas	0.64	113	66%
Electricity	0.15	124	62%

Source: Energimyndigheten, 2017a

As this table indicates, both vehicle gas (which contains a mix of biogas and natural gas) and electricity perform well in terms of energy efficiency and greenhouse gas emissions reduction. Vehicle gas has a lower energy efficiency than traditional fossil fuels, but has a

¹ These numbers were taken from a Swedish Energy Agency report. The statistics for GHG emissions were calculated based on a lifecycle perspective for the Swedish mixes of these fuels from 2016.

significant impact on emissions, while electricity performs well on both energy efficiency and emissions reduction.

2.2.1 BIOGAS

Biogas is a methane-based fuel generated from organic materials that are broken down in an environment without oxygen. It can be generated from a number of raw materials including organic waste (collected from households or industrial food production), manure or energy crops (Lantz et al. 2007). The outcome is a gaseous fuel that can be utilized for energy, combined heat and power, or as a vehicle fuel. This gas is primarily composed of methane but has a substantial amount of carbon dioxide and traces of other components as well. For vehicle usage, however, biogas must be upgraded, which can be done through a number of processes including water scrubbers, pressure swing adsorption, and chemical scrubbers (Lantz 2013). The upgrading process removes the impurities from the biogas, generating a product with a higher percentage of methane (around 97%) that can be used in internal combustion engines (Lantz & Börjesson 2014). The upgrading process creates an output that is chemically similar to natural gas and in Sweden these gases are often combined and sold as "vehicle gas" (Larsson et al. 2015).

In addition to the biogas itself, the digestion process also creates a liquid by-product often called "digestate" that can be used as a fertilizer for crop production. In some cases, this by-product is certified to ensure that it is safe for use as a fertilizer. Digestate is also important for the biogas system because it can contribute to the financial viability of biogas production through this second source of income for biogas producers. Furthermore, digestate is also beneficial from a sustainable agriculture perspective because it contains all the nutrients of the original feedstocks and can be used to replace mineral fertilizers which require their own fossil fuel input and CO₂ emissions for production (Lantz & Börjesson 2014).

Vehicle gas was introduced as an alternative fuel in Sweden in 1995, although at first it was composed primarily of natural gas due to the fact that biogas production was limited (Lönnqvist 2017). Although biogas production was already underway in a number of waste-treatment plants as of the mid-20th century, biogas was originally viewed as a by-product and was not utilized (Olsson & Fallde 2015). In the late 1990s and early 2000s, many municipalities began to invest in their own biogas production processes (Hjalmarsson 2015; Olsson & Fallde 2015). This investment was largely driven by interest in developing a renewable vehicle fuel. Use of biogas as a vehicle fuel has increased steadily since this time from 100 GWh in 2001 (Lönnqvist 2017) to 2068 GWh in 2017 (Swedish Energy Agency 2019).

Figure 1. Biogas production by method in Sweden in GWh

Source: Swedish Energy Agency 2019

In the European context, biogas has become a significant biofuel, with 156 TWh produced across the EU in 2013. Germany, Italy and the United Kingdom are the three countries with the largest biogas production, most of which is used for combined heat and power production (Larsson et al. 2015). Swedish producers generate less biogas than these other countries, but biogas nonetheless plays a significant role in the energy system. As Figure 1 shows, biogas is mostly generated from anaerobic digestion facilities and sewage waste treatment facilities (Swedish Energy Agency 2019). One notable difference from other European countries is the limited presence of farm-based biogas production facilities (only 3%). Elsewhere in Europe, agricultural biogas plants are very common, located at farms and utilizing substrates from the farm or other nearby sources (Markard et al. 2009). In Sweden the raw material mix, however, is based primarily on waste products as shown in Figure 2. The Swedish biogas network also differs from the rest of Europe because of the large percentage which is upgraded and used as a vehicle fuel. While this is only a marginal use elsewhere in Europe, as of 2017, almost two-thirds of Sweden's total biogas stock was upgraded for vehicle use (Energimyndigheten 2019a). In recent years, the volume of upgraded biogas has increased, which also has an impact on the composition of the vehicle gas. As of 2016, biogas reached 80% of the vehicle gas stock, meaning that only 20% was natural gas (Energimyndigheten 2017a).

Figure 2. Raw material usage for Swedish biogas

Source: Energimyndigheten 2017a

Biogas is a promising vehicle fuel in the Swedish system, but it is not without its challenges. While many liquid biofuels can use similar infrastructure to fossil fuels, most of the vehicle gas used today is used in compressed form, which means that it requires specific types of vehicles and infrastructures which are often more expensive than liquid alternatives (Larsson et al. 2015). Biogas vehicles can use two types of engines: Otto engines that are similar to the type used in gasoline vehicles and compression-ignition motors similar to those used for diesel fuel (Anderson 2014). One drawback is that these vehicles tend to have a lower energy efficiency than liquid fuel vehicles (as shown in Table 1).

For the most part, upgraded biogas is transported through compressed bottles, although in some cases it is injected into the natural gas distribution grid (Lönnqvist 2017). Although grid distribution is more economical, this is only a viable option in a limited area of Sweden where a grid for natural gas exists. The national gas grid enters the country from Denmark in the south and travels up the west coast. In the early days of gas use there were discussions about extending this grid into larger portions of the country, although this was never realized (Fallde 2011). In addition to this national grid there are also local vehicle gas grids in Stockholm, Västerås and Linköping (Lönnqvist 2017). Outside of these areas, compressed gas must be transported via trucks, which adds to the cost in both time and fuel (Lantz & Börjesson 2014). This transportation takes the gas to fueling stations where it can be inputted into vehicles; however, such stations are not always widely available. Larsson, et al. (2015) for example note that there is a distinct lack of fueling stations outside of the largest urban areas.

While the largest quantity of biogas in Sweden has been used in compressed gas form, liquification is another alternative. Liquid biogas could be used in more vehicle applications, including long-haul trucks and buses (Magnusson & Berggren 2017). Liquification of biogas requires additional processing to take the gas to liquid form by pressurization and

refrigeration, which can be completed by a number of methods including cascade liquification, mixed refrigerant-liquification, and expander liquification (Baccioli et al. 2018). This process has a number of benefits for use as a vehicle fuel through the relative ease of transporting liquid fuel, abundance of available vehicles, and the compact filling tanks. So far, only one liquified biogas (LBG) plant is in use in Sweden, with three others being built, so LBG is likely to become more common in the coming years (Interview S2).

2.2.2 ELECTRICITY AND ELECTRIFICATION

Due to large investments in hydro and nuclear power, the Swedish electricity system is largely based on non-fossil alternatives. As of 2015, 159 TWh of electricity were produced primarily by fossil fuel free means, as shown in Figure 3 (Energimyndigheten 2017b). Development of non-fossil electricity was driven by the 1970s oil crises (Wang 2006). As hydropower, nuclear power, and biomass were each introduced as alternative energy sources, they also created widespread political frictions (Haikola & Anshelm 2016). In each instance, introduction of large-scale projects were met with resistance from environmental groups, who argued that the power plants would have negative impacts on environmentally sensitive areas. Nuclear power has an especially problematic history, as the Swedish people voted to decommission nuclear power in the 1980s, leading to a political decision to phase-out nuclear use by 2010. Nevertheless, nuclear power is still in use, showing that although the Swedish electricity system is largely fossil fuel free, its energy mix is far from uncontested. Swedish electricity is supplied by a national grid that connects Sweden to neighboring countries.

Figure 3. Swedish electricity production by source, 2015

Source: Energimyndigheten 2017b

In the past several years, concerns about climate change and energy security have led to increased interest in electrification of the transport sector. To a certain extent, this is neither a new nor a novel trend as electrification has been central to transportation, and particularly

public transportation, for generations. In addition to driving metros, trams, and trolley buses in many cities today, many electric cars were introduced in the early days of the automobile only to be outcompeted by their internal combustion counterpart (Kirsch 2000). In recent years, however, the discussion has again shifted to electric cars and buses which can use electricity with limited infrastructure. This trend is part of a larger global narrative advocating for widespread electrification as a means of handling multiple sustainability issues, including handling the peaks and troughs of electricity demand, distribution of renewable energy sources such as solar and wind power, and improved efficiency.

Electrification is currently often presented as a central part of one international vision of the transport future that suggests that vehicles will be "shared, autonomous, and electric" (see for example Morgon Stanley 2016). As a result, electric vehicles are taking hold, with major vehicle manufacturers setting ambitious goals to develop and market electric vehicles. Two examples of this phenomenon are General Motors' commitment to developing twenty new electric car and truck models by 2023 (Ashbrook 2017) and Volvo's pledge to shift all of their models to electric-driven vehicles (including hybrids) by 2019 (Vaughan 2017). This vision is also prevalent in the Nordic countries, where Sovacool et al. (2019) have identified the vision of a rapidly electrified society as the most commonly shared in interviews with over 200 experts.

Interest in the potential of electric vehicles is also prevalent in Sweden, where electric vehicles are often presented as one of the alternative solutions to help achieve the fossil fuel free future (Regeringskansliet 2013, 2009). The share of plug-in electric vehicles in Sweden has grown substantially in recent years, reaching 2.5% of newly registered vehicles in 2015, making Sweden the country with the third largest percentage of electric vehicles sold after Norway and the Netherlands (Energimyndigheten 2017b). However, electric vehicles are still only a marginal part of the transport system, accounting for 1.35% of personal vehicles in 2018 (Andersson & Kuhlin 2019). Many actors believe this share will continue to grow, even dominating the market by 2026 (Ibid.). In addition to electric cars, electric buses are also gaining popularity in Europe, including the Nordic countries, with an increasing number of cities testing electric bus lines (for a more detailed description of these see the work of Borghei and Magnusson 2016, 2018). In Sweden, the number of electric buses has grown rapidly, almost doubling from 53 in 2017 to 95 in 2018 (Andersson & Kuhlin 2019). This places emphasis on public transport buses as a venue of competition between electricity and biogas vehicles, as will be explored in the municipal case studies.

For the purpose of the thesis, I use the term "electric vehicles" quite broadly, although this can include hybrid or plug-in vehicles as well as fast or slow charging structures. In my definition, I focus on plug-in alternatives, although in some cases these are categorized together with other battery powered vehicles.

2.3 SWEDISH TRANSPORT GOVERNANCE

Governance of the transport sector in Sweden is administered on multiple levels. The national government plays a central role by setting overriding policy priorities and measures, exemplified by the 2050-vision described above. These agendas are supported by policy instruments that are meant to incentivize actors to choose renewable fuels. However, local and regional governments also have significant influence in transport planning and implementation. While the regional government is empowered with public transport provision, municipal governments have considerable autonomy over transport planning

within their jurisdiction. This section will provide context for aspects of transport governance that are of particular importance for this thesis.

2.3.1 NATIONAL POLICY MAKING

Policy making at the national level follows a number of stages and is often initiated when the Government requests additional background information on a specific issue to inform the policy-making process. This information gathering can be carried out in a number of different constellations and is sometimes delegated to one of the government agencies. In other cases, it is deferred to a commission of inquiry which may be composed of one or several qualified individuals, including academic experts and Parliamentary politicians (Larsson & Bäck 2008). These committees are informed about the expected content and scope of their investigations through terms of reference (*kommittédirektiv*) that are set by the Government. Each year, this process results in many Swedish Government Official Reports (*Statens Offentliga Utredningar*) as guidance for emergent policy.

This process is particularly important for the thesis because I use one such report as the basis for my analysis of paper 4. This document *Fossil fuel freedom on the road - A report of the investigation on fossil free vehicle traffic* (often referred to as the FFF-investigation, as noted earlier) emerged as an extremely important report for images of the Swedish fossil fuel free future. Because of the high number of SOU investigations that are published (84 in 2013), not all of these receive much attention after their release. However, the FFF-investigation has been widely cited in the years since its publication in 2013, both in subsequent policy reports and in academic publications.

The aim of the FFF-investigation was to "map possible actions and identify measures for reduced transport sector emissions and dependence of fossil fuels in line with the vision for 2050" (Näringsdepartementet 2012, 78). The resulting report was over 1,000 pages long and included a multitude of suggestions for technologies and policy measures that could help achieve the 2050-vision for fossil free transport in Sweden. One of the most important conclusions from the FFF-investigation as discussed in Section 2.1 concerns the feasibility of achieving large-scale reduction of fossil fuel dependence. The FFF report has had a surprising amount of longevity, maintaining relevance even after a shift in national political power in 2014 when the red-green coalition replaced the conservative alliance in national elections. The FFF-investigation proposed multiple concrete policy initiatives, many of which resulted in specific measures that were eventually passed into law.

Following the completion of the FFF report, the document was circulated for comment, a specific consultation process whereby many relevant actors are invited to submit letters in response to the content of the report. As part of the governance process, the relevant ministry circulates the report to a group of actors that are likely to have opinions on the content, including representatives from local and regional governments, universities, interest groups, and industry. This process is explicitly open: all actors in the country are welcome to submit a response, even if they are not part of the group that is formally invited to do so. This consultation process is intended to overcome conflict and help achieve consensus and collaboration within Swedish policy making (Friberg 2011). In the case of the FFF investigation, more than 100 responses were submitted, which largely supported the intention of a transition to a fossil fuel independent vehicle fleet by 2030.

The government investigation process, as used in the FFF-investigation, is an example of one type of governance that sets broader agendas and priorities for policy within a specific area. Additionally, this process also recommends a number of concrete policy instruments, which in the case of the FFF-investigation provide support for renewable fuels and encourage the phase out of fossil fuels. Over the years, many initiatives have been introduced to encourage renewable fuel adoption. Below I describe those that are deemed the most relevant for biogas and electricity. Those proposed in the FFF-investigation are marked by an asterisk.

Bonus-malus system for personal vehicles* - This policy measure was put into place in mid-2018 to encourage consumers to choose low-emissions vehicles, replacing a previous policy called the super environmental car premium. The bonus-malus system provides benefits for consumers buying low-emission vehicles and penalties for those who buy high-emissions vehicles. The bonus can be up to 60,000 Swedish crowns (around \$6,400 USD) while the malus is a heightened tax that increases depending on how much greenhouse gases the vehicle emits (Transportstyrelsen 2019).

Electric bus premium* - Launched in 2015, the electric bus premium is a subsidy for the purchase of electric buses of up to 20% (Dädeby 2018). This program is intended to encourage investment in renewable fuel buses by offsetting the higher cost of electric buses, but it does not apply to any other renewable fuels.

City environment contract * - This funding instrument awards a certain amount of money annually (470 million Swedish crowns in 2017) to municipalities in the form of grants toward the development of low emission transport, including public transport infrastructure such as electric vehicle charging infrastructure (Magnusson & Berggren 2017).

