Transitioning to zero emission buses for public transport in the Netherlands.

Bringing together the Multilevel perspective and the Multiple Streams framework to explain sustainability transitions.

TU Delft

Shaista Kalpoe

Master thesis CoSEM

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by

Shaista Kalpoe

Student number: 4025105

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Graduation committee

Chair:	Dr. Thomas Hoppe,	Section O&G
First supervisor:	Dr. Nihit Goyal,	Section O&G
Second supervisor:	Dr. Linda Kamp,	Section E&I

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Preface

This thesis is the final part of my studies for the degree of Master of Science in Complex Systems Engineering & Management (CoSEM). The research was conducted from March to July 2022 at Delft University of Technology (TU Delft), in the faculty of Technology, Policy, and Management (TPM). I want to take this opportunity to express my gratitude to the people that helped me achieve my academic goal.

I would like to thank the members of my graduation committee, Dr. Thomas Hoppe, Dr. Nihit Goyal and Dr. Linda Kamp, for their time and effort in guiding me during this research project. I am especially thankful to my first supervisor, Dr. Nihit Goyal, for his constructive feedback, patience, understanding and reassurance. I appreciate the time you provided for our weekly meetings to not only discuss my progress, but also listen attentively to any questions I had or obstacles I encountered during my research. Thank you for helping me from the start of this project and making me critically reflect on and improve my scientific research skills. The feedback I received from Dr. Thomas Hoppe and Dr. Linda Kamp during the kick-off and midterm meetings was very helpful to me as well and their interest in what I presented during those meetings only motivated me to continue the research.

I would also like to thank all the interviewees, who took the time in their busy schedule to help me out with my research and were very interested to provide their view on the transition to zero emission buses in the Netherlands.

I am especially grateful to my parents, Jagdies and Chiquita, who provided me with the opportunity to continue my studies. I would also like to thank all my family and friends for supporting me in many ways during my studies.

Shaista Kalpoe

Delft, August 2022

Summary

To fight against climate change the Dutch government wants to reduce CO_2 emissions in the Netherlands by 49% in 2030 and 95% in 2050, compared to 1990 levels. This transition towards sustainability is set to be achieved through agreements with several sectors, including mobility. Buses using conventional fuels are one of the biggest sources of air pollution in cities. Zero emission buses (ZEBs) do not generate any polluting emissions and they are being increasingly deployed globally. They have become an important part of the transition to sustainable urban transport. In 2016 a "Zero Emission Regional Public Transport by Bus" administrative agreement was signed, stating that from 2025 onward all new buses must use 100% renewable energy and from 2030 all buses must be fully emission free. Since then the Dutch public transport system has added more than 1000 battery electric and hydrogen fuel cell buses to their bus fleet. This increase in alternatives to diesel and gas powered buses is not only driven by sustainable mobility policy, but also due to advances in battery technology, increased competitiveness in cost on a lifecycle basis, an established electric vehicle supply chain and increased charging infrastructure. This research aims to answer the following research question:

"How can the ongoing transition to zero emission public buses in the Netherlands be explained using the Multiple Streams Framework and the Multilevel Perspective?"

To study this ongoing transition to ZEBs in the Netherlands, first it is explained what sustainability transitions are according to the literature. Then the theoretical background of the study is addressed, which is a combination of the Multilevel Perspective (MLP) and the Multiple Streams Framework (MSF). The MLP is used to describe what socio-technical regime change is: a transition that takes place due to internal pressure in the regime or when developments in the landscape level put pressure on the existing regime so niche innovations can break through from the niche level, causing a "window of opportunity". The MSF is used to describe policy change: when the problem stream, the policy stream and the politics stream are coupled by policy entrepreneurs or through focusing events, creating a "policy window", policy shift takes place. Using this combination of theories gives a more comprehensive explanation of the feedback between policymaking processes and socio-technical transitions.

Subsequently, the methodology, a combination of desk research and interviews for data collection and a combination of qualitative coding and process tracing, is discussed. Next, the case study on the ongoing transition to ZEBs in the Netherlands is conducted. This reveals that when applying the MLP,

there are elements missing that are explained better using the MSF. These are the events that would be placed in the political stream, policy window and activities carried out by the policy entrepreneur, like the perception of the government to match the switch to electric cars in the public transport sector, how policies were being steered towards ZEBs, how the growing collaboration in networks for ZEBs helped to generate a coherent set of proposals with the aim of achieving the carbon reduction target in 2030 or the lobbying by green organizations and electric transport organizations. Alternatively, when applying the MSF, there are elements missing which can be found using the MLP. These are events that happen on the niche level and incremental changes in the socio-technical regime, like the pilot projects that took place concerning ZEBs, the higher costs of ZEBs, the reduction of battery costs, the limited availability of charging and fueling infrastructure, the different results in market share growth of BEBs and FCEBs after initial implementation or the growing need for collaboration with the energy sector regarding the electricity demand and grid capacity.

After comparing the case study results from applying the two frameworks and assessing the implications for elaborating on the theories, a proposition towards an integrated framework that combines the strengths of the two theories and gives a better understanding of sustainability transitions is formulated. It can be argued, based on the case study results, to extend the definition of the window of opportunity to not only entail the destabilization of the regime due to internal pressure or pressure from the landscape, but also include discussion events and the influence of key actors that are aiming to influence policy outcomes. Another important element missing from the MLP is the importance of the effects of policy change on transformative change, which is almost always necessary in the case of sustainability transitions, as well as on future policy changes.

The first recommendation for future studies is to apply the combination of the MLP and MSF as is done here, to other cases. The second recommendation for future studies is to consider the effects that socio-technical regimes have on each other. The third recommendation for future studies is regarding the analysis of sustainability transitions using multiple theoretical lenses. Studying the ongoing transition to ZEBs in the Netherlands using a different combination of theories, for example the MLP with the Advocacy Coalition Framework, could reveal interesting insights as well. A fourth recommendation is for policymakers and stakeholders in regards to the deployment of FCEBs. The case study showed a clear difference in the percentage and rate of the deployment of FCEBs as compared to BEBs. With the growing demand load of the electric grid, it would be not only smart but perhaps necessary to push alternative fuel drivetrains, like fuel cell electric vehicles, into further development.