Reduction requirement * - In 2017 the Swedish Parliament passed a law requiring a gradual reduction of diesel and gasoline in the vehicle stocks (Sveriges Riksdags Trafikutskottet 2018). This law requires all distributors of diesel and gasoline to include certain volumes of biofuels into the fuels they distribute as a way of reducing greenhouse gas emissions each year. As of 2019, these amounts were 2.6% biofuels in petrol and 20% in diesel (Energimyndigheten 2019b).

The Climate Stride - This funding instrument provides support for local and regional solutions to reduce emissions of greenhouse gases. This was originally introduced as a limited program from 2015-2018, however in June 2019 the Government decided to extend this program by providing an additional budget for this fund (Naturvårdsverket 2019).

Landfill ban - This policy was introduced in 2005, banning the landfilling of organic waste (Lantz et al. 2007). The policy requires municipalities to find other ways of getting rid of organic waste substrates, such as biogas production.

Tax exemptions - Historically biofuels have been exempted from energy and carbon dioxide taxes. Due to free trade laws within the EU, these exemptions must be approved by the Union. The exemption for biogas is currently approved until 2020. While some actors suggest this is the most important policy measure because it helps create demand for biogas, others note the limitation of this short term policy, with the Swedish government requesting exemption for only six years at a time (Larsson et al. 2015; Xylia and Silveira 2017; Interview S4).

The pump law - In 2005, the Swedish government introduced a law that requires all fueling stations that sell more than 1,500 cubic meters of fossil fuels per year to offer a renewable alternative (Larsson et al. 2015). In practice, however, most fueling stations opted to offer liquid biofuels because they required less initial investment.

Environmental zones- This regulation allows Swedish cities to establish areas where only certain types of vehicles can drive (such as inner-city zones) in an attempt to reduce air pollution. There are three types of environmental zones: type 1 sets minimum standards for combustion engines based on the European standard classifications, type 2 sets an even higher standard for combustion engines and type 3 limits zones to electric, fuel cell and gas engine vehicles only. As of 2013, eight Swedish cities had type 1 zones but types 2 and 3 will only go into effect in 2020 (Transportsyrelsen 2013).

2.3.2 SWEDISH REGIONS AS TRANSPORT PROVIDERS

Since 2012, it is the middle level of governance in Sweden, namely the regions, that are responsible for providing public transportation (Khan et al. 2017). Each public transport authority or PTA is run by a political entity and is responsible for providing public transportation within its region, including local and regional buses, as well as sometimes trams, regional trains, and ferries, and service transportation. As part of this mission, the regions periodically publish a report called the Traffic Provision Plan (*Trafikförsörjningsprogram*) to help outline future challenges and plans for public transport development with the respective region.

Public transport is then serviced by private bus operators, which are selected and contracted by a tendering process that is usually completed every 8 to 10 years. As part of this tendering process, regions and municipalities can set sustainability requirements for their bus fleets either by setting functional requirements such as a maximum level of CO₂ emissions or through specific requirements such as a vehicle or fuel type (Aldenius 2018). This tendering process is quite important for the choice of fuels in public transportation because in cases where the type of fuel is not specified, the operator usually chooses the cheapest alternative that fits the other requirements, often leading to a higher percentage of liquid biofuels (Khan et al. 2017). This is the most popular strategy across the regions, whereas most biogas-based systems were the result of tendering agreements that specifically requested biogas-based vehicles.

2.3.3 TRANSPORT GOVERNANCE IN MUNICIPALITIES

Swedish municipalities also play an important role in transport governance, particularly through traffic planning. Traffic planning intersects with other areas of municipal governance including the development of attractive, livable cities. Municipal traffic plans are included in comprehensive plans (*översiktsplan*) which is a type of municipal planning document mandated by law (Finansdepartementet 2010). Although comprehensive plans are non-binding, they lay out long-term objectives for sustainable municipal development, including transportation. This is only one example of how municipalities include transport planning in their regular activities. From a public transport perspective, municipalities are also involved in decision making despite the fact that the regions have a more formal responsibility from the Government to supply public transport. Municipalities are involved in more localized activities such as route planning and infrastructure provision. Furthermore, municipalities also have the

responsibility for energy provision and activities such as distribution of electricity, district heating and gas which are often supplied by municipally owned companies (Falde 2011).

CHAPTER 3. THEORETICAL PERSPECTIVE - SOCIOTECHNICAL IMAGINARIES OF THE FOSSIL FREE FUTURE

In order to understand how alternative fuel options shape the ongoing fossil fuel independent transport transition, I will draw on a combination of theoretical perspectives: sociotechnical ensembles, obduracy and change, and sociotechnical imaginaries. In order to emphasize the complex entanglements surrounding biogas and electricity for transport, I will analyze these fuels as *sociotechnical ensembles* to highlight the way that they are interlinked with heterogeneous networks of actors, institutions and regulations, social practices and cognitive constructs. The development of these ensembles is then situated within the broader context of an ongoing process of *sociotechnical change*. Within these processes of change, visions of the future play a central role, as they impact the way that actors mobilize the resources at their disposal to drive change processes in a specific direction. In order to explore these visions of the future as part of such broader sociotechnical ensembles, I then use the concept of *sociotechnical imaginaries* which emphasizes the way that such visions become collectively held and institutionally stabilized within a certain population. The thesis analyzes sociotechnical imaginaries of biogas and electric vehicles, emphasizing how these interact with each other. Each of these perspectives are introduced in the following chapter, with the relationship between them elaborated in section 3.4.

3.1 SOCIOTECHNICAL ENSEMBLES

This study of biogas and electricity in the transport sector relies upon an understanding of the networks around these energy sources as complex entanglements of social and material components. The interconnectedness of technologies and sociality has been widely studied in Science and Technology Studies, where three seminal theories have been developed to explain the interactions between these interlinked components. The perspective of large technical systems (LTS) uses the term system to describe these structures, emphasizing how they are composed of "messy, complex, problem solving components" and are "both socially constructed and society shaping" (Hughes 1987, 51; see also Hughes 1983). Actor-network theory (ANT) analyzes associations of human and non-human elements (called "actants") and the distribution of agency within these networks (Callon 1986; Latour 2005; Akrich 1992). Finally, the approach of social construction of technology (SCOT) puts science and technology at the center and analyzes how different actors are enrolled and contribute to different interpretations of so-called "sociotechnical ensembles" (Bijker 1995; Pinch & Bijker 2012).

The thesis will draw on technological development as described by the SCOT framework, utilizing the concept of sociotechnical ensembles and focusing on how this perspective seeks to explain why some technologies succeed while others do not. SCOT emphasizes the way that enrollment and formation of ensembles can be multidirectional, with selection of a technological alternative emerging from the interactions of different social groups (Pinch & Bijker 1984). This perspective points to the way that the design of a technology partially develops through the enrollment of relevant actors and actor groups with different

perspectives on (or understandings of) the technology in question. Within this framework, technologies are part of sociotechnical ensembles, a type of configuration that Bijker does not explicitly define. Instead, he writes how these refer to the "heterogeneous system- or network-building rather than straightforward technical invention" that occurs as the technology develops (Bijker 1995, 273). Bijker uses sociotechnical ensembles as a tool to emphasize the point that:

the sociotechnical is not to be treated as merely a combination of social and technical factors...Society is not determined by technology, nor is technology determined by society. Both emerge as two sides of the sociotechnical coin during the construction process of artifacts, facts, and relevant social groups (Ibid. 274).

This understanding relates the multidirectional trajectory of technological development to the idea that these technologies do not exist in a vacuum but instead are continually shaped by multiple understandings among various groups in heterogeneous networks.

Building on this framework, the thesis uses the concept of sociotechnical ensembles to explain the multifarious and extensive networks that surround biogas and electric vehicles. By focusing on the ensembles of biogas and electric vehicles, I want to emphasize how the role of these fuels in the fossil fuel free future is inherently entangled with wider networks, that include a range of entities from the fuels themselves and the vehicles that drive them, to the infrastructures through which these fuels are transported and inserted into vehicles. Another motivation for studying these ensembles is that the interconnection of these configurations contributes to the way they interact, with some of the actors and artefacts of the biogas ensemble also taking part in the electric vehicle ensemble. This conceptualization is deployed most explicitly for paper 2, where I focus on obduracy and change within these ensembles, utilizing the case studies of urban public transport in Linköping and Malmö. It is to these dynamics of obduracy and change that I now turn.

3.2 CHANGE AND OBDURACY IN TRANSPORT ENSEMBLES

Sociotechnical ensembles undergo continual processes of sociotechnical change, where the complex developments of technology are shaped by a multitude of social, political, and economic factors (Bijker & Law 1992). These processes are fundamentally important for the transformation to a renewable transport sector in Sweden, because they will determine whether the fossil fuel independent vehicle fleet is achieved. Elsewhere, these types of transformation are examined in transition studies, which focus on the way that one sociotechnical system replaces another (Shove & Walker 2007; Geels 2002, 2011). While there is an abundance of literature that explores these transitions on a systemic level, this thesis is more concerned with smaller steps towards achieving a new type of transport ensemble. Rather than contributing to a specific conceptual tradition, I will engage with the idea of sociotechnical change more broadly, attempting to understand obduracy and change of renewable fuel ensembles. To better comprehend various actors' and actor groups' contestations around ensembles of biogas and electric vehicles, it is helpful to consider the ongoing processes of sociotechnical change at work in the transition to a fossil fuel free future. This dynamic includes both the overarching change inherent in plans to complete a total shift to renewable fuels, but also the change processes in the ensembles of biogas and electric vehicles as these develop their roles within the new transport future. The thesis also utilizes the concept of obduracy, which describes the characteristic of some ensembles to become static or resistant to change. This dynamic is important for the ensembles of biogas and electric

vehicles, because in order to become an enduring part of the transport system these must achieve some level of obduracy. Likewise, obduracy is an important concept for understanding the difficulty of displacing the global fossil fuel ensemble which has an abundance of factors supporting its resistance to change.

In order to further study obduracy in sociotechnical ensembles, the thesis utilizes a specific conceptual model of obduracy as introduced by Anique Hommels, who uses the framework to understand change processes in case studies from urban planning projects. Hommels (2008, 10) writes:

but despite the fact that cities are considered dynamic and flexible spaces, numerous examples illustrate that it is very difficult to radically alter a city's design: once in place, urban structures become fixed, obdurate, securely anchored in their own history and in the histories of the surrounding structures.

This theoretical perspective builds on previous work in both Science and Technology Studies and Urban Studies, particularly SCOT. Hommels employs three conceptual models to identify different tools that can be used to explore various aspects of obduracy. These models are used as independent ways of conceptualizing obduracy, and to highlight this point Hommels uses them autonomously to explain three different urban renewable projects, as described below.

Hommels' first model of obduracy focuses on the idea of dominant frames, building on previous work of Bijker on 'technological frames' within the SCOT perspective (Aibar & Bijker 1997; Bijker 1995). Bijker conceptualizes a technological frame as a shared understanding that emerges from interactions around a technology and may consist of "goals, problems, problem-solving strategies, standards, current theories, design methods, testing procedures, tacit knowledge, user practices, and so forth" (Hommels 2008, 23). These technological frames "comprise all elements that influence the interactions within relevant social groups and lead to the attribution of meaning to technical artifacts" (Bijker 1995, 123). Hommels uses the model of dominant frames to study the redesign of an area of Utrecht called Hoog Catharijne, which includes a shopping mall, apartments, offices, and a railway station. In this case, two alternative designs were suggested, one featuring a ground floor thoroughfare to the central train station and one featuring a raised alternative. These two plans emerged as what Hommels refers to as alternative technological frames, which competed with each other to become dominant. While the city was committed to the success of the ground floor plan, the developer was devoted to the raised walkway frame. These two groups competed to have their alternative declared the dominant frame and to move forward with planning of the neighborhood. However as neither group was willing to compromise and accept any other alternative than the frame they supported, neither plan could progress. The existence of these two competing frames led to obduracy in Hoog Catharijne because neither group was willing to consider the alternative plan. This obduracy was only eventually overcome through the involvement of a new actor, an external planner who was not committed to either technological frame (Hommels 2008). This planner suggested a third alternative in the form of a large inclined square that spanned both levels. As this new alternative included aspects of both the ground floor and the raised walkway designs, both the city and the developer were able to agree and the redevelopment of Hoog Catharijne was able to move forward.

Hommels' second model of obduracy emphasizes the relationship between technologies and the greater context that surrounds them. This model of embeddedness considers the way that technologies can be embedded in a multitude of different networked entities, from

infrastructures and material flows, to policies and values. Hommels notes that the model of embeddedness is especially relevant in cities, particularly because of the interlinkages between infrastructures in urban areas (Hommels 2008). The more embedded an artifact is, the more difficult it is to change it (Hommels 2005). Hommels uses this second framework to study the reconstruction of a highway through the city of Maastricht in the Netherlands. Here she found that the obduracy of the highway redesign is a product of both physical embeddedness as well as user practices and planning structures. This embeddedness leads to obduracy because the other elements of the ensemble act as a stabilizing force, making it difficult to change the character of the relevant artefact without also changing the other parts of the ensemble. In the Maastricht case, a variety of solutions were suggested, including a raised overpass, redirecting the highway around the city, and building a tunnel. Hommels notes how this project faced obduracy both as a result of physical embeddedness within the network of highways and surrounding buildings where it resides, but also embeddedness in an imaginary where the idea of a tunnel became entrenched in the expectations and ideals of the actors, creating resistance to other alternatives (Hommels 2010). As a result, as of 2009, the rebuilding of the highway in Maastricht had still not taken place.

Hommels' third and final model of obduracy emphasizes the importance of earlier choices through the concept of persistent traditions. This model builds on LTS work, particularly the idea of technological momentum, which can be described by the dynamic where "the systematic interaction of men, ideas, and institutions, both technical and nontechnical, led to the development of a supersystem—a sociotechnical one—with mass, movement and direction. An apt metaphor for this movement is 'momentum'" (Hughes 1987, 140). This is another way of explaining that the way an ensemble is built-up can make it harder to change in the future, making it more obdurate. As Hughes' notion explains, the developments of systems or ensembles can set them on a trajectory that is hard to influence.

Hommels' concept of persistent traditions is also inspired by path dependency, which refers to the fact that previous events determine the long-term path of technological development (Mackenzie & Wajcman 1999). Unlike path dependency, however, obduracy as a result of persistent traditions is closely linked to the way that actors understand the role of the artifact or ensemble. Hommels uses the model of persistent traditions to explain obduracy within the Bijlmermeer neighborhood in Amsterdam. This neighborhood was built in the 1960s, inspired by the modernist movement which sought to build utopian housing neighborhoods for middle-class families (Hommels 2008). The development of the neighborhood was, however, unsuccessful, both because modernist principles were not fully upheld and because the neighborhood quickly developed an unsavory reputation as a home to unemployment and crime. However, in subsequent attempts obduracy, in Hommels' understanding, emerged from the way that actors involved in the process, mainly policy makers and architects, continued to mobilize the modernist tradition.