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List of Abbreviations

BAZEB – Bestuursakkoord Zero Emissie Regionaal Vervoer per Bus
BEB – Battery electric bus
CNG – Compressed natural gas
FCEB – Fuel cell electric bus
PTA - Public transport authority
PTO – Public transport operator
ZEB – Zero emission bus

1. Introduction

To fight against climate change the Dutch government wants to reduce CO_2 emissions in the Netherlands by 49% in 2030 and 95% in 2050, compared to 1990 levels (Rijksoverheid, 2022; Rijkswaterstaat, 2022). This transition towards sustainability is set to be achieved through agreements with the electricity, industry, traffic and transport, built environment and agriculture sector. Thus, to meet climate goals while maintaining accessibility, the Netherlands needs to change its mobility system (Rijksoverheid, 2019).

The Dutch government's vision for sustainable mobility includes cycling, filling and charging infrastructure, shipping, passenger and freight transport and public transport (Rijkswaterstaat, 2022). Many changes can already be seen in the public transport sector. Since 2017 trains in the Netherlands have been running fully on wind energy (NS, 2020; Sense & Sustainability, 2018) and since 2015 more than 20% of public transport buses have become emission-free (Sustainable bus, 2020). Buses using conventional fuels are one of the biggest sources of air pollution in cities (Brdulak et al., 2020; Kok et al., 2017). Zero emission buses (ZEBs) do not generate any polluting emissions and they are being increasingly deployed globally, with a majority in China (Brdulak et al., 2020; Thorne, 2021). They have become an important part of the transition to sustainable urban transport (Bakker and Konings, 2018).

In 2016 a "Zero Emission Regional Public Transport by Bus" administrative agreement was signed by the Dutch Ministry of Infrastructure and the Environment and 14 transport authorities. This agreement states that from 2025 onward all new buses must use 100% renewable energy and from 2030 all buses must be fully emission free (International Energy Agency, 2020; Rijkswaterstaat, 2022). Since then the Dutch public transport system has added more than 1000 battery electric and hydrogen fuel cell buses to their bus fleet (Sustainable bus, 2020; Fuel Cell Works, 2019). This increase in alternatives to diesel and gas powered buses is not only driven by sustainable mobility policy, but also due to advances in battery technology, increased competitiveness in cost on a lifecycle basis, an established electric vehicle supply chain and increased charging infrastructure (Vox, 2018). There are also many types of actors involved, like bus manufacturing companies, charging infrastructure and solutions providers, electric transport partnerships and organizations, government institutions and policymakers. As it comprises of socio-cultural and technological elements, the current transition to zero emission public transport buses in the Netherlands can be conceptualized as a sociotechnical transition.

Research problem and knowledge gap

At present a lot of innovation is taking place in the sustainable mobility transition, from the way people travel, like ride-sharing and cycle renting, to the technologies used for transport, like hydrogen and electric vehicles. Some of these sustainable mobility alternatives are taking off quicker or becoming more successful in terms of market share than others. The ongoing transition to ZEBs in the Netherlands is a leading example in Europe. In 2020 more than 80% of newly purchased buses in the Netherlands were zero emission, bringing the total share of ZEBs in the fleet well over 20% (European Federation for Transport and Environment, 2022). These shifts towards increased sustainable mobility are influenced by policy changes and innovation in technology and institutions (Brdulak et al., 2020; Bakker and Konings, 2018). In order to explain how such complex socio-technical transitions develop, it is therefore important to look at them from both a socio-technical and a policy perspective.

Problem exploration

From an innovation point of view, to explain how technology transitions develop through the dynamics in socio-technical regimes, the multilevel perspective (MLP) on transitions has proven to be one of the established frameworks (Markard et al., 2012; Geels, 2002; Geels and Schot, 2007). The framework describes technology transitions as consisting of three levels: technological niches, socio-technical regimes and the socio-technical landscape. A transition, or regime shift, takes place when developments in the landscape put pressure on the existing regime so niche innovations can break through, causing a “window of opportunity” (see Figure 1). The framework combines evolutionary economics and technology studies to show the complexity of socio-technical transitions. However, it does not include actors and the interactions between them (Geels, 2002). Over the years the scholars have built on the MLP and added more details to the levels and dynamics, which is discussed in chapter 3.

From a policy perspective, the multiple streams framework (MSF) has been widely applied to analyze the policy process and explain policy change (Kingdon, 1984; Weible and Sabatier, 2018; Llamosas et al., 2018). The framework describes a policy process as consisting of three parallel processes: the problem stream, the policy stream and the politics stream. When these largely independent streams are coupled as a result of focusing events in the problem stream or due to activities of policy entrepreneurs at the right point in time, during a “policy window”, policy shift takes place (see Figure 2). Over the years the MSF has been incrementally refined or extended by scholars, to include more aspects of the policy process, which is discussed in chapter 3.

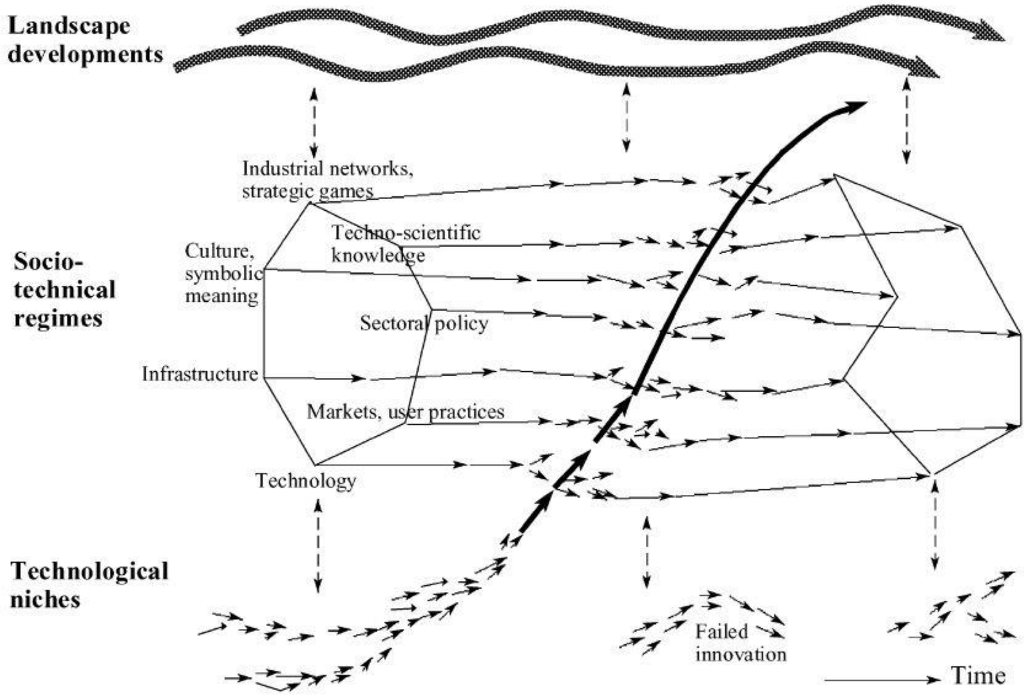

Figure 1 - Geels' multilevel perspective on technology transitions (Source: Geels, 2002)

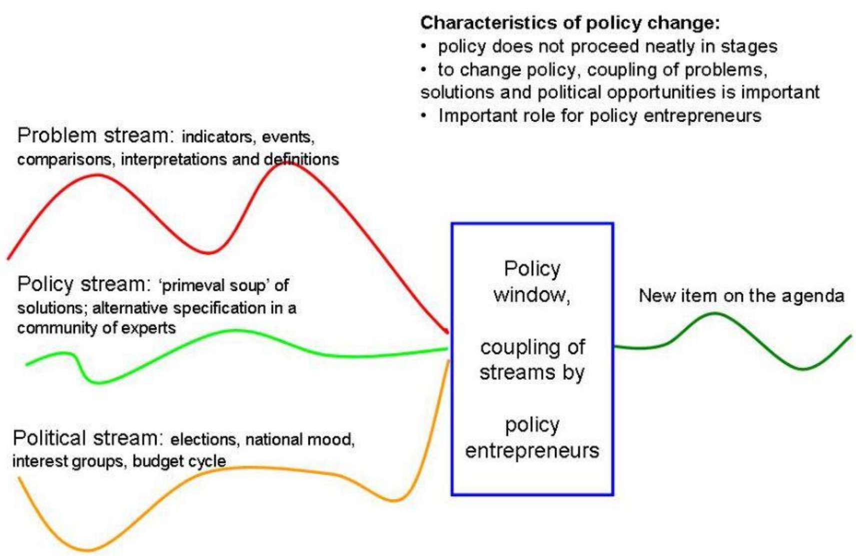

Figure 2 - Kingdon's multiple streams model (Source: Paredis and Block, 2013)

A recent study by Derwort et al. (2021) takes a step in the direction of combining the socio-technical and policy perspective by using the MSF to examine the political dimension and the MLP to examine the technological innovation dimension of the German energy transition. By applying both frameworks to the case of the German energy transition, they demonstrate how sustainability transitions emerge from interaction between socio-technical and political dynamics. In order to get empirically generalizable results, they state that the parallel use of the MSF and MLP needs to be applied to other cases of sustainability transitions. Edmondson et al. (2018) also combined policy and innovation literature to study the dynamics between policy mix change and socio-technical change. They developed a conceptual framework to analyze the co-evolution of policy mixes and socio-technical systems and applied it to the case of zero carbon homes policies in the UK. Such cross-fertilization between policy and innovation studies however still remains greatly understudied and should be implemented further to examine policy-technology feedback links (Derwort et al., 2021; Schmidt and Sewerin, 2017).

Several studies have also looked into the switch to ZEBs for public transport from different perspectives. Pedrosa et al. (2018) focus on the user's perspective in Ekaterinburg by studying their concerns about air pollution and the environment and how this influences their willingness to pay for the introduction of ZEBs in the public transport fleet. They argue that user's concern about the environment has a questionable relevancy, but their concern for the air quality is relevant for the willingness to pay and support of ZEBs. Brdulak et al. (2020) studied the rate at which ZEBs will be introduced in the public bus fleet of certain European countries in the next years. They conclude that most of these European countries will not be able to replace their traditional bus fleet with ZEBs by 2050, but they state that this also depends on technology developments and how this can be financed as well as on the economic situation of the countries. Abdelwahed et al. (2020) focus on the charging strategy challenges that public transport operators face, by optimizing the opportunity fast-charging schedule of battery electric buses in Rotterdam to minimize costs and impact on the electric grid. They presents different optimized charging strategies and determine the amount of chargers needed at terminal stations. These studies do not focus on the innovation or policy perspective of the transition to ZEBs.

Problem statement

Technological innovation and policy innovation are analyzed in different research fields, namely innovation studies and policy studies (Schmidt and Sewerin, 2017). In policy transition theory technological changes are considered as exogenous events, which can also be said about the MSF. It does not consider the differences in innovation patterns of technologies, which is the case in most policy literature (Schmidt and Sewerin, 2017). Meanwhile in technology transition theory policy changes are seen as a black box, which can be seen in the MLP as well. It does not include the ways that policies develop and the effects of interactions between actors. This makes it difficult to identify important policy-technology feedback links and dynamics in sustainability transitions.