Although each of the three models of obduracy explain a different way that artifacts or ensembles become resistant to change, each of these is (at least partially) the result of the way that actors' visions build meaning surrounding these technologies. Obduracy as a result of dominant frames results when competing social groups become so entrenched in contrasting visions of a technology that they are unwilling to consider alternative options. Obduracy is a result of a technology's embeddedness in complex ensembles that are difficult to change. These ensembles include expectations surrounding the technology that influence further planning decisions. Finally, persistent traditions are linked to imaginaries and visions through the way

that socially constructed notions of value may create an unwillingness to stray from original principles and paths. The interaction between visions of the future and obduracy and change are central to this thesis because of the way that visions and expectations surrounding biogas and electricity can contribute to obduracy. These dynamics are further explored in the following section.

In this thesis, I operationalize Hommels' three models of obduracy - dominant frames, embeddedness, and persistent traditions - in an analysis of biogas and electricity in urban public transport in the cities of Linköping and Malmö, where Hommels' models provide a basis for understanding the propensity of these two incumbent biogas ensembles to change.

3.3 IMAGINARIES OF THE DESIRABLE FUTURE

The concept of sociotechnical imaginaries developed from previous social science work, which used the notion of imaginaries to describe visions that were the product of a collective. This is one part of a long tradition that used the term imaginary to describe social aspects of collective imagination (McNeil et al. 2017). For example, in his book *Imagined Communities*, Benedict Anderson proposes that nations could be defined as imagined political communities explaining, "it is *imagined* because the members of even the smallest nation will never know most of their fellow/members, meet them, or even hear of them, yet in the minds of each lives the image of their communion" (Anderson 1983, 6). The impact of this conclusion is twofold. First Anderson challenges the notion that nations are discrete political domains, instead suggesting that they are the product of collective understanding. Second, he implies that this viewpoint is shared by all the members of a nation, emphasizing the scope and power of collectively held imaginaries.

Appadurai also engages with this idea, suggesting that the collective imagination is impacted by technology. He suggests, "there has been a shift in recent decades, building on technological changes over the past century or so, in which the imagination has become a collective, social fact" (Appadurai 1996, 5). In his work, Appadurai reflects about how modernity has changed in the preceding decades, so that new electronic media has changed the way we perceive culture and the types of futures we imagine. Here, Appadurai goes beyond the national, implying that our collective imaginary crosses borders, allowing that;

Turkish guest workers in Germany watch Turkish films in their German flats, as Koreans in Philadelphia watch the 1988 Olympics in Seoul through satellite feeds from Korea, and as Pakistani cabdrivers in Chicago listen to cassettes of sermons recorded in mosques in Pakistan or Iran (Ibid., 4).

Appadurai's assessment seems almost prophetic, because in the years since writing, the phenomena he describes in response to radio and television has increased through the internet revolution. This development only makes Appadurai's point more apt, as in the 21st century we live in an even more global society which has dramatic implications for our social imaginary.

Finally, Taylor also considers the role of modernity in social imaginaries, suggesting "the social imaginary is not a set of ideas: rather it is what enables through making sense of, the practices of society" (Taylor 2002, 91). This conclusion about the embeddedness of imaginary in practice underscores how imaginaries are inherently interconnected with social practices and sense making processes, as well as how these practices are collective and facilitated by our common understanding. Taylor suggests that a successful social imaginary goes a step further,

"the ideal social order is one in which our purposes mesh, and each in furthering oneself helps the others" (Ibid., 96). Here, Taylor indicates that imaginaries also link together communities in their quest for collective wellbeing.

The work of Jasanoff and Kim specifically on sociotechnical imaginaries builds on this earlier work to emphasize how social imaginaries are collectively held, often national in scope, linked to technologies, and practiced through the sense making processes of society. Sociotechnical imaginaries are defined as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology" (Jasanoff 2015a, 4). The concept of sociotechnical imaginaries can be situated within a myriad of theoretical perspectives that study the way that futures are enacted.

I will argue that the concept of sociotechnical imaginaries is a fruitful tool for describing and analyzing the visions surrounding future use of biogas and electricity in Swedish transport. I chose this concept because of the way it addresses the "abstract yet durable" aspects of human understandings of the future with specific emphasis on the way that visions of technologies influence these understandings (Jasanoff 2015a, 24). In line with the imaginaries literature that it builds upon, this perspective addresses the idea that the visions we have for the future are collectively held with other members of our society. The way we understand a sociotechnical ensemble is influenced by our social practices. Thus, the information we take in and our experiences influence the ways that we view this ensemble, as do the interactions we share with other actors. Through this process we develop collectively held visions or sociotechnical imaginaries that in turn impact our daily practices and how we work to affect a certain future.

Jasanoff & Kim, however, have also developed this theoretical perspective to address a specific type of imaginary they observed when comparing "long-lasting cross-national variations in S&T (science & technology, my note) policy" through the comparison of imaginaries of nuclear power in the US and South Korea (Jasanoff & Kim 2009, 120). In the US the legacy of Hiroshima and Nagasaki led to a culture of containment surrounding nuclear power because of widespread awareness of the risk that nuclear technology poses to humanity. In South Korea, in contrast, nuclear power was viewed as a "symbol of the power of science and technology" (Ibid., 131). For this reason, atomic energy was emphasized as a necessary technology of Korean self-sufficiency and development. Building on this first example, the nature of sociotechnical imaginaries has been widely developed in subsequent literature (Korsnes 2016; Tidwell & Tidwell 2018; Tozer & Klenk 2018; Schelhas et al. 2018), including through further work of Jasanoff & Kim.

In this thesis, I examine sociotechnical imaginaries of biogas and electric vehicles, analyzing how these are present both in municipal case studies and at the national level. However, I also utilize other terminology to add to the discussion of ideas about the future. As this section describes, the term sociotechnical imaginaries is conceptually laden referring to specific types of collectively held visions of the desirable future. To further this discussion, I also use two additional terms to describe ideas of the future: *visions* and *expectations*. While "visions" have been used somewhat ambiguously in previous literature, "expectations" is often used more specifically, particularly to describe collective expectations surrounding technologies (Budde & Konrad 2019). For the purpose of this dissertation, I will use the term "vision" most broadly to generally categorize all conceptualizations of the future. Additionally, I will define "expectation" as "an idea, explicit or implicit, about whether a development or

state is considered likely" (Ibid., 1099). Both visions and expectations can be part of sociotechnical imaginaries of the future. For example, the expectation that one technology will become predominant can be part of an imaginary that projects a better future as a result of that technology. The boundary between these visions and expectations and imaginaries is hard to define, however, I have tried to use these additional terms to add to the discussion of the future.

3.3.1 SOCIOTECHNICAL IMAGINARIES - FOUR DIMENSIONS

Sociotechnical imaginaries has been widely used as a theoretical concept to study visions of transport and energy ensembles (Tozer & Klenk 2018; Kuchler & Bridge 2018; Schelhas et al. 2018; Ryghaug & Toftaker 2016; Sengers 2017). Sociotechnical imaginaries is particularly useful for studying ensembles of fuel provision, because of the way that the concept attends to the complex entanglements between visions of the future and socio-material aspects of the ensembles themselves. In the following I outline four dimensions of imaginaries as a means of focusing on characteristics that are most relevant for my study of ensembles of biogas and electric vehicles, namely: processes of enrollment, co-production in policy, materiality and normativity of imaginaries. This thesis draws on these four dimensions to help examine imaginaries of renewable fuel ensembles.

Processes of enrollment - Sociotechnical imaginaries gain power from their ability to enroll others and embed themselves in public consciousness. This aspect of imaginaries seems particularly important when multiple technologies are under consideration, because the dominance of one imaginary over another could have a substantial impact on the role of biogas or electricity in the future transport system. In a study of offshore wind imaginaries in China, Korsnes (2016, 51) explains the power of imaginaries by suggesting that they are performative in two ways: "they enrol and convince new actors, and they gradually transform the idea of what a technology could mean for the future and nest it with more purposes than were inherent to the initial idea." One of the central points of this perspective emphasizes how the spread of imaginaries to additional actors helps to build the imaginary and, with it, support for a specific idea. As more actors come to support sociotechnical imaginaries of renewable fuel vehicles, the more likely that these imaginaries will come to pass. One aspect of this dynamic, however, has to do with who is empowered with the ability to form these imaginaries. While Ballo (2015) emphasizes the role of experts in imaginary setting, even noting their ability to frame understandings of consumers within the smart grid imaginary, Smith and Tidwell (2016) suggest that local actors can have their own types of imaginaries surrounding coal and uranium. One overarching perspective notes the role of policy in this process, for example Burri (2015, 250) writes, "during processes of technology assessment and governance, sociotechnical imaginaries are enacted and (re)constructed at the same time, thus shaping the forms of political action." This point on the role of imaginaries in policy leads to the following theme.

Co-production in policy - The imaginaries literature frequently emphasizes the role of policy agents in setting imaginaries. As Jasanoff (2015b, 333) writes, "though individuals matter (as also in classic accounts of actor-network theory), unsurprisingly it is institutions of governance that operate as some of the most effective agents of extension." Jasanoff points out that sometimes governments are the most effective agents of imaginary setting because of the way that policy documents set collective goals for the desirable future. Elsewhere, Jasanoff specifically notes the role of "policy discourses and processes of issue framing and agenda setting" as adding power to imaginaries (Ibid., 25). These tools help to add legitimacy to

imaginaries and draw support from other types of actors. Eaton et al. (2014, 232) describe this dynamic, elaborating that "sociotechnical imaginaries are most certainly 'real,' as opposed to being 'imaginary,' in the sense that state actors have made concrete policy moves to enact their collective visions." Here, Eaton et al. imply that these policy actions work to make the imaginary "real", thereby adding legitimacy to their aims. This aspect is important for sociotechnical imaginaries of biogas and electricity because of the way these are influenced by renewable energy targets and policy measures.

Materiality and embeddedness - Sociotechnical imaginaries differ from other social imaginaries in the way they are inextricably linked with material aspects of the technologies they support. This characteristic is also important for this thesis' understanding of imaginaries of renewable fuel vehicles, because these are also embedded in the complex ensembles of these technologies. This is once again emphasized by Eaton et al. (2014, 229) who write that:

there are no purely material or ideational things. Instead, the material world is constituted symbolically, so the world is always both material and symbolic (Busch, 1996). In short, alternative imaginaries are woven around material resources and ideational definitions in ways that challenge extant framings of both the past and the future.

This perspective challenges the notion that imaginaries exist only in the minds of actors by emphasizing the way that these ideas shape the material world and vice versa. Jasanoff (2015a, 22) makes a similar point suggesting that imaginaries can engage with:

the ways in which people's hopes and desires for the future (...) get bound up with the hard stuff of past achievements, whether the material infrastructures of roads, power plants, and the security state or the normative infrastructures of constitutional principles, juridical practices, and public reason.

Jasanoff thus gives a vivid explanation of the way that imaginaries are influenced by the material results of previous planning decisions. However, this interaction goes both ways: the material aspects of these ensembles are equally likely to be influenced by the imaginary. As Yang, Szerszynski, and Wynne (2018, 281) put it, sociotechnical imaginaries are "coproduced, emerging from policy discourses, state administration, and established institutions and are backed up by technical routines and material infrastructures." This conception underscores how this is an iterative process, where imaginaries are built around the material world and as a result influence it.

Normativity in imaginaries - One central tenant of work on sociotechnical imaginaries is their role in defining a desirable future, connecting specific technologies to what "should" come to pass. This point is central to the use of imaginaries to study sustainability transition, where there are sometimes significant expectations on alternative technologies to reduce the demand for fossil fuels. Jasanoff and Kim (2009, 123) suggest that "imaginaries are instrumental and futuristic: they project visions of what is good, desirable, and worth attaining for a political community; they articulate feasible futures." Imaginaries are widely used to connect visions of the future to these types of valuations, connecting expectations around technologies with wider understandings of what type of future society is desirable. This connection is central to the imaginaries of biogas and electric vehicles studied in this thesis, because these imaginaries are widely linked to ideas of how the future transport sector should look.

Taken together, these dimensions of sociotechnical imaginaries are beneficial for the study of ensembles of biogas and electric vehicles. Enrollment of actors in imaginaries and embedding in policy are essential for how fuel imaginaries are stabilized. As described in section 3.1, both biogas and electricity are part of complex ensembles that embed them within material infrastructures that impact upon imaginary development. Finally, as there are numerous alternative fuels under consideration within the fossil fuel free future, normativity plays a central role in sociotechnical imaginaries of biogas and electricity. Here, the aspect of imaginaries that influences what role actors think these technologies should play is of particular importance in how they will be included in the renewable fuel future.

3.3.2 UNDEREXPLORED THEMES

While this thesis draws heavily on the previous literature on sociotechnical imaginaries of transport and energy ensembles, my ambition is also to contribute to three underexplored areas of the literature. While analyzing the imaginaries of biogas and electric vehicles in Sweden, I identified three areas for expansion related to: scalarity of imaginaries, the contested nature of imaginaries, and the relationship between imaginaries and obduracy. Unlike previous imaginaries literature, this study focuses on imaginaries surrounding two different technologies, biogas and electric vehicles, and considers the interactions between these. This approach has allowed me to build on the imaginaries' literature in these three areas. In the following paragraphs I briefly explain these areas and why they are of interest. My analysis and conclusions surrounding these will be expanded upon in section 7.2.

Scalarity of imaginaries - Within the previous literature on sociotechnical imaginaries, the majority of studies have emphasized the role of hegemonic national sociotechnical imaginaries. This literature builds on the seminal work by Jasanoff & Kim (2009) and includes numerous other studies on national energy imaginaries (Yang et al. 2018; Ballo 2015; Kuchler & Bridge 2018; Simmet 2018). Taking a national approach to the study of imaginaries works in many cases because energy imaginaries are often nationally held, particularly as a result of the connection between imaginaries and policy-making discussed above. National imaginaries are also important for this thesis, where national sociotechnical imaginaries are present, especially surrounding electric vehicles. However, in this case imaginaries of other scales also emerge. Local imaginaries, for example, are sometimes determined to differ from place to place within Sweden, as evidenced by the case studies that explore local perceptions of biogas and electric buses. Furthermore, in an increasingly globalized world it is clear that sometimes national and local imaginaries are influenced by international imaginaries.

In the last several years, issues related to the scalar boundedness of imaginaries have been increasingly discussed within the literature (Eaton et al. 2014; Miller 2015). For example, Smith and Tidwell (2016) examine energy communities in the mid-western United States, concluding that local visions that define a desirable future based on job accessibility acted as a sort of 'bounded imaginary' that differs from the national level imaginary which emphasizes sustainability of the energy carrier. Meanwhile Kuchler (2014) shows how international imaginaries can emerge from the deliberations of international organizations on second generation biofuels. These studies, however, make up only a small portion of the literature on imaginaries, which generally focuses on national sociotechnical imaginaries.