Knowledge gap

As stated by Edmondson et al. (2018), in the field of sustainability transitions there is still a lack of explanation of how policymaking processes and socio-technical innovation influence one another. Although some scholars have started to address this (Derwort et al., 2021), the coevolution between technology and policy in sustainability transitions is not conceptualized and empirically analyzed enough. For the purpose of theory-building there is a need for a more holistic view to explain complex socio-technical transitions that involves both policy and technological innovation dynamics and their coevolution. Such a framework does not exist yet and will require much empirical input. The knowledge gap that is addressed in this research is the way in which the MLP and the MSF complement each other to provide a more holistic explanation of sustainability transitions and how this can be used in future research for theory synthesis. This will be done through a case study of the ongoing transition to ZEBs in the Dutch public transport sector.

Research objective

The objective of this research is to find ways in which the two frameworks strengthen one another, based on the findings of the case study. This will then be used to generate propositions to help synthesize and develop a conceptual framework in future research, which combines the MSF and MLP in order to have a more comprehensive explanation of sustainability transitions.

Research questions

Based on the knowledge gap and research objective discussed in the previous section, the following main research question can be been formulated:

How can the ongoing transition to zero emission public buses in the Netherlands be explained using the Multiple Streams Framework and the Multilevel Perspective?

To help answer the main research question, the following sub-research questions are formulated:

1. What is socio-technical regime change through the Multilevel Perspective?
2. What is policy change through the Multiple Streams Framework?
3. How can the transition to zero emission public transport buses in the Netherlands be analyzed using the MLP?
4. How can the transition to zero emission public transport buses in the Netherlands be analyzed using the MSF?
5. In what way do the MSF and MLP complement each other in explaining the transition to zero emission public transport buses in the Netherlands?

Research perspective

The research will follow a deductive approach of comparative nature by applying both the MSF and MLP in a case study of the transition to zero emission bus transport in the Netherlands. The case follows a sustainable transition which involves policy interventions as well as technological innovation and as such, can be studied using both the MSF and MLP separately. Berggren et al. (2015) applied the MLP to show that incumbents in the heavy vehicle industry are active on both the regime and niche levels, developing multiple technologies simultaneously. The MSF has not yet been applied to study the transition to zero emission public transport.

Scientific relevance

The scientific relevance of this research project is its contribution to the academic body of literature on policymaking, innovation and sustainability transitions and the combination of frameworks to study transitions. Transitions are complex phenomena and researchers have different opinions on how to study them. As stated by Geels (2011), this will most likely not change because there is not one right or appropriate way to study socio-technical transitions. It is a multi-faceted topic that is still being explored in literature. The aim of this research is to find ways in which the MSF and MLP may have conceptual similarities, how they contribute to each other and strengthen one another in providing a more complete picture of the trajectory of sustainable transitions. This is done by generating propositions, based on case study results, which then can be used for theory synthesis in future research. In doing so it takes a step in the direction of potentially developing a more comprehensive framework, which combines these two analytical lenses from different research fields, to better understand sustainability transitions. As the research involves a case study, it also contributes to the literature on ZEBs, which is an actual topic in the fields of sustainability, mobility, energy, policy, and environmental sciences.

Societal relevance

The societal relevance of this research project are the empirical insights on the sustainable mobility transition and public transport policy-making. By conducting a case study on the transition to zero emission public bus transport in the Netherlands, the results can contribute to the understanding of how such sustainability transitions take place, what are the driving factors and what are the hurdles along the way. It provides insights to policymakers advocating sustainable mobility who can use this knowledge to design better policies in the future. These insights can be used to accelerate the transition or to learn from what has been achieved so far and apply the lessons learned to other sustainability goals. Another societal relevance is the what the combination of two different perspectives can provide to stakeholders. It gives a more comprehensive explanation of the ongoing transition to zero emission public buses in the Netherlands. This can be used by public bus transport authorities, bus operators and bus manufacturers to collaborate more efficiently in the growing market of ZEBs. The case study results can also be used in future research to compare with other countries what has been done differently in the Netherlands, as it is a leading example in the ongoing transition to ZEBs in Europe.

Relevance to the CoSEM program

In this study the ongoing transition to ZEBs for public transport in the Netherlands is studied through the lens of the MLP and the MSF. It can be conceptualized as a sociotechnical system because it involves several aspects, like institutional changes, policy changes, technological developments and different groups of stakeholders. The transition to ZEBs in an actual global development and has over the recent years gained a lot of attention from policymakers, bus manufacturers, public transport authorities (PTAs) and public transport operators (PTOs). This study takes a systems approach by including both the technical and societal developments, making it a suitable topic for the CoSEM program. The societal component here is the expected contribution to a more sustainable mobility sector in order to reduce greenhouse gas emission and air pollution caused by transport. This has created support from the bus market, as well as political and policy support. Policymaking plays a key role in the development of sustainable transitions, which is also the case in the public bus transport sector. The technical component is the development of zero emission technologies, battery electric and hydrogen fuel cell, for buses and the accompanying charging infrastructure development.

Research design

The design used to conduct this research is depicted in Figure 3. The first and second sub-research questions cover the theoretical grounding of the research. Here the literature on the MSF and MLP will be studied to understand the theories, their limitations and their recent developments. To answer the third and fourth sub-research question the MSF and the MLP are applied in a case study of the transition to zero emission public buses in the Netherlands. The background of the case will be explained as well as the context and suitability for the purpose of this research project. The case study will be used to apply the theories and provide practical insights. It will result in explanations of events and trajectories in the transition to zero emission buses in the Netherlands from a policy as well as innovation perspective. While a single case study provides less basis for generalization, it is still a suitable method for qualitative research (Yin, 2009). Then for the fifth sub-research question the case study results are discussed and used as a basis for generating more widely applicable propositions to help synthesize the MSF and MLP. To verify these propositions, interviews will be conducted with scholars whose research expertise includes the MSF and MLP. These interviews can result in adjustments needing to be made to the propositions, as they should be generalizable and applicable to other sustainability transitions as well.

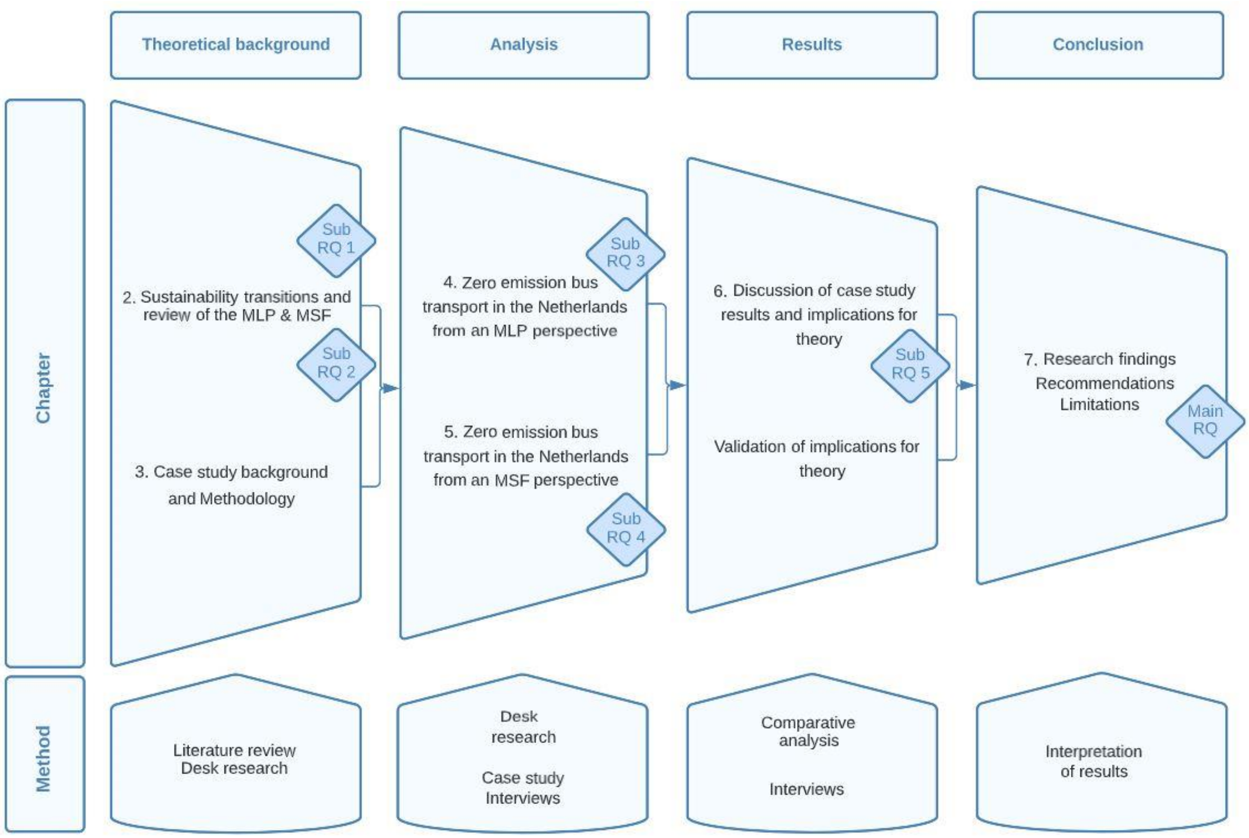

Figure 3 - Research flow diagram

Thesis structure

As depicted in Figure 3 this research is structured into four phases and seven chapters. This chapter introduced the research problem, the research questions, the scientific and societal relevance and discussed the research design. In chapter 2 the theoretical background phase starts with a discussion of sustainability transitions. Then it provides a review of the MLP and the MSF, with the refinements made by scholars over the years. Together this forms the theoretical foundation of the research. Next, in chapter 3, the case study is introduced and the methodology is discussed. The analysis phase starts in Chapter 4, where the ongoing transition to zero emission public buses in the Netherlands is analyzed from the perspective of the MLP. Then, in chapter 5, this is done from the perspective of the MSF. Chapter 6 presents the discussion of the case study results, implications for theory and validation. Finally, the conclusions, limitations of the research as well as recommendations for future research are discussed in chapter 7.

2. Theoretical background

In the previous chapter the research problem was introduced. This chapter first describes what socio-technical systems and sustainability transitions are through literature research. Then it presents a literature review of the MLP on technology transitions. It also discusses how scholars have built on this theory and added more details to the levels and dynamics over the years. Next a literature review is presented of the MSF on policy change and how it has been incrementally refined or extended by scholars to include more aspects of the policy process over the years.

2.1 Socio-technical systems

A socio-technical system is a concept used to describe the elements and linkages of a societal sector, like energy supply, water supply, communication or transportation. It is a network of physical components, legislative components, organizations, resources, culture and knowledge that interact in order to achieve societal functions (Hughes, 1987; Geels, 2004; Markard et al., 2012).

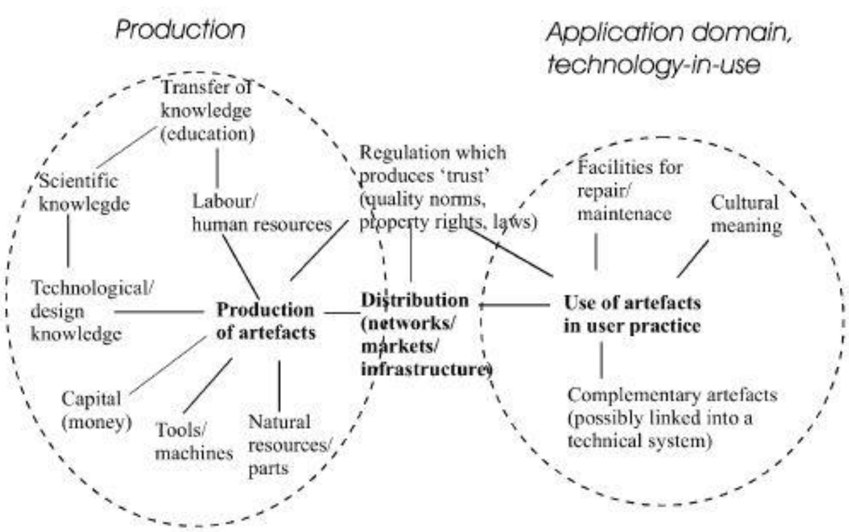

Figure 4 – Socio-technical systems (Source: Geels, 2004)