Contested nature of imaginaries - Another relevant aspect for the empirical material is the co-existence and contested nature of versions of the desirable future. When a large-scale transformation is underway, as in the transition to a fossil fuel independent vehicle fleet, there are often different opinions about the best alternatives for achieving this transformation. This dynamic is evident in the empirical material where imaginaries of both biogas and electricity are under consideration. While some actors subscribe to an imaginary of electric vehicles where rapid electrification will help achieve the desired fossil fuel independent future, others place biogas in a more prominent role. In this case it is clear that more than one imaginary co-exists, depicting different pathways towards the fossil fuel free future.

Additionally, incoherence can also exist within sociotechnical imaginaries, where different visions are linked to the same technology. In a study of Nordic transport experts, Sovacool et al. (2019) find the coexistence of eight different visions surrounding electric vehicles. Meanwhile, in a study of Finnish politicians Karhunmaa (2018) finds that while actors agree on an imaginary of achieving carbon neutrality they do not agree on how this outcome should be reached. This type of study introduces the possibility that imaginaries are fragmented and heterogeneous rather than hegemonic and universally shared. Although one of the core tenets of sociotechnical imaginaries is the expectation that they are collectively held visions of the desirable future, there is some debate about how uniform these visions must be to count. This thesis contributes to the imaginaries literature by engaging with this discussion with a focus on interconnected imaginaries of biogas and electricity in transport.

Imaginaries and sociotechnical change - Although sociotechnical imaginaries have been widely used to explain the emergence of alternative energy futures, the explicit connection between imaginaries and obduracy has not been explored. Sociotechnical imaginaries are inherent parts of sociotechnical ensembles and can contribute to their obduracy, but alternative imaginaries can also challenge the obduracy of existing ensembles. While Hommels does not directly discuss imaginaries in her framework, she does emphasize the role of collectively held social values as contributing to obduracy. Likewise, the imaginaries literature references stabilizing dynamics although the explicit connection to obduracy is not made. Karhunmaa (2018, 2), for example, writes about the degree of stability within sociotechnical imaginaries suggesting that this "both enables and restricts the scope for individual and collective action." Relating to my previous point, these actions typically support the fulfilment of the imaginary. One example of this dynamic in action comes from Ponte and Birch (2014, 271) who suggest that:

what brings the contributions together is their focus on how these imaginaries represent biofuels as appropriate, attractive, and sustainable technologies within specific, geographically situated governance practices that, therefore, are meant to deliver on such imaginaries and maintain them accordingly.

This thesis seeks to build on the exploration of these dynamics, particularly by examining case studies of imaginaries surrounding biogas and electricity as future vehicle fuels for urban buses in Sweden. Here, the imaginaries of both existing biogas and emergent electric vehicle ensembles are examined, emphasizing the way that these imaginaries are an inherent part of the dynamics of obduracy and change.

3.4 CONCLUDING REFLECTIONS

This chapter has introduced three theoretical concepts that provide the analytical framework of this thesis: ensembles, change and obduracy, and sociotechnical imaginaries. Each of these three perspectives helps contribute to a better understanding of the dynamics that are the focus of the thesis. By considering the *sociotechnical ensembles* of biogas and electric vehicles, I am able to emphasize the complex entanglements surrounding these alternative fuel vehicles. Biogas and electric vehicle ensembles are multifarious configurations that encompass a multitude of socio-material components and impact their implementation. Concepts of *obduracy and change* help lend understanding of factors that contribute to stabilization or destabilization of transport ensembles. Finally, *sociotechnical imaginaries* emphasizes the visions of relevant actors and actor groups with regard to biogas and electric vehicles and their role in Sweden's fossil fuel free future. Together, these three perspectives provide a framework of analysis for the understanding of visions of biogas and electric vehicles both within selected municipalities and in the national Swedish context.

CHAPTER 4. METHODS & MATERIALS

The imaginaries literature lacks a unified methodological approach for how to identify sociotechnical imaginaries. In their original work, Jasanoff and Kim note that "the methods best suited to studying sociotechnical imaginaries therefore are the methods of interpretive research and analysis that probe the nature of structure-agency relationships through inquiries into meaning making" (Jasanoff 2015a, 25). While this point provides a broad suggestion of how imaginaries should be studied, it leaves the actual methods of inquiry open to interpretation. Early work on imaginaries focused on the use of historical studies, following the recommendation that "historical research in our view is essential to the exploration of imaginaries: it is only by following ideas through time that one gains a feel for what is fixed and what is changeable in social self-understandings as well as the reasons why" (Ibid., 28). This type of methodology is used in a number of studies where historical analysis is used to examine imaginaries that originate from vanguard visions of individual actors (Bowman 2015; Moon 2015; Storey 2015; Barker 2015). These historical studies typically utilize textual analysis to follow the development of imaginaries over time.

In contrast, I have chosen to follow the development of present-day sociotechnical imaginaries, a decision which has its own methodological challenges since the imaginaries have not yet stabilized. I will base much of my analysis on interviews, following the guidance of other researchers who have interviewed different actor groups to understand modern sociotechnical imaginaries. Ballo (2015), for example, has used interviews of smart grid experts to explore how they understand the smart grid imaginary, while Delina (2018) and Trencher and van der Heijden (2019) have chosen to interview a variety of different actors in their studies. In each of these cases, interviews are used as a complement to textual or policy analysis. Elsewhere, researchers such as Sengers (2017) and Smith and Tidwell (2016) draw their understandings of imaginaries from ethnographic studies of local energy imaginaries. I have built on this work while also determining my own method of identifying imaginaries.

In this thesis, I studied imaginaries about biogas and electricity in Sweden primarily based on interviews with relevant actors and document studies. By focusing on the way that the actors interpret the role of biogas and electric vehicles in the future transport system, and specifically the benefits they attributed to these technologies, I was able to understand both individual and collective perspectives on broader imaginaries. The interviewed actors were chosen on the basis of their affiliation with specific relevant actor groups for public transport and policy. Documents were also important in this respect because many of the documents studied represented the position of a specific organization or group. In this way, the visions presented in many of the documents were collectively held. By engaging with visions from both text-based sources and interviews I thus employ the two primary methods recommended by scholars in previous imaginaries literature. This approach has the benefit of triangulation, providing multiple points of entry for studying imaginaries and incorporating positions from a multitude of actors.

4.1 PROJECT TIMELINE

Inspiration was taken from initial desk research, where it became evident that urban buses had been central to the introduction of biogas ensembles in many Swedish municipalities. One of

the emerging questions in this field was concern about potential conflicts between biogas and electric vehicles. As transition researchers often focus on the competition between renewable fuels and fossil fuels, I became interested in better understanding the dynamics of competition and complementarity between renewable fuel alternatives. In 2016 I was invited to participate in a project at Linköping University that focused on the technical aspects of the interactions between biogas and electricity, asking the question "What is an environmental bus, actually?" This provided an initial point of contact for my Linköping case.

I started collecting material for the Linköping case in 2017, and through these interviews Malmö was suggested as a contrasting case. I concluded the Linköping interviews in Fall 2017 and the Malmö interviews in March 2018. This material is described in Section 4.2 and forms the basis for papers 1 and 2. From this material, it became evident that many of the interviewed actors in the local cases frequently referred to visions and expectations on the national level, indicating the presence of national imaginaries. In Fall 2018 I began to examine relevant documents on the Swedish national level. In early 2019 I visited the government archives to examine the responses to the national FFF-investigation. I also performed interviews with five actors on the national level from April to September 2018. This material was analyzed and used for Papers 3 and 4.

4.2 MUNICIPAL CASE STUDIES

The first phase of material collection focused on the competition (and complementarity) that emerged between biogas and electric vehicles in urban public transport. In order to better understand the interactions between these two fuel ensembles on a local level, I utilized a case study approach. Case studies are often suggested as preferable methods to answer "how" and "why" research questions to gain a more complex level of understanding as intended here (Yin 2007). Although knowledge generated by case studies is sometimes criticized as not generalizable (Flyvbjerg 2001), the lessons that can be learned from studying the interaction between biogas and electric vehicles in these local contexts may illuminate some of the issues of relevance for other contexts.

This thesis uses a comparative case methodology, using the two examples of Malmö and Linköping to provide counterpoints to each other. This approach was considered relevant, because comparison is one of the recommended methods in sociotechnical imaginaries literature (Jasanoff 2015a). In this case, the point of comparison focuses on imaginaries regarding the role of electric vehicles in the municipalities studied. While in Linköping electric buses were only newly introduced for consideration when I collected material, in Malmö electrification of two bus lines was already underway. This was considered relevant because in Linköping, electric buses posed only a theoretical threat to the existing biogas-based bus system, while in Malmö they had already started to replace biogas on some routes.

As for the choice of cases for comparison, Linköping was chosen because it has a long history of biogas and is home to the largest biogas producer in Sweden. The development of biogas in Linköping has been widely studied elsewhere in social science literature (Falldé 2011; Falldé & Eklund 2015; Olsson & Falldé 2015; Palm & Falldé 2016). This study builds on and extends this previous work by studying the role of imaginaries in this case. Linköping was chosen because it can be considered an exemplary case due to the way that the biogas ensemble evolved through the collaboration of the local municipality, energy and waste management company, and the public transport authority. Malmö was chosen as a contrasting case partially because it is situated in the region of Skåne which also has a strong biogas history. Malmö was

suggested as an interesting case within this region largely because of ongoing plans to replace biogas with electrification of existing bus lines. Thus, Malmö provided an interesting contrast to the Linköping case because the obduracy of a biogas-based bus system had been (partially) overcome. It is worth noting, however, that these two cities are not comparable in all ways. The local contexts of these biogas systems are quite different, as is discussed in article II. Additionally, Malmö is a much larger city than Linköping, which has implications for its planning process. The diversity of these cases, however, can be considered as an advantage that add to the richness of the case work by providing examples of how imaginaries about renewable fuels unfolds in different ways in these two places.

Public buses have become a venue of contention within the renewable transport transformation because they are both prioritized as a sector for “easy” electrification and already tout a much higher percentage of biofuels than the general transport system. Biogas, specifically, has become prominent in public transportation in Sweden, with 20.3% of bus kilometers driven by biogas in 2017, and is especially common in urban bus systems where shorter routes and limited ranges allow for predictable refueling (Svensk Kollektivtrafik 2018). This creates a space for conflict as many of the Swedish municipalities that have traditionally utilized biogas are starting to test electric buses in urban areas. To further explore this dynamic, this thesis investigates two case studies of urban bus systems where visions of an electrified future have emerged in municipalities with a biogas-bus history. The following sections will elaborate on the role of biogas and electricity in Linköping and Malmö’s public transport system.

The case studies focused on the local or municipal level of public transport governance. This choice was a way of focusing the cases on the urban areas where biogas and electric vehicles interact most. By focusing on municipalities, the case studies delimit this range to only one type of public transportation, namely inner-city bus routes (in contrast to the regional level where public transport consists of numerous transport modes such as buses, trains and trams, service transport, and in some cases ferries). Both of the municipalities chosen used biogas in their inner-city buses at the time of material collection, even though urban buses are the area where potential electrification is most emphasized.

4.2.1 LINKÖPING

Linköping is a middle-sized municipality located in south-central Sweden, roughly 200km south of Stockholm. It is the capital of Östergötland region and is home to a major university and several large industries, including aerospace and defense company Saab and branches of several telecom companies. Linköping was an early developer of biogas due to the role of a strong local coalition that included a powerful municipally owned energy and waste management company, Tekniska verken, which is also a large employer in the area (Palm & Falde 2016). Interest in alternative fuel vehicles (including electricity in the form of trolley buses) came about in the 1970s, driven by air pollution in the city center (Falde 2011). Ultimately, however, biogas was identified in the 1990s as a combined solution to air pollution and municipal waste. Tekniska verken, with support of the municipality, took the lead by researching and developing a biogas production process and building facilities to anaerobically treat municipal organic waste. At the time, the municipality also owned a public transport company LiTA (a predecessor to today’s Östgötatrafiken), whose buses were driven by diesel fuel. The municipality implemented biogas as a joint solution to both problems, waste management and air pollution, by replacing the diesel burning buses in the city center with

biogas-driven buses, thereby mitigating the problem of harmful emissions on city streets (Fallde & Eklund 2015). Additionally, installing biogas in buses also solved the potential economic problem of establishing a reliable market for the biogas generated: municipal buses became a stable market for municipally-generated biogas. Eventually, this fuel was also generated from organic waste, which also contributed to renewable waste management in the municipality.

The first biogas buses were introduced in Linköping in the 1990s, with the city bus system shifting entirely to biogas in 2016. Biogas is currently used throughout Östergötland region, including as the primary fuel in other regional cities such as Norrköping and Motala. Over the years, the biogas ensemble has expanded to enroll numerous other actors, including the regional government. A change in the law in 2012 established Swedish regions as the entity responsible for public transport provision. This decision empowers Östergötland region with public transport decision making, including the oversight of Östgötatrafiken. Local farmers have also become involved in the system as users for the by-product digestate, creating close ties with the agricultural sector. Linköping University has played a central role as a knowledge-building center for biogas development, especially since the 2012 establishment of the Biogas Research Center, a biogas competence center that is funded by the Swedish Energy Agency.

Despite Linköping's biogas history, electric vehicles have recently emerged as a competing technology in discussions of future public transport, resulting in increasing debate around the future of the municipality's biogas-based bus system. When I collected the material for this case in 2017, the regional council had already decided to introduce electric bus trials in Östergötland, although there was uncertainty around exactly where this would be (Interview L10). In January 2019, however, the regional transport provider Östgötatrafiken released the result of their most recent tendering process to cover urban bus service in Linköping and nearby municipality Norrköping for 2020-2030, announcing that electric buses will be introduced into service in both of these municipalities. This is clearly an important development, but as it occurred after my material collection it is not included in the material for this thesis.

4.2.2 MALMÖ

Malmö is the third largest city in Sweden, located at the very southern tip of the country across the Öresund straight from Copenhagen. Malmö was one of the earliest Scandinavian towns to industrialize and is home to a number of IT and biotech companies. It can be seen as a transport gateway connecting Sweden to the European continent. Malmö was one of the first municipalities in Sweden to introduce gas-driven buses, which took place in 1988 (Ericsson et al. 2013). These buses, however, were run by natural gas due to the introduction of the national gas network in Malmö in the 1980s. In the early 2000s, biogas development began in Skåne region and as of 2011 it had become one of the largest producing regions in Sweden, contributing 21% of the national biogas stock. This system produces biogas from a combination of municipal waste treatment, co-digestion of organic food and industry waste, and landfill collection (Björnsson et al. 2011). As compared with Östergötland where much of the biogas is produced by one company, production in Skåne is distributed among smaller scale facilities. Additionally, compared to the rest of Sweden, a relatively large percent of biogas is used for heating through a district heating network (Ericsson et al. 2013). Despite this fact, the regional public transport company Skånetrafiken is the largest consumer of biogas in Sweden (Skånetrafiken 2016). All city buses in the region (including Malmö) have been fueled by

renewable fuels since 2015, and 54.6% of total regional bus traffic was driven by biogas in 2017 (Svensk Kollektivtrafik 2018). Malmö's city buses are fueled by biogas that originates from as many as 15 different biogas providers in Sweden and Denmark (Interview M2, energy company employee).

Despite its strong biogas history, Malmö has identified “clean” electricity as their preferred fuel of choice for city bus traffic (Skånetrafiken 2017). While electricity has already played some role in the public transportation system in Malmö through the city tram system, starting in 2014 Malmö began to experiment with electric buses. The first line to be partially electrified was trafficked by gas-electric hybrid buses as part of a bus rapid transit (BRT) trial. Malmö city often describes this concept with the slogan “think train, drive bus” to explain the ways this line differs from standard bus lines, including longer buses, the ability to get on or off through all doors, and the prioritization of the buses in specific lanes and platforms (Malmö Stad 2017). Planning for the first two full electric lines was well underway when material for this thesis was collected. As of December 2018, the first Volvo buses were put into circulation, operated by bus company Nobina. According to interviews carried out in Malmö, these lines are expected to be followed immediately with the electrification of additional bus lines (Interview M4, municipal civil servant).

4.2.3 CASE STUDY INTERVIEWS

Interviews are a well-established method for collecting case study material (Yin 2007). With regard to urban public transport in Linköping and Malmö, interviews also provided understanding of the case by contributing to the knowledge base on the transport systems in these two municipalities. Case study interviews were carried out with multiple actors in each case in order to gain an understanding of how these actors view biogas and electricity as part of the future of their municipal public transport system. By finding similarities between the perspectives and conclusions used by multiple actors I was able to find commonly held imaginaries in both of these cases.

To explore the two case studies described above, I carried out a series of semi-structured interviews with actors from key social groups involved in transportation. Semi-structured interviews were viewed as well suited for this project because they allow enough structure to ensure the same themes are addressed by each interviewee while providing enough flexibility to allow follow up questions where the interview subjects follow a different but interesting path.

These interviews followed an interview guide based on the following themes:

- Views about electric vehicles as an emerging trend;
- Views about competition and complementarity between biogas and electricity;
- Imaginaries and expectations of the future public transport system; and
- Views of how changes in the local system (Linköping/Malmö) compares with developments in other parts of Sweden.

Interview participants in these two cities were chosen based on their relevance for urban public transport, specifically with regard to issues related to biogas and electricity as fuels. In each case I started with a group of actors that were considered central to public transport

decision making, after which I worked with a snowballing process, asking in each interview for additional suggestions of relevant interview subjects. While some of these actors had formal roles in the planning or provision of urban public transport buses, others were chosen because they were knowledgeable about the municipality's public transport system. In the Linköping case, I first interviewed participants from the environmental bus project mentioned earlier. I started with exploratory interviews with biogas researchers and eventually used my contacts to interview representatives from the municipal and regional government, the public transport provider Östgötatrafiken, the municipal energy company Tekniska verken, and the bus operator Transdev. In the Malmö case I began with the intention of interviewing the same actor groups as in the Linköping case. Here I also interviewed representatives from the municipal government, the public transport provider Skånetrafiken, the energy company Tekniska verken and the bus operator Nobina.

As table 2 shows, however, I did not interview the same number of actors in both cases. Although I used a snowballing approach to find additional interview subjects in both cases, this strategy did not have the same result in Malmö as in Linköping. While in Linköping it was extremely successful, leading to many suggestions and contacts for additional interviews (resulting in 14 interviews), in Malmö this resulted in fewer suggestions about additional relevant actors (resulting in only 7 interviews). In hindsight, this disparity was due to a number of factors. As the analysis shows, the biogas system in Linköping is heavily embedded in other municipal practices. The system is largely based on local substrates and the biogas provider, Tekniska verken, is owned by the municipality. As a result of this embedding, the suggestion of introducing electric buses was also a bit controversial, with many actors concerned about what this would mean for the biogas system. This resulted in the suggestion of many additional actors, including additional actors from Tekniska verken and the municipality (including two politicians that sat on the board of either Östgötatrafiken or Tekniska verken), a regional civil servant with a specialty in biogas, as well as a regional politician and a representative who could speak on agricultural interests in relation to biogas.

In Malmö, while snowballing was also fruitful, it became clear that actors did not perceive the decision to switch to electric buses as very controversial. Another notable difference was that some groups which had been relevant in the Linköping case were not similarly relevant in the Malmö case. Specifically, in Malmö I did not interview any researchers, regional civil servants, or representatives for agricultural interests due to differences in the ensemble surrounding the biogas system. In Malmö, the biogas used in city buses is supplied by an international energy company, E.ON, which sources this fuel from some 15 different producers. This means that there are no direct linkages to the local agricultural system. Similarly, there was no research group working on related topics as with the Biogas Research Center in Linköping, which is active in the discussion there. Finally, the relationship between Skåne region and the public transport provider (PTA) is also different. Despite the smaller number of interviews, actors in Malmö were open to interviews and provided valuable input.

Table 2. Case Study Interviews

Interview Code	Date	Position	Category
Linköping Interviews			
L1	15 February 2017	Linköping University Professor	University Researcher
L2	22 February 2017	Linköping University Post Doctoral Researcher	University Researcher
L3	15 March 2017	Civil Servant for Region Östergötland	Region Civil Servant
L4	17 March 2017	Civil Servant for Linköping Municipality	Municipal Civil Servant
L5	30 March 2017	Employee Östgötatrafiken	PTA
L6	31 March 2017	Linköping Municipal Politician/ Board Member of Östgötatrafiken	Municipal politician
L7	7 April 2017	Tekniska werken Employee	Energy Company
L8	19 April 2017	Tekniska werken Employee	Energy Company
L9	26 April 2017	Linköping Municipal Politician/Head of Tekniska werken board	Municipal Politician
L10	5 May 2017	Region Östergötland Politician	Regional Politician
L11	15 May 2017	Civil Servant for Linköping Municipality	Municipal Civil Servant
L12	27 June 2017	Linköping University Professor	University Researcher
L13	30 August 2017	Transdev Employee	Bus Operator
L14	24 October 2017	Federation of Swedish Farmers Representative	Agricultural Interests
Malmö Interviews			
M1	12 October 2017	Skånetrafiken employee	PTA
M2	14 November 2017	E. On Employee	Energy Company
M3	20 November 2017	Nobina Employee	Bus Operator
M4	1 February 2018	Civil Servant Malmö Municipality	Municipal Civil servant
M5	1 February 2018	Civil Servant Malmö Municipality	Municipal Civil servant
M6	1 March 2018	Politician Region Skåne	Regional Politician
M7	2 March 2018	Politician Malmö Municipality	Municipal Politician

As the table indicates, I have anonymized interview subjects and refer to them in the analysis by their interview codes. The column labeled category is included to help the reader draw parallels between organizational structure in the two cases. All case-study interviews except one (L10) were completed in person, and most (except for L1 to L3 which were in English) were completed in Swedish. I made this choice because the majority of my interview subjects were native Swedish speakers and all of them used Swedish as their primary working language. This decision also could have led to some slight barriers of understanding on my part, however, since I am not a native Swedish speaker. Each interview took between 25 and 90 minutes, and except for interviews M4 and M5 were completed individually. I have fully transcribed each interview and coded the text as described in section 4.5.

4.2.4 CASE STUDY DOCUMENTS

The second main method used in this thesis is document analysis. This method was chosen because of the relevance of documents for laying out statistics, plans, and priorities for the future transport system. Document analysis can add to the strength of case studies by reinforcing the material found in other sources (Yin 2007). In the case studies of Linköping and Malmö, these documents helped to contextualize the choice of public transport fuel within wider policies and priorities for municipal and regional planning. Two important documents in both cases were the regional traffic provision plans (*regional trafikförsörjningsprogram*) and municipal comprehensive plans (*översiktsplan*) for the case locations. The former lays out the statistics and plans for public transportation within the region, while the latter plays a similar role within municipal urban planning. These documents were important because they set clear priorities and objectives for how the municipality and region should develop. Additionally, I also consulted the sustainability plans for the public transport authorities and studies on the feasibility of electrification. The context of these studies, however, were not comparable as the Malmö feasibility study was completed by the public transport authority to facilitate decision making in preparation for electrification of two bus lines, while the Linköping study was completed by a third-party actor as part of a research project.

Table 3. Case Study Documents

Year published	Author	Title
Linköping Documents		
2010	Linköping Municipality	Comprehensive Plan for Linköping City - Traffic Strategy
2016	Linköping Municipality	Traffic Plan for Linköping's Inner City
2016	Region Östergötland	Regional Traffic Provision Program for Östergötland ->2030
2017	Lars Lindgren, Lund University	Electrification of Linköping City Bus Traffic - A Simulation Study
2018	Östgötatrafiken	Sustainability Statement for AB Östgötatrafiken
Malmö Documents		
2015	Malmö Municipality	Action Plan for the Environmental Program - Priority Work in Malmö Municipality from 2015-2018
2016	Region Skåne	Traffic Provision Program for Skåne 2016
2016	Skånetrafiken	Environmental and Sustainability Program for Skånetrafiken - Together Towards a Sustainable Future 2016-2025
2016	Skånetrafiken	Sustainability Statement
2017	Skånetrafiken	End Station Charged Electric Buses in Malmö - Preliminary Study for Lines 3 and 7
2018	Malmö Municipality	Comprehensive Plan for Malmö - Plan Strategy

4.3 NATIONAL IMAGINARIES OF BIOGAS AND ELECTRIC VEHICLES

The exploration of the national imaginaries of biogas and electricity grew out of the municipal case studies, where I became increasingly curious as to how biogas and electricity are understood on the national level. This part of the thesis also engages with the imaginaries literature, where the national level is emphasized, as well as issues related to understanding how national imaginaries influence local imaginaries and vice versa. As the analysis shows, in the two municipal cases the biogas imaginaries differed, which raised questions about whether a national imaginary of biogas existed. Meanwhile, the imaginary of electric vehicles that emerged within these cases was sometimes presented as though it was coming from the national level. Thus, in the latter part of the dissertation work I began to explore the way that biogas and electricity were presented in the Swedish national discourse on the fossil fuel free future.

This stage of the investigation, however, utilized a different approach than the municipal case studies. Here, I started my work by delving into one specific policy document that had emerged during the first years of the thesis work, namely Swedish Government Official Report *Fossil fuel freedom on the road - A report of the investigation on fossil free vehicle traffic*. I was introduced to this policy report through the environmental bus project and it was referenced in several of the subsequent interviews for the case studies. For a detailed explanation on the relevance of this document and how it came about, see section 4.3.1. My intention in choosing this document was to try to understand the origin of the electric vehicle imaginary; however, it became clear that establishing the exact origin of any imaginary is challenging. Nevertheless, the core relevance of this document for renewable transport in Sweden was evident and I focused on this document for the national level imaginary. This analysis was the basis for Paper 4. In addition to the close analysis of the FFF-investigation, the study of the national level imaginaries of biogas and electricity also included interviews and additional textual analysis. Although the FFF-investigation is the center point of the national level imaginaries, in order to achieve triangulation and context I collected additional materials. These analyses of the additional documents and interviews had two aims. First, they provided background on the development of Swedish policies to better understand the emergence of renewable energy policy in the years following the FFF-investigation. Second, they provided additional material for exploring the presence of imaginaries of biogas and electric vehicles at the national level.

One notable difference between the national level and the municipal case studies is that in the national case, more emphasis was placed on document analysis. This emphasis was partially motivated by the imaginaries literature which emphasizes the role of policy making as a sphere for imaginary creation. Many policy documents (including the FFF-investigation) have been published outlining the aims and challenges for achieving a fossil fuel independent vehicle sector. A second reason is that document analysis is an efficient way of considering the perspectives of the many stakeholders that are relevant for the national case. Many Swedish policy documents such as the FFF-investigation are written in cooperation with different actor groups including experts, civil servants and elected officials. Furthermore, by consulting documents published by individual actor groups (such as the FFF responses, but also more formal position papers) the perspectives of these actors come to light.

4.3.1 DOCUMENT ANALYSIS - THE FFF-INVESTIGATION

My analysis of the FFF-investigation started with coding the document itself. As it is over 1,000-pages long, I searched the document for terms related to electric vehicles (such as 'electrification', 'electric vehicles', and 'electricity driven') and biogas (such as 'biogas' and 'vehicle gas'). I coded the resulting sections as described in section 4.5, as well as the sections considered most relevant for the imaginaries, including the introduction, the reference scenarios for 2030 and 2050, the chapters on biofuels and electric vehicles, and the special opinions.

In addition to the investigation itself, I also investigated the actors' responses submitted in the months following its publication. As these are only available electronically for one year following their submission (and the window for responses was in the first half of 2014), I accessed these in paper form in the Parliamentary archives. I visited the archives in February and March 2019 and read each of the over 100 responses, taking notes on the aspects that referred to imaginaries of electricity and biogas. I also acquired digital copies of these where they were available (for example if they were published on the actor's webpage) and I also retained copies of the responses which explicitly discussed some dimension of electric vehicles. In later stages of the research, I returned to my notes and the obtained copies, which I also coded in atlas.ti.

4.3.2 INTERVIEWS

Following the analysis of the FFF-investigation I began to contact actors who could add to my understanding of the imaginaries on the national level. These actors were chosen because of their prominent roles in Swedish transport policy making. On the national level, interviews were a way of triangulating the imaginaries that emerged from the FFF, but also as additional points of information on the policy-making process to facilitate the fossil fuel free future.

I interviewed five different actors at the national level. The first interview subject (S1) was chosen because of the subject's engagement in the FFF-investigation as the designated special investigator (*särskild utredare*). In this position, this actor was given the assignment of overseeing the work of designing, researching and compiling the report. Two subjects (S2 and S4) were chosen as representatives from the Swedish vehicle industry as employees of the two major vehicle producers Scania and Volvo. These actors were recommended during the case study interviews, as the Swedish vehicle industry is relevant for public transport because both Scania and Volvo are major producers of buses that use renewable fuel. These actors also provided insight into the attitudes and expectations of other actors within the vehicle industry as well as within the transport policy sector. The subject S5 was a representative from the main organization for the Swedish industrial gas branch, The Swedish Gas Association, was similarly recommended from the municipal interviews, and was chosen as a perspective that could add context to the national biogas imaginary. Finally, the subject S3 was a university researcher within the biogas area, who was included to provide additional information about both the historical development and current issues in the renewable transport sector. Since these actors were chosen for different reasons and had different expertise, the content of these interviews varied more than in the municipal case studies. This resulted in the creation of a slightly different interview guide for each subject, but all included the following topics:

- What policies do you consider most important for achieving the renewable fuel transition?
- What policies do you think are needed and how does your organization (if relevant) work to influence policy-making?
- How do you imagine the transport sector will look in 2030/2050?