As technology plays a major role in modern society, Geels (2004) divided the socio-technical system into production, distribution and use of technologies, each with their needed resources, like tools, capital, labor etc. (see Figure 4). Dominating structures in society are referred to as the regime, or the "deep structure" of rules that coordinate the activities between actors and keep the existing socio-technical system stable (Geels, 2011). These highly institutionalized rules (like regulations, shared beliefs or capabilities) develop and are developed by actors in the regime and the innovations that take place are mostly incremental (Fuenfschilling and Truffer, 2014). As there are different groups of actors (like industries, users, public authorities or research institutes), there are also different rules, which can be grouped into different regimes (like user regimes, policy regimes or science regimes) within the regime itself (see, Figure 5). These regimes are autonomous, but at the same time also interdependent (Geels, 2004). A distinction can be made between formal and informal institutions, where formal institution are laws and regulations and informal institutions are ideas and norms that guide actions (Negro et al., 2012). Geels (2004) makes a more elaborate distinction between regulative, normative and cognitive institutions, which includes values, beliefs and priorities.

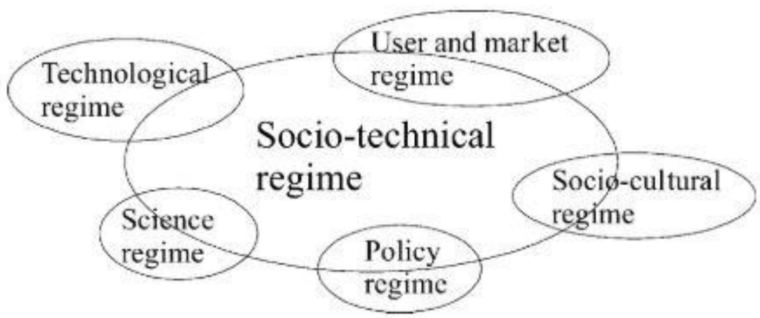

Figure 5 - Socio-technical regime (Source: Geels, 2004)

2.2 Socio-technical transitions and sustainability

Socio-technical systems in society have faced, and are still facing, structural problems in many sectors. For example the environmentally damaging greenhouse gas emissions in the energy sector or traffic congestion and air pollution problems in the transport sector. To solve such problems, which are deeply rooted in existing socio-technical systems, regime change may be necessary (Berkhout, 2002). This change or shift from one socio-technical configuration to another is what is referred to in literature as a socio-technical transition (Kemp, 1994; Geels, 2002). It involves changes in technological, institutional, political and socio-cultural dimensions, with many types of actors during a considerable timespan. During the transition new products, services, business models, organizations, regulations and user practices complement or replace the existing structures (Markard et al., 2012). For example the transition from horse-drawn carriages to automobiles, which has been studied by Geels (2005), required not only the automobile technology itself, but also the development of roads, fuel supply, traffic systems, maintenance services, user practices etc.

Sustainability transitions are purposeful socio-technical transitions towards a sustainable society (Markard et al., 2012; Grin et al., 2010). They are highly complex, as they involve many actors and interests, and they are of high societal relevance, given the many sustainability challenges we are facing in the world today. The transition from combustion engines to zero emission buses is driven by the fact that the transport sector is responsible for almost 25% of European greenhouse gas emissions and a major cause of urban air pollution (Thorne, 2021). In sustainability transitions governance plays an important role, as there are long-term goals and different actors need to coordinate and work together to achieve them. Transitioning to a more sustainable regime requires not only necessity, but also feasibility and benefits for the broad range of actors and institutions involved (Berkhout, 2002). This is why political actors and regulatory and institutional support are expected to play a major role (Smith et al., 2005; Markard et al., 2012). While it is vital for governments to make strong commitments to an emergent technological regime, there is also a risk of, in hindsight, supporting a sub-optimal technological alternative (Berkhout, 2002). This is especially the case with new and unknown technologies or applications. Fostering trajectories for a wide range of options would then be the rational strategy. This could explain the application of both battery electric and hydrogen fuel cell buses in the transition to zero emission public bus transport. Understanding the dynamics of sustainability transitions can help policy makers implement or facilitate the needed changes for sustainability goals.

2.3 The Multilevel perspective on technology transitions

As previously mentioned, the MLP describes technology transitions as consisting of three levels: technological niches, socio-technical regimes and the landscape developments. There is a hierarchical relation between the levels, which is illustrated in Figure 6. This means that niches are embedded within regimes and regimes are embedded within landscapes (Geels, 2002).

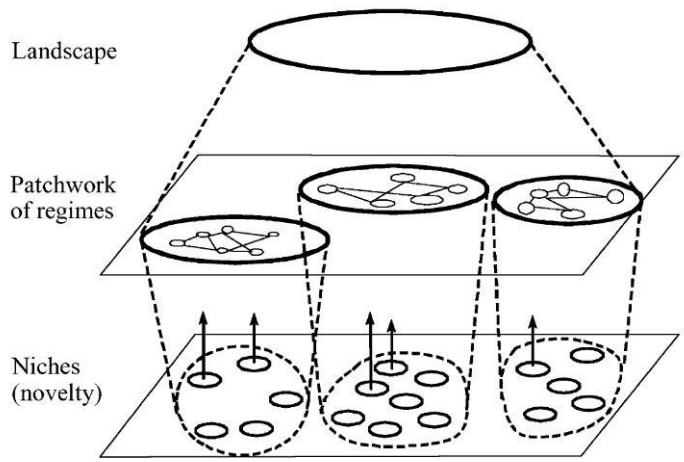

Figure 6 - Multiple levels as a nested hierarchy (Source: Geels, 2002)

A transition, or regime shift, takes place when developments in the landscape put pressure on the existing regime so niche innovations can break through, causing a "window of opportunity" (Geels, 2002). These key elements of the MSF are explained next.