Table 4. National level interviews

Interview Code	Date	Position	Category
S1	14 March 2019	Special Investigator for FFF investigation	Policy Expert
S2	30 April 2019	Scania Employee	Vehicle Industry Representative
S3	20 August 2019	Professor Linköping University	University Researcher
S4	5 September 2019	Volvo Employee	Vehicle Industry Representative
S5	6 September 2019	Swedish Gas Association Employee	Gas Association Representative

Each of the interviews in this group were between 45 and 90 minutes long and carried out in Swedish. All except S4 (which was done via Skype) were completed in person and were recorded. I reviewed each of them, but in these cases only selectively transcribed them, using a mix of transcription and thematic notes.

4.3.3 ADDITIONAL DOCUMENTS

Aside from the FFF-investigation and the interviews with key actors, I also consulted a number of additional documents to help contextualize the imaginaries of biogas and electric vehicles. Many of these acted as background material, providing information on the biogas and electricity ensembles and the national policies. They also grounded the imaginaries by providing additional support for specific visions of the future. Some of these documents were suggested by interview subjects, while others I identified through desk research. Documents 1, 3, and 5 were chosen specifically for the relationship to the FFF-investigation, while documents 4 and 8 provide information on more recent policy agendas. Documents 2, 6, and 7 were published by electric vehicle or biogas interest organizations and provide insight into how these organizations view the imaginaries of biogas and electric vehicles.

Table 5. National level documents

Doc #	Date	Author	Title
1	2012	The Ministry of Enterprise and Innovation	Committee Directive: Fossil Fuel Independent Vehicle Fleet - A Step on the Road to Zero-emissions of Greenhouse Gases
2	2014	Roadmap: Sweden	Roadmap: Sweden - A Strategic Agenda for Innovation and Development of E-mobility in Sweden
3	2014	2030 Secretariat	Fossil Freedom on the Road: Compilation of Response Letters by Actor A-Ö
4	2016	The Government, Moderate Party, Center Party, and Christian Democrat Party	Energy Agreement
5	2017	Swedish Energy Agency, National Board of Housing, Building, and Planning, The Environmental Protection Agency, Transport Analysis, The Transport Administration, and the Transport Agency	Strategic Plan for the Transition of the Transport Sector to Fossil Independence
6	2018	The Swedish Gas Association	Proposal for a National Biogas Strategy 2.0
7	2018	Power Circle	State of Electric Cars 2018
8	2018	Swedish Parliament	Fossil Free Fuel to Reduce the Transport Sector's Climate Impact - Liquid, Gaseous and Electric Fuels in Road, Sea, Air, and Rail Traffic

4.4 ANALYSIS AND WRITING

Through the thesis work, I collected a wide variety of materials to help understand the empirics of this case. I entered all of the documents and interview transcripts into atlas.ti with different project documents to group the Linköping materials, Malmö materials, and national level materials. I then coded all documents using inductive coding inspired by the themes that arose from the materials. These inductive codes emphasized what issues individual actors valued and also connected to their visions of the future. Finding commonalities within the coding was one way of finding imaginaries within groups of interviews.

I transcribed and coded the documents as I collected them. The only materials that were not coded in atlas.ti were the responses to the FFF-investigation as I was unable to obtain a hard copy of all of them. I did, however, gather hard copies of several (either through internet searches or scanning the archive copies) and coded these as well. I started writing the first paper before I had finished gathering the materials, and thus material collection, analysis, and writing were all completed as an iterative process. This strategy was useful for a number of reasons. First, it led to additional materials for analysis, for example when an interviewee suggested a relevant document or another interview subject. Second, it also allowed me to begin writing before all material collection and analysis were completed and new material sometimes also emerged from this phase.

I used different materials for the four papers of the thesis. I wrote Paper 1 first based on the material gathered from the Linköping case study, and Paper 2 second using the material from both municipal case studies. Papers 3 and 4 are largely based on the national level material, although Paper 4 almost exclusively utilizes material related to the FFF-investigation and Paper 3 uses a combination of all the materials to inform a more theoretically oriented paper

CHAPTER 5. ARTICLE SUMMARIES

5.1 ARTICLE I

Title: Mobilizing sociotechnical imaginaries of fossil-free futures – Electricity and biogas in public transport in Linköping Sweden

Published in Energy Research and Social Science, Volume 49 (2019), pp. 1-9.

This article focuses on the interactions between imaginaries of biogas and electric vehicles in the Linköping case study. The aim is to examine the socio-material systems of biogas and electric buses in Linköping with an emphasis on actors' perspectives, answering three research questions:

1. How are biogas and electricity as alternative energy sources understood in the future visions of key public transport actors?
2. How do these actors mobilize sociotechnical imaginaries surrounding these two technologies in their explanations of the desirable future?
3. What do these mobilizations show about the interaction between local and national level imaginaries?

This article employs the theoretical approach of sociotechnical imaginaries (Jasanoff & Kim, 2015) to show how local imaginaries emerge around visions of biogas and electricity as part of the public transport future. Analysis for this paper focuses on material from interviews with fourteen actors with interest in the public transport future in Linköping, where the current material reality of an integrated biogas system is being challenged by increased interest in electric vehicles. Interview material is supplemented by relevant documents for public transport planning.

This paper shows how two competing sociotechnical imaginaries of the future were present among actors in Linköping: one surrounding the role of biogas and another the role of electric vehicles. The biogas imaginary presents a future where biogas continues to contribute to the sustainable region through its reuse of waste substrates, low-carbon emissions, and life-cycle nutrient perspective. This imaginary is supported by central local actors including the municipality, the region, the local energy company, and the public transport authority. The electricity imaginary, in contrast, suggests that electrifying the city bus fleet could improve the urban environment through more efficient and lower-emission vehicles. This imaginary also has widespread support from many of the same actor groups. This shows how rather than aligning actors into two networks in support of the alternative imaginaries, these imaginaries work side by side, with many actors reconciling both imaginaries together in their visions of the future. Instead, most actors present some combined vision of the future that includes aspects of both imaginaries.

This paper contributes to the empirical understanding of this thesis by providing an in-depth introduction to a case where the emergence of interest in electric buses for public transportation creates a contested understanding of the desirable future. In this case, it is clear that the socio-material infrastructure of the biogas system, and particularly the way that this

contributes to regional sustainability through waste recycling and organic agriculture creates widespread support for the continued use of this fuel. This results in the reconciliation of the new imaginary of electrification and the positive implications this offers for the urban future with these pre-existing notions. As a result, most actors present a vision of the future where electrification of urban buses is prominent, however only in scenarios that do not threaten the continued production of biogas in Linköping. Specifically, actors suggest scenarios that allow them to reconcile these two imaginaries together, either by imagining electrification of urban buses in cities other than Linköping or by imagining electrification of Linköping's city buses alongside a shift of the locally produced biogas to another type of vehicle.

The main theoretical contribution of this paper is that it addresses a gap in the sociotechnical imaginaries literature by comparing how imaginaries of two different technologies interact on a local level. This paper shows how the biogas imaginary in Linköping could be considered as a bounded imaginary (Smith & Tidwell 2016), meaning that its influence is limited to the geographic context where it originates. By studying the dynamic between the biogas and the electric vehicle imaginary in this case, this paper also contributes to the understanding of sociotechnical change by showing how interactions between renewable fuels imaginaries contribute to contested understandings of the desirable future.

5.2 ARTICLE II

Title: Obduracy and Change in Urban Transport - Understanding Competition Between Sustainable Fuels in Swedish Municipalities

Published in Sustainability, Volume 11:6092 (2019).

This paper addresses processes of obduracy and change in urban transport in Linköping and Malmö, considering how actors in these two municipalities have reacted differently to the emergence of imaginaries of electric vehicles. While both municipalities historically have had a biogas-based bus ensemble, the ensemble in Linköping remains obdurate and resistant to the introduction of electric buses, while the biogas ensemble in Malmö is more malleable, with plans for the introduction of electric buses already underway. The aim of this paper is to explore what factors have led to the disparate treatment of urban electric buses in these two seemingly similar cases. Analysis is based on interviews with key public transport actors, as well as supporting documents. To understand the factors that contribute to obduracy and malleability in these two cases, Hommels' (2008) three models of obduracy are used: dominant frames, embeddedness, and persistent traditions. This perspective is complemented with the perspective of sociotechnical imaginaries (Jasanoff & Kim 2009), which is used to consider how visions of the future influence these dynamics of obduracy and change.

While the two biogas-based bus systems in Linköping and Malmö may seem similar on the surface, there are a number of factors that contribute to obduracy in Linköping and malleability in Malmö. In Linköping, the dominant framing of biogas as a vehicle fuel, embeddedness of the biogas producer in the municipality, and importance of biogas within other local ensembles of organic agriculture and sustainable waste management were all considered as contributing to the obduracy of the biogas ensemble. In Malmö, in contrast, the disparate sourcing of biogas led actors to frame this as an unsustainable choice. In this case, the embeddedness of the biogas ensemble within the gas distribution infrastructure and local sustainability tradition of viewing the city as a test bed contributed to willingness to adopt electric buses.

By using these two cases as examples, the empirical contribution of this paper is to improve the understanding of what aspects of sociotechnical ensembles contribute to obduracy or malleability. This suggests that understanding the complexity of local contexts is necessary to understanding the changeability of these systems. In the case of Linköping, embeddedness contributed to obduracy by linking the biogas bus ensemble with the sustainable resource loop, while in Malmö this contributed to malleability by connecting the bus system to natural gas infrastructure. Furthermore, this paper shows that it is as much the imaginaries of these ensembles as the ensembles themselves that contribute to obduracy or malleability. For example, in the Malmö case, the natural gas infrastructure contributed to an imaginary of biogas that connected it to unsustainable sourcing, leading to the perception that electrification would be replacing a fossil fuel.

The theoretical contribution of this paper comes from the joint usage of Hommels' three models of obduracy and Jasanoff and Kim's (and others') work on sociotechnical imaginaries. By using these two theories together, this paper demonstrated how imaginaries can also contribute to obduracy and malleability of sociotechnical ensembles. Sociotechnical imaginaries are inextricably linked to the futures that actors want to come to pass. These imaginaries work by either contributing to obduracy where actors value the continuation of the existing ensemble or to malleability where the promise of a new technology leads to change.

5.3 ARTICLE III

Title: Competing transport futures: Tensions between imaginaries of electrification and biogas-fuel

Co-authored with Harald Rohrer, to be submitted to Science, Technology, & Human Values.

This paper analyses the tensions and interactions between the imaginaries of biogas and electric vehicles in Sweden as a consequence of the specific qualities and structures of these two sociotechnical imaginaries (Jasanoff & Kim 2009). Analysis focuses on three specific qualities of imaginaries that appear to be particularly important for the interactions between renewable fuel imaginaries: the potential boundedness of imaginaries to different spatial scales, not only the national level; the contestedness and internal coherence of imaginaries; and the entanglement of imaginaries with the materiality of the technologies they refer to.

Using material from document analysis and interviews with Swedish transport actors, this paper explores the two imaginaries of biogas and electric vehicles along these three lines of inquiry. The biogas imaginary is often bounded on a local scale, due to dramatic regional variation in use and the physical boundedness of the biogas ensembles. One example of this comes from the case material in Linköping and Malmö which demonstrates that while the imaginary in the former considers biogas as a central part of the sustainable public transport system, the imaginary in the latter is aligned with natural gas calling the sustainability of biogas into question. These contrasting examples also show that the imaginary of biogas is somewhat contested, with multiple imaginaries of biogas co-existing in different parts of Sweden. These examples also show the importance of materiality as it is largely the connection to material infrastructures (one of sustainable waste management and agriculture, and the other an international gas pipeline) that leads to these divergent imaginaries.

In contrast, the electricity imaginary is more uniform in nature. Electric vehicles are understood as efficient and carbon reducing solutions primarily for urban areas. This imaginary is less contested on the national level and even aligns with international expectations that imply that future transport will be shared, autonomous, and electric. This example shows an imaginary that is more national or even international in nature. Although this imaginary is more uniform, some level of contestation remains, particularly due to concerns for what widespread electrification would mean for the capacity in the electricity grid and for the impact of battery production.

The empirical contribution of this paper is to demonstrate the way that imaginaries around biogas and electricity are characterized by different profiles and characteristics connected to specific socio-material arrangements of these energy sources and their embedding in different geographical and historical contexts. This conclusion can have implications beyond biogas and electricity and can help explain the understandings of other types of renewable energy alternatives. Additionally, the interactions between different fuel imaginaries is highlighted. For example, although biofuels in Sweden are almost exclusively generated from waste substrates, elsewhere biofuels compete with food production for land use and can even be connected to problematic palm oil which has a negative impact on visions of biogas in some cases.

The theoretical contribution of this paper is to utilize the analysis of the imaginaries of biogas and electric vehicles to highlight three dimensions of imaginaries: that imaginaries relate in different ways to spatial scales, that imaginaries are contested and interconnected, and that imaginaries are inextricably linked to their socio-material relations. This analysis emphasizes the complex way we understand imaginaries and stresses how tensions and relations between sociotechnical imaginaries must be considered to better understand the role of imaginaries in world-making and processes of sociotechnical change.

5.4 ARTICLE IV

Title: Embedding imaginaries - Electric vehicles in Sweden's fossil fuel free future

Submitted to Futures.

This paper considers the process by which sociotechnical imaginaries become stabilized in policy through analysis of a Swedish Government Official Report *Fossil fuel freedom on the road - A report of the investigation on fossil fuel vehicle traffic* (The FFF-investigation). In the imaginaries literature, Jasanoff (2015b) suggests four stages of imaginary formation: origin, embedding, resistance, and extension. This paper employs these stages in a discussion of how an imaginary of electric vehicles as expressed in the FFF-investigation are stabilized through subsequent processes of consultation and policy instruments. This paper uses document analysis and interviews with five key actors to answer the following questions:

1. What vision of the electric vehicle future is expressed in the investigation?
2. How is this vision reflected in a subsequent policy document and concrete policy instruments?
3. How does this process show contestation or stabilization of the imaginary of electric vehicles?

The FFF-investigation presents an imaginary of electric vehicles that emphasizes four aspects of the electric vehicle future: mitigation of climate change, energy efficiency of electric vehicles, improved city environments, and electrification of certain niches. Furthermore, this report presents electrification as part of a scenario for achieving the fossil fuel free future where electrification occurs most rapidly in city buses and personal vehicles. This scenario aligns the electric vehicle imaginary with a specific policy agenda that prioritizes electrification of these areas of transport. The responses submitted during consultation largely supported the goal of a fossil fuel independent vehicle fleet and those that mention electrification (only 20 of over 100) shared many aspects of the electrification imaginary. Within these, two main tensions arise. The first is with respect to the agenda for electrification, with the pro-electrification responses suggesting alternative agendas for electrification. The second is the division between supporters of electric vehicles and those of biofuels, with many actors who did not mention electrification emphasizing the need for additional policy support for biofuels. Many of these responses specifically call for technologically neutral policies, although several of the resulting policy instruments (including those analyzed) provide support only for electric vehicles.