The landscape development

The landscape development occurs on the macro level and contains the technology-external factors and structural trends that emerge and change slowly over time, such as oil prices, broad political coalitions, environmental problems and wars (Geels, 2002).

The socio-technical regime

The socio-technical regime occurs on the meso level and contains the dominating and stabilized structures, rules and practices that enable and constrain existing systems. It can be structured into technology, techno-scientific knowledge, policy, market and user practice, culture, infrastructure and industrial networks. Innovation also occurs at this level, but in an incremental way (Geels, 2002).

The technological niche

The technological niche occurs on the micro level and contains the protective spaces where radical technology innovations can take place and develop further. Here they are given space to go through a learning process and build the needed social networks to support their growth and increase their resources (Geels, 2002).

Window of opportunity

A window of opportunity is an interaction between the micro, meso and macro levels when pressure from the landscape destabilizes the regime or due to internal tension within the regime building up to change the landscape. Radical innovations can then break out of the niche level (Geels, 2002).

2.4 Building on the MLP

In a follow up study Geels (2004) reflected on the use of the MLP in several empirical studies and the criticisms received from peers. He then identified a need to differentiate the multi-level perspective, in order to include the differences between sectors and industries. To address this the author recommended the creation of different routes in systems innovations and transitions. This led to Geels and Schot (2007) then developing four transition pathways: transformation, reconfiguration, technological substitution, and de-alignment and re-alignment (see Figure 7).

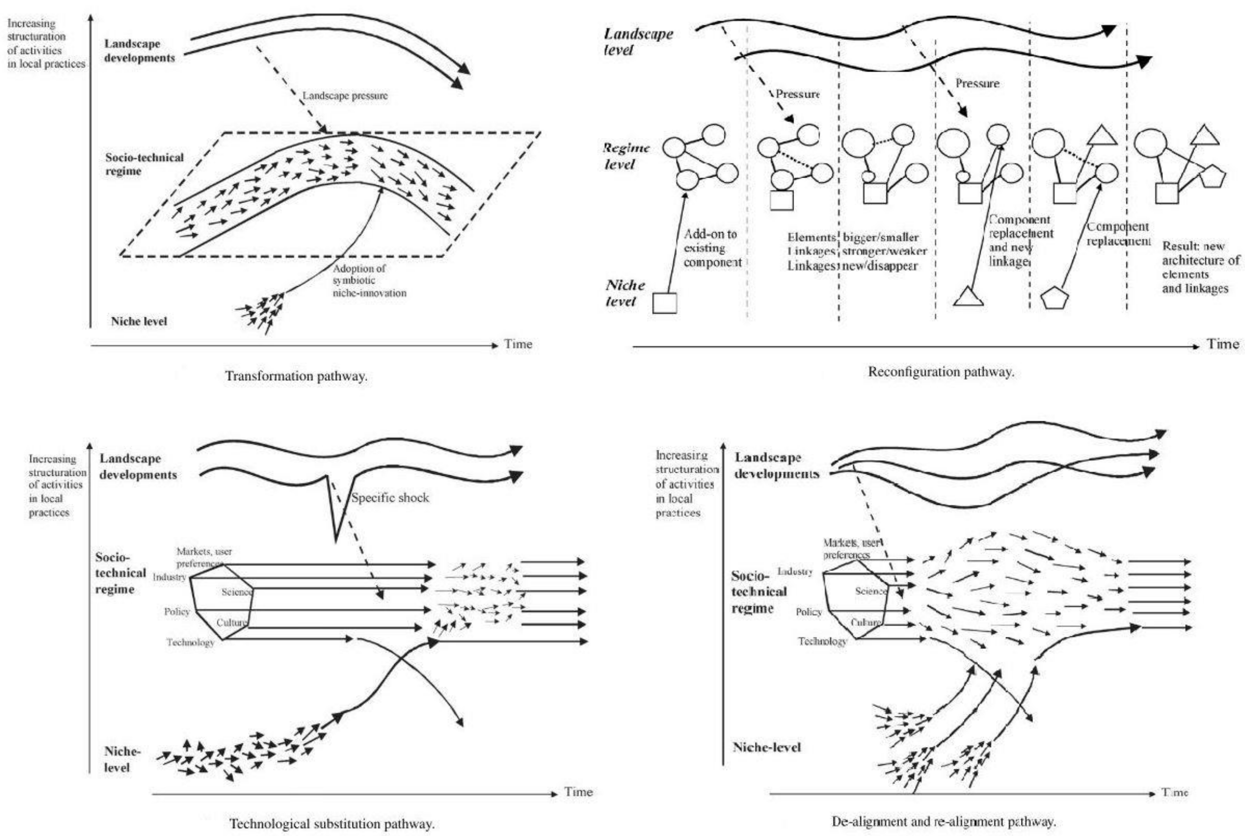

Figure 7 - Transition pathways (Source: Geels and Schot, 2007)

In doing so they built on the MLP by addressing differences in timing and nature of interactions between the three levels and by including agency and (inter)actions. They state that these pathways are not deterministic and do not necessarily occur purely, but they do add to the logic of the framework. They also state that it is possible to have a sequence of paths, meaning that a transition can start with one path and then shift to another (Geels and Schot, 2007). In the transformation pathway there is moderate pressure from the landscape on the regime. At this time innovations on the niche level have not been sufficiently developed yet. As a result, the regime will change the direction of development paths and incremental innovation activities (Geels and Schot, 2007). In the reconfiguration pathway symbiotic innovations developed on the niche level enter the regime to solve local issues. In doing so they then trigger further adjustments in the structure of the regime (Geels and Schot, 2007). In the technological substitution pathway there is a lot of pressure from the landscape on the regime. At this time innovations on the niche level have already been sufficiently developed. They then break through and replace the existing regime (Geels and Schot, 2007). In the de-alignment and re-alignment pathway the changes in the landscape are sudden, large and divergent. This causes problems in the regime leading to de-alignment. There is no dominating niche innovation, resulting in the co-existence and competition for resources of multiple niches. Eventually one of the niche innovations dominates and starts to re-align the new regime (Geels and Schot, 2007).