The empirical contribution of this paper is to provide an example of how visions of the future can become stabilized using this specific example from policy. In this case, the relative agreement with the electric vehicle imaginary as presented in the FFF-investigation show how this imaginary becomes embedded through these interactions. The stabilization of the imaginary is somewhat surprising considering the previously contested nature of visions of electrification and in light of the prevalence of biofuels in the existing transport system. Furthermore, this paper also shows how the FFF-investigation somewhat limits the possible futures of transport by presenting an imaginary of the future that is based on continued dependence on personal vehicles.

The paper's theoretical contribution is to the understanding of imaginary formation by providing a case study of how one imaginary of electric vehicle is expressed in the FFF-investigation and stabilized in subsequent policy steps. This paper shows how the use of scenarios aligns the FFF with a specific policy agenda for electrification and indicates how this document does the work of "institutional stabilization" in line with the definition of sociotechnical imaginaries. Furthermore, actors' responses provide passive support for electrification and place agency back on the government by asking for financial support for electrification through policy measures as discussed through the "city environmental contract" and the "environmental bus premium." An additional conclusion is how this imaginary is able to achieve relative stability despite the presence of some tensions from supporters of biofuels and actors who advocate electrification of different types of transport.

CHAPTER 6. DISCUSSION

This thesis considers the emergence of alternative visions of the desirable future within the context of a fossil fuel free transport transformation. By focusing on the interaction between visions of biogas and electric vehicles, we can draw attention to how visions of different renewable fuels interrelate, including how these dynamics unfold on different geographic scales and how they contribute to processes of obduracy and change.

I examined these dynamics at both the local and national level to better understand the interactions between imaginaries of biogas and electric vehicles. By investigating comparative case studies of Linköping and Malmö, I was able to better understand how actors in these municipalities comprehend the role of biogas and electric vehicles in their future urban bus ensembles. These cases emphasized how local context influences actors' visions of these two alternative fuels in a specific area of transportation, where public support allows for greater investment in infrastructures to supply energy.

In addition to the municipal case studies, I also explored the way these imaginaries were presented on a national level, particularly through the FFF-investigation and its subsequent consultation process. This analysis was augmented by examination of additional policy documents, position papers, and interviews with national actors. This line of inquiry highlighted the way that imaginaries of these fuels are explained on a national level and showed the different scales for these imaginaries. To address these problems, I have drawn on three theoretical concepts: sociotechnical ensembles, obduracy and change, and sociotechnical imaginaries. *Sociotechnical ensembles* was used to emphasize the complex socio-material networks that biogas and electric vehicles are a part of. *Obduracy and change* provided a framework for understanding the way that these ensembles become stabilized or destabilized within the ongoing renewable energy transformation. Finally, *sociotechnical imaginaries* is used to explain the way that visions surrounding these technologies are collectively held and normatively defined.

This chapter summarizes the main findings from the four papers and explains how the aim for this thesis has been met by addressing the research questions in the following sections.

6.1 IMAGINARIES OF BIOGAS AND ELECTRIC VEHICLES

1. What are the visions of local and national actors concerning the future of biogas and electricity as fuels in urban transport in Sweden?

Visions can play a powerful role in the transformation to a fossil fuel independent vehicle fleet because they influence the way that actors support different alternative technologies. Within the empirical material, these visions are expressed through the way that actors and texts offer support for biogas or electric vehicles as important technologies for reducing demand for fossil fuels. Here, sociotechnical imaginaries can be used as a conceptual lens to show how such imaginaries of biogas and electric vehicles (following the definition of sociotechnical imaginaries) are *collectively held* and *institutionally stabilized* visions of the *desirable future*. My analysis shows that sociotechnical imaginaries surrounding ensembles of biogas and electric vehicles incorporated aspects of how each of these fuels are understood as contributing

to a better transport future, as well as the specific roles these fuels are expected to take and the arguments that motivate these choices.

The Swedish biogas imaginary is based on the role of biogas as simultaneously contributing to a sustainable region and to energy security, thereby creating a better society. This imaginary is exemplified by the support for biogas in the Linköping case, where many actors motivate the continued use of biogas for these reasons. As described in Papers 1 and 2, biogas in Linköping is a locally produced renewable fuel that can be generated from waste substrates including food waste, leftovers from food production, and sewage sludge. These factors contribute to an imaginary that places biogas at the center of a renewable resource loop that connects the biogas system to local waste management and agriculture. The imaginary surrounding the ensemble of biogas vehicles is based on the belief that the continued and expanded use of biogas will have positive implications for the future. Furthermore, this imaginary connects biogas to a desirable future that integrates regional infrastructures and economies to facilitate a more efficient and resource effective society. This understanding of biogas is central to the Linköping context, where all actors shared the opinion that biogas was a desirable fuel to be used in the future transport system, particularly because of the local characteristics of the Linköping ensemble, which allowed biogas to be generated from locally collected organic waste and used in regional public transportation. However, the contrasting example of the biogas ensemble in Malmö demonstrates how this imaginary is not universally shared in Sweden. In Malmö, the dispersed sourcing of biogas meant that actors did not share the same commitment to the continued biogas use in the region. This indicates that rather than fitting the mold of a national sociotechnical imaginary, the biogas imaginary in Linköping can be considered as a bounded imaginary (Smith & Tidwell 2016) indicating that local context plays an important role in how biogas is understood.

The electric vehicle imaginary emphasizes that electrification is an optimal means of achieving a fossil fuel free vehicle future. This imaginary is evident in the empirical material where support for electrification emerges from both interviews and national policy documents such as the FFF-investigation. This report, for example, promotes electric vehicles as an essential part of achieving the fossil fuel independent future because they are more energy efficient than internal combustion vehicles, reducing the overall energy demand. Electric vehicles also reduce greenhouse gas emissions because they have no in-place emissions and in the Swedish case are supplied primarily from renewable energy sources. Actors in the Malmö interviews, for example, also explain how electric vehicles are an ideal solution for urban areas because they contribute to better air quality and reduced noise in areas with high traffic volumes. The sociotechnical imaginary links electric vehicles specifically to these applications because of the way these vehicles can have positive implications for such urban areas. Thus, many actors suggest that electrification should take place in inner city buses and goods transport, as well as in personal vehicles. Furthermore, this imaginary connects electricity with the idea of a modern digitalized future where electrification reduces energy demand so that the fossil fuel free future can be achieved.

Using the concept of sociotechnical imaginaries, this thesis shows how these imaginaries reflect the ways that actors support alternative fuel technologies based on their normative understanding of how these fuels can help bring about a better future. This point is especially relevant within the renewable energy transformation because many alternatives are available. Biogas and electric vehicles could both have positive implications for the future transport system; however, as the analysis shows, these fuels are sometimes potentially competitive with

each other in specific instances (such as urban public transport). In these cases, imaginaries play an important role because actors are unlikely to mobilize resources to support a future they do not believe in. For this reason, sociotechnical imaginaries surrounding specific technologies like biogas and electric vehicles are important because they can influence the support for these technologies. One example of this comes from the policy instruments following the FFF-investigation. As Paper 4 shows, many of these provide specific support for the introduction of electric vehicles, providing financial incentives for electrification that do not exist for other renewable alternatives.

Despite the presence of these individual imaginaries, one unifying understanding is that multiple renewable fuels will be necessary to achieve a fossil fuel independent future. Imaginaries in support of specific fuel ensembles might advocate for their introduction in specific cases, or the importance of their inclusion in the future transport system. However, nearly every one of the actors who were interviewed during the work of this thesis voiced some version of the position that multiple fuels are needed. This dynamic is particularly evident with the imaginary of biogas because in contrast to electrification (which some argue could be ubiquitous), raw materials for biogas production are limited, meaning that biogas could never be the sole fuel for transport. This shows the widespread understanding that although these renewable fuel imaginaries exist, they are ultimately part of a larger imaginary where the introduction of multiple renewable fuels are viewed as necessary to achieve the fossil fuel independent future. This position is especially evident in the short term, where smaller scale implementation of multiple fuels can be used to replace fossil fuel alternatives.

6.2 INTERACTIONS BETWEEN IMAGINARIES OF THE FOSSIL FREE FUTURE

2. How do these visions of biogas and electric vehicles interact with each other and how do these interactions vary on different geographic scales?

As the previous section suggests, visions of biogas and electric vehicles co-exist on both the local and national levels. The analysis has shown how imaginaries of these two fuels often interact with each other, with views about what role one fuel will play in the future transport system impacting expectations of what role the other will play. Furthermore, the imaginaries of biogas and electricity are not entirely universal but can also be fragmented and contested as a result of the complex understandings of the future that co-exist.

The interaction between imaginaries is especially evident on the local scale, where actors reconcile the two imaginaries to support concrete plans for the future public transport system. In Linköping this results in some hesitance towards urban electric buses, with actors believing these will have a future in Linköping only if the displaced biogas is used elsewhere. In Malmö, the imaginary of biogas is not as positive, allowing actors to commit to the belief that electric vehicles will replace the biogas bus fleet. These two contrasting examples show how the interaction of these imaginaries is also somewhat bounded depending on the understandings of these two fuel ensembles that are prevalent in local communities.

These interactions emerge on the national level as well, as shown in the analysis of the FFF-investigation and its consultation process, which form the central empirical focus for Paper 4. In over 100 responses to the FFF-investigation, only 20 specifically advocated for electric vehicles. Perhaps a more interesting conclusion, however, was that no responses specifically criticized electric vehicles. Rather, if the actor wanted to take a "contrasting

position" it was done by advocating for more support for biofuels. A number of the policy measures suggested by the FFF-investigation, including several of those that were eventually enacted, offered support to offset costs and provide infrastructure specifically for electric vehicles. This implies a dynamic where alternative fuel vehicles can be seen as competing for policy support, particularly where support is not technologically neutral. This sentiment was mirrored in interview S5 with a gas branch representative who shared in the imaginary of electric vehicles but noted the challenge that some initiatives, such as the bonus-malus system for cars, represent for biogas vehicles. Although this initiative offers a financial bonus for the purchase of fossil-free vehicles, the sum is much higher for electric vehicles than gas vehicles.

Another conclusion from this analysis is that biogas and electricity have different scalar profiles. As explained in the previous section, sociotechnical imaginaries of biogas tend to be locally bounded, partially because of the nature of biogas production and use. Biogas ensembles are often localized, with the fuels and substrate by-products finding use close to their production (Mol 2014). This is frequently a result of economics, as the further you transport substrates for production or the final product for use, the higher the cost. This creates some ensembles that are geographically limited, with the source of the raw materials, the biogas production facility, and the fueling station all within a certain region. The Malmö case, however, shows that this is not how all biogas ensembles work. In areas of the country with access to the gas pipeline, the localization of biogas ensembles is overridden by the ability to distribute biogas to and from much greater distances. Imaginaries of electric vehicles, however, have a more national scope. The national imaginary that identifies electric vehicles as an efficient and emissions free solution for urban transport is more widely spread, even if the way this is interpreted differs somewhat in different places. Furthermore, this imaginary is inspired by international perceptions of the electric vehicle future which connect electrification to international trends of digitalization and automation.

Additionally, the imaginary of electric vehicles demonstrates how imaginaries can interact on different scales. Particularly in the Linköping case, actors voiced the opinion that the drive for electrification of the urban buses came from the national level. Although it is the regional council that is formally empowered with decision-making for public transport, these actors are strongly influenced by national policies. In this case, both policy agendas such as those laid out in the FFF-investigation, as well as concrete policy instruments such as the electric bus premium, encourage electrification in urban areas.

6.3 OBDURACY AND CHANGE

3. What factors contribute to obduracy or change in configurations of biogas and electric vehicles in different local contexts?

This thesis is based on Swedish goals of achieving a fossil fuel independent future transport system, a target which will require an enormous transformation to replace the current fossil fuel-based ensemble which has been built up over generations. This context places emphasis on the role of obduracy and change in local transport ensembles, as the fossil fuel independent transformation relies on the stable introduction of renewable fuels in each of these. Obduracy or malleability of these local transport ensembles is influenced by a variety of factors including imaginaries of the desirable future. On the one hand, imaginaries of the desirable future that include the continuation of the existing ensemble can be a powerful force in this ensemble remaining, while on the other imaginaries that favor the role of an alternative ensemble can lead to the abandonment of the existing technology.

This thesis examines these dynamics through analysis of urban public transport ensembles in Linköping and Malmö. Although both municipalities had developed renewable biogas-based bus systems, these were not equally obdurate when a new alternative was introduced. In Malmö, the promise of electric buses had actually destabilized the biogas imaginary, resulting in widespread support for electrification of the urban bus fleet. In Linköping, in contrast, support for the existing local biogas ensemble remained steadfast, even as some actors began to accept that the outlet for the biogas may need to be relocated to other types of transport.

The contrasting cases of Linköping and Malmö highlight a variety of factors that influence obduracy or malleability in ensembles of biogas and electricity. To relate this point back to Hommels' three models of obduracy, I argue that each of these were related to sociotechnical imaginaries. *Dominant frames* is the result of a group of actors conforming to an imaginary that visualizes one particular type of future, as the Linköping actors tend to with the vision of biogas as a fuel for public transport. In Linköping, this framing leads to a concern that replacing biogas with electricity in urban public transport will lead to the demise of the biogas ensemble which is valued for its contributions to regional sustainability. In Malmö, however, this framing is not as strong. Here, biogas is also used more extensively in other applications such as municipal heating and power, making it easier for actors to envision a shift of biogas to any number of applications.

Embeddedness is evident in the case studies, including how each ensemble is embedded in complex infrastructures of biogas provision. This leads to an obdurate biogas ensemble, where biogas is part of a system of local biogas provision which also contributes to nutrient recycling, sustainable waste management, and organic agricultural production in the region. Because of these connections, actors are hesitant to replace biogas in the urban bus system. In Malmö, in contrast, the provision of biogas is widely spread thanks partially to the connection to the international gas grid. This embeddedness has the opposite effect contributing to a malleable ensemble because actors perceive the origin of the biogas as unsustainable since it may contain higher percentages of natural gas or be internationally sourced. Embeddedness also interacts with sociotechnical imaginaries because imaginaries are closely linked with the material infrastructures of the ensembles they relate to in an iterative process. While sociotechnical imaginaries are impacted by the materiality of these ensembles, they also influence views of how these ensembles can come to develop, limiting the willingness of actors to abandon the material infrastructures of technologies they see as part of the future. In Linköping, this results in a commitment to the biogas imaginary as a central part of regional sustainability, while in Malmö this is evident in the electric vehicle imaginary which places this technology at the center of the future of dense and desirable cities, committing actors to achieving this future, even where electric vehicles have not been introduced. This parallels a conclusion from Hommels' example of the tunnel through Maastricht, where obduracy resulted from the commitment to shifting the highway from an overpass to a tunnel, even though the tunnel didn't exist yet.

Finally, sociotechnical imaginaries can also be seen as contributing to *persistent traditions*, in the way that sociotechnical imaginaries also work to carry the results of previous planning decisions into the future. Here, I relate persistent traditions to the way that sustainability is understood in the two municipalities. While in Linköping, biogas is championed largely for its contribution to sustainability by bolstering the ecological health of the municipality and its surrounding region, biogas does not have the same sustainability

profile in Malmö. Here, rather, sustainability is often linked to the role of the city as a test bed for new technologies and solutions. While the understanding of sustainability in Linköping contributes to the obduracy of the biogas ensemble, the understanding in Malmö contributes to malleability. In Malmö, the decision to test electric vehicles is in line with the perception of the city as a test bed because of the way that it explores a new technology. Persistent traditions can also be linked to obduracy, because these definitions of sustainability are part of imaginaries of the desirable future. While in Linköping, this future includes biogas and can contribute to regional sustainability, in Malmö, this includes experimentation with new sustainable technologies in the form of electric buses.

CHAPTER 7. CONCLUDING REFLECTIONS

While the previous chapter addressed the way that the material answered the three research questions, this section introduces overarching conclusions from the combined work. The first section addresses the overarching contribution to the empirical field outlining the interactions between visions of biogas and electric vehicles. The second section returns to the theoretical perspective by addressing the ways this thesis contributes to the literature on sociotechnical imaginaries. Finally, the third section addresses gaps for further research.

7.1 CONTESTED VISIONS OF THE FOSSIL FUEL FREE FUTURE

The aim of this thesis has been to explore visions of biogas and electric vehicles within a transformation of Swedish urban transport to a fossil fuel free future. To achieve this transformation, many alternative fuel technologies have been suggested which are accompanied by alternative visions of the future transport system. These alternative visions interact with each other, leading to contested understandings of the fossil fuel free future that then impact the present through how these visions are enacted. Furthermore, each of these visions surround alternative technologies that are inextricably entangled with complex socio-material ensembles complicating the way they can be implemented.

Sweden has provided an interesting context for performing this study. As a result of early investment and pro-renewable fuel policies, Sweden has already achieved 22% renewable fuels in transportation (Energimyndigheten 2019a). This leads to novel dynamics such as in the municipal case studies in Linköping and Malmö, where interest in electric urban buses has emerged in sectors where biogas is already in use. This creates potential competition between these fuels, where public transport actors must choose whether to subscribe to visions of the future that feature biogas or electricity in urban public transport. In practice, this competition is not very contentious in Linköping or Malmö where actors tend to reconcile the possibility of displacing biogas from the urban bus fleets with visions that the same biogas stocks will be repurposed elsewhere. Regardless, these fuels still compete for specific markets, and if renewable fuels are able to replace fossil fuels in more places, competition between renewable fuels could become more common worldwide.

One area where competition between biogas and electricity arises is within policy, as shown in the analysis for Paper 4. As explained, both the city environmental contract and electric bus premium provide incentives to purchase electric vehicles but not other renewable fuel vehicles. The responses following the FFF-investigation make this competition clear because of the way that actors advocate for support for different alternatives. As discussed, many of the responses that did not support electric vehicles instead advocated for biofuels. This creates an undercurrent of competition between these fuels even if it is not explicitly expressed through actors criticizing the other alternative. This dynamic shows how alternative renewable fuels like biogas and electric vehicles can compete for policy support.

The interactions between alternative imaginaries is also an important topic on a wider scale, particularly within sustainability transitions. If the fossil fuel free future is to be achieved internationally, renewable fuels will need to take a more prominent place in the transport sector. Within the renewable energy transformation, these types of interactions between

alternative imaginaries of energy technologies will likely have a significant impact on the way this transition unfolds.

7.2 SOCIOTECHNICAL IMAGINARIES OF ELECTRICITY AND BIOGAS

Throughout this thesis, the theoretical perspective of sociotechnical imaginaries is used to describe the visions of biogas and electric vehicle ensembles in Sweden. As explained in Chapter 3, this perspective emphasizes the ways that visions of the future become collectively held and institutionally stabilized within a society. This thesis seeks to build on this perspective by using it slightly differently. Rather than emphasizing the role of hegemonic national imaginaries, I consider the interactions between two distinct sociotechnical imaginaries in the Swedish context. Ensembles of both biogas and electric vehicles have been introduced as potential solutions to help achieve the fossil fuel free vehicle transformation, and imaginaries surrounding both of these have emerged in Sweden. However, the co-existence of these two imaginaries highlights some aspects of imaginaries that have, so far, been underemphasized. This section returns to the three themes introduced in section 3.3.2, to describe how a focus on the role of scalarity, the contested nature of imaginaries, and the role of sociotechnical imaginaries in processes of obduracy and change can contribute to the analysis of the empirical material.

Scalarity of Imaginaries - By examining the imaginaries of biogas and electric vehicles on both the national and local levels, the analysis has shown how sociotechnical imaginaries of fuel ensembles exist on different scales. The analysis of policy documents such as the FFF-investigation indicate the emergence of national sociotechnical imaginaries. Paper 4 shows how this specific policy document expresses a national imaginary that indicates electric vehicles as a desirable part of the future transport system, particularly in urban areas, because of the way that electric vehicles reduce climate impact, reduce energy demand via more efficient engines, and reduce air and noise pollution in high-traffic areas. This analysis both conforms with the dominant understanding of sociotechnical imaginaries as nationally held and contributes to this understanding by showing how nationally held imaginaries can interact with imaginaries on different levels. For example, in Paper 3 we show how the Swedish imaginary of electric vehicles shares many characteristics with the international imaginary, which describes the future transport system as "shared, electric, and autonomous" (Morgon Stanley 2016). Additionally, Paper 1 considers the way that this national electric vehicle imaginary is understood by local actors in Linköping. Here, many actors reconcile the expectation that urban electric buses will be central to Swedish cities with the local biogas imaginary that considers biogas as central to regional sustainability. This results in a reconciled imaginary that stipulates that urban electric buses could be the future in Linköping, but only if other uses are found for locally produced biogas. In addition to showing that the local imaginary is influenced by the national electricity imaginary, this analysis also shows the way that some imaginaries, like those of biogas, are locally bounded. Biogas ensembles tend to develop as localized systems due to physical limitations in transporting the substrates and the fuel (Mol 2014). Analysis of the municipal cases shows how sociotechnical imaginaries of biogas are also locally bounded, dependent on the local character of the biogas sociotechnical ensemble. While the Linköping imaginary considers biogas an essential part of maintaining the sustainable waste management and agricultural ensembles that biogas is linked to, the Malmö imaginary instead considers biogas as a fuel that is widely sourced and connected to

the fossil natural gas ensemble. These contrasting cases show how imaginaries of biogas in Sweden are locally disparate.

Contested nature of imaginaries - The analysis for this thesis considers the contested nature of imaginaries in two ways: both by examining the existence and interaction of imaginaries of two different fuel sources and by emphasizing the fragmentation that occurs within visions of the same technology in different contexts. Imaginaries of both biogas and electric vehicles are present on both local and the national levels. These imaginaries interact with each other, as shown in the municipal case studies where expectations of electric vehicles are influenced by imaginaries of biogas. For example, in Linköping the biogas imaginary is relatively positive and connects the biogas bus ensemble to a number of benefits for a sustainable region. This leads to a hesitance to accept the electric vehicle imaginary, unless it is reconciled with continued use of regionally produced biogas elsewhere. In Malmö, in contrast, the imaginary of biogas is more negative, which opens up actors to subscribe more wholly to the imaginary of electric vehicles. These contrasting examples show how imaginaries surrounding one fuel are influenced by imaginaries of another. This point is also reiterated in the analysis for paper 3, which explains the interconnectedness with imaginaries of other types of fuels. For example, since biogas is sometimes included in broader sociotechnical imaginaries of biofuels, this connects biogas to additional types of controversies. In some cases, biofuels are generated with energy crops that take land away from food production, leading to a negative image. This connection can have a negative impact on the biogas imaginary, even though Swedish biogas is mostly generated from waste substrates.

The second point relates to how imaginaries of the same fuels can be heterogeneous and sometimes contradictory. This is most clearly presented by the divergent biogas imaginaries that are prevalent in Linköping and Malmö, showing how the local contexts of these biogas ensembles influence their role in visions of the future. This builds on the concept of bounded imaginaries as used by Smith and Tidwell (2016) by showing how multiple versions of bounded imaginaries can exist in different areas of the same country. Another example that speaks to the multiplicity or flexibility of imaginaries comes from the responses to the FFF-investigation, where many actors agree with the overall imaginary but not with the pathway to achieve it (for example where some actors suggest personal vehicles, transport trucks, or even rural vehicles should be electrified more rapidly than urban buses). This example also shows contestation within imaginaries of the electric vehicle future where different pathways can be used to achieve the same desirable future.

Imaginaries and change - Finally, this thesis contributes to the sociotechnical imaginaries literature by considering the way that imaginaries can influence processes of obduracy and change. The premise for the empirical material is the Swedish national target of obtaining a fossil fuel independent vehicle fleet by 2030. As most vehicles are still dependent on fossil fuels, this means that a considerable transformation is necessary to achieve the 2030 target. Proponents of both biogas and electric vehicles suggest that these fuels can play a substantial role in achieving fossil fuel independence. However, this transformation is dependent on the ability for incumbent ensembles to change, adopting alternative fuel ensembles. Paper 2 of the thesis examines these dynamics using the concepts of obduracy and malleability. While obduracy denotes an incumbent ensemble that resists change, malleability denotes one that is more open to modification. In this case, the empirical material focuses on incumbent ensembles that are already fossil free because the case studies examine municipalities where biogas is already the dominant fuel in urban buses. Despite the specificity

of this type of case, the lessons learned can also be applied to the more common case of replacing fossil fuels with renewable alternatives.

The analysis of the municipal case studies explored in Paper 2 show that imaginaries of both incumbent technologies (in these cases biogas) and emergent technologies (in these cases electric vehicles) contribute to the obduracy or malleability of local transport ensembles. A strong positive imaginary of biogas in Linköping contributes to obduracy because it influences the hesitancy among actors to give up an ensemble that improves regional sustainability through its linkages with organic agriculture and resource reuse. Meanwhile, in Malmö the local imaginary around incumbent biogas is less positive, leading to a willingness to accept alternative technologies and a malleable ensemble. The imaginary of emerging electric vehicles also contributes to malleability in this case because actors' expectations that electric vehicles will lead to an improved city environment contribute to the willingness to abandon the incumbent biogas ensemble and once again are linked to a malleable ensemble open to change.

7.3 FUTURE RESEARCH

This thesis has examined imaginaries of biogas and electric vehicles within Swedish urban public transport. One aspect of these imaginaries which could be further explored is their interconnectedness with other fuel imaginaries, as this was a factor that influenced the way that actors understood the potential success of biogas and electric vehicles. One line of inquiry could be to compare the imaginary of electric vehicles to historical renewable fuel imaginaries. Some actors in the local cases voiced skepticism for the electric vehicle imaginary by comparing it to the historical emphasis on ethanol, fuel cells, central heating and even biogas. In these cases, actors used the success or failure of these previous technologies as a motivation for their support or skepticism for the electric vehicle imaginary. These parallels could be more explicitly explored to find parallels between the modern electric vehicle imaginary and other historical imaginaries in order to find out if there was a correlation between how these technologies were imagined by the public and the eventual role they played in the future transport/energy system. Alternatively, the interaction between imaginaries of different technologies could be studied within other fields of sociotechnical change.

Another intersection that could be elucidated is the relationship between renewable fuel imaginaries, such as those I have discussed here, and fossil fuel imaginaries. This relationship was clear in the Malmö case study, where actors were often skeptical of biogas because of its linkage to natural gas. In many cases, the renewable fuel assemblages and fossil fuel assemblages are closely linked, which can lead to questions about what role fossil fuels play in renewable fuel imaginaries. Another example of this dynamic comes from the question of how increased electrification would impact the electricity system. While interview subjects sometimes noted that electric vehicles would lead to exported emissions, they would likely also lead to a need to increase electricity generation in Sweden, an ambition which may or may not be achieved with renewable fuels. Future research could look more closely into this dynamic and how it influences visions of the future.

The municipal case studies for this thesis showed how local fuel imaginaries can be considered as materially embedded in infrastructures of fuel provision. Future research could consider the role that such socio-material infrastructures play in imaginaries more generally. One example could be in exploring the trend of liquified biogas. As this development could fundamentally alter the materiality of biogas ensembles, one line of inquiry could be to explore the impact of this shift on the biogas imaginary.

Finally, this thesis contributes to the growing body of sociotechnical imaginaries literature by highlighting these three areas where this perspective can be further explored: scalarity of sociotechnical imaginaries, their contested nature, and their role in processes of obduracy and change. Further research, however, is needed to fully understand these complex dynamics of imaginaries including how they are relevant for other empirical cases. One type of study could follow the formation of a sociotechnical imaginary over time to understand how it becomes stabilized and how the stabilization impacts the obduracy of a sociotechnical ensemble. This could include a longitudinal study that analyzes the development of an imaginary in policy over time. Another type of study could look more specifically at the way that global imaginaries “trickle down” and influence local understandings surrounding specific technologies. By further exploring the interaction between imaginaries and obduracy, we can work to better understand the role of visions and expectations in the achievement of the renewable transport future.

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In the wake of the climate crisis, it has become increasingly evident that the fossil fuel-based transport system must undergo a global transformation. Numerous renewable fuel alternatives have been suggested, accompanied by imaginaries of how these technologies will contribute to a better future. These imaginaries have a wide-ranging impact because the implementation of each alternative technology will require the build-up of multifarious socio-technical ensembles that support their use. As a result, replacing fossil fuels with these renewable alternatives is likely to be a complex process. This dissertation considers the emergence of two such visions of renewable fuels studying imaginaries of biogas and electricity in the Swedish context. Biogas has a long history of use as a transport fuel in Sweden, where although it makes up a small percentage of total fuel use it also forms the basis of numerous municipal public transport systems. Meanwhile, electric vehicles have become increasingly attractive as more actors subscribe to an imaginary that sees the future as shared, autonomous, and electric. This interaction is exemplified in urban public transportation as many municipalities begin to implement electric buses in an attempt to increase energy efficiency and reduce pollution.

This thesis considers the imaginaries of biogas and electric vehicles in two case studies of urban public transport in the municipalities of Linköping and Malmö, as well as a national case study of a national policy document. It contributes to a wider understanding of how visions can influence obduracy and change within the wider transformation to a fossil fuel free future.

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