Fuenfschilling and Truffer (2014) look further into the operationalization of the regime level using institutional theory. They explain the nature of structures and how they establish in regimes and they analyze how this influences the behavior of actors and the diffusion of practices. This contributes to the understanding of the dynamics within the regime level, as well as the interactions between landscape developments and emerging technological niches (Fuenfschilling and Truffer, 2014).

Geels (2011) also responded to several other criticisms on the MLP, like lack of agency or the specification of regimes. He states that the MLP does make certain tradeoffs, but that transitions are complex phenomena and they will simply always have elements of creative interpretation.

2.5 The Multiple streams framework on policy change

The MSF, as previously mentioned, describes a policy process as consisting of three parallel processes: the problem stream, the policy stream and the politics stream. When these largely independent streams are coupled as a result of focusing events in the problem stream or due to activities of policy entrepreneurs at the right point in time, during a "policy window", policy shift takes place (Kingdon, 1984). These key elements of the MSF are explained next.

The problem stream

The problem stream consists of conditions that have been labeled as problematic (Kingdon, 2003). These conditions become problems when policymakers decide that action needs to be taken (Llamosas et al., 2018). This happens mostly through focusing events, where attention is brought to problems (like natural disasters or strikes) and systemic indicators of situations are presented (with data, statistics, reports etc.) (Kingdon, 2003). Conditions are evaluated through a set of values, by comparison (of the situation in different countries for example) or categorization (of a condition as sub-optimal in relation to the ideal for example) (Llamosas, 2018).

The policy stream

The policy stream consists of solutions, ideas, alternatives and policy proposals that have been developed by a community of specialists (Kingdon, 1984). They interact, modify, refine and either discard or endorse proposals to what they consider societal problems (Llamosas, 2018). This collection of proposals is what Kingdon refers to as the "policy primeval soup" and they may or may not solve the problem at hand. After discussions, modifications and arguing a limited number of policy proposals survive, based on their technical feasibility, value acceptability, public acceptance and financial viability (Weible and Sabatier, 2018).

The political stream

The political stream consists of interest groups, national mood (public opinion) and political interests that motivate policymakers to focus on a specific problem and solution (Kingdon, 2003). This can be influenced by strong views of popular politicians, organized forces (in politics, business or industry), political parties and government officials (Llamosas, 2018).

Policy window

A policy window is a point in time when there is an opportunity for advocates to push their policy proposal or attention to their problem (Weible and Sabatier, 2018). They can open as a result of changes in the problem or political stream or due to activities of policy entrepreneurs (Herweg et al., 2015). Agenda change is more likely to happen when there is a policy window, but it does not always lead to a solution of the problem. The three streams need to ready for coupling as well. (Kingdon, 2003).

Policy entrepreneur

A policy entrepreneur is an actor who tries to influence policy outcomes by presenting their preferred solution to a problem at the right moment (Herweg et al., 2015). This can be a politician, leader, journalist, academic or any policy relevant actor (Weible and Sabatier, 2018). They try to gain support from policy makers, attach problems to their solutions and take advantage of new political developments to push forward their favorite policy (Kingdon, 2003).

2.6 Building on the MSF

Extending the MSF, one of the refinements made by Herweg et al. (2015) is including the decision-making phase of the policy process. To do so they introduced a second coupling process, the "decision window", which takes place after a new item has been set on the agenda (see Figure 8). Here the focus lies on the negotiations around the concrete design of the policy proposal. They argue that introducing a second coupling process into the framework allows for more focus on the circumstances for policy adoption, as well as the influence of agenda coupling on the negotiations during the decision-making phase (Herweg et al., 2015).

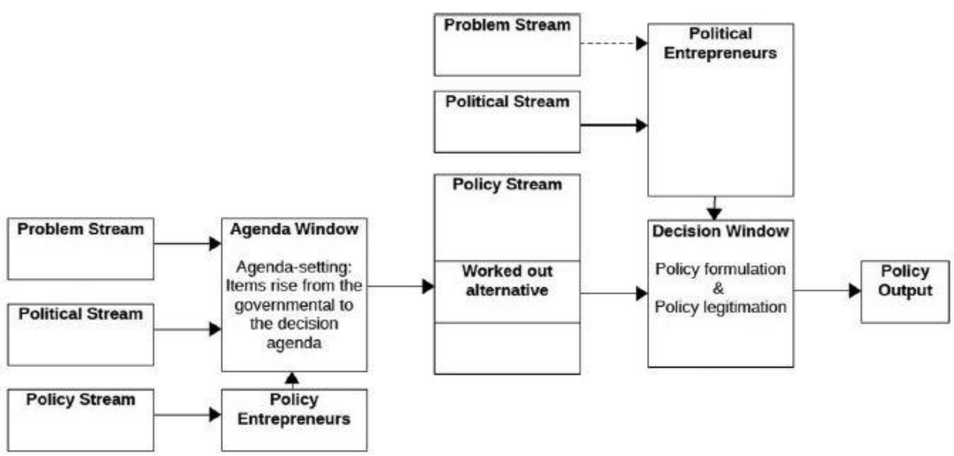

Figure 8 - Modified Multiple Streams framework with decision window (Source: Herweg et al., 2015)

Howlett et al. (2015) argue that the MSF does not suffice complexities and unexpected changes of the policy process, because the three streams are independent until they become coupled. They propose a five stream metaphor, based on a combination of policy stages/cycles and multiple streams, which includes aspects of agency, power, ideology, turbulence and complexity. Here, there is also differentiation between a policy-making and decision-making phase. They argue that each of these phases start with a "whirlpool" of appraisal followed by a consolidation phase, consisting of five streams (see Figure 9). The two new streams introduced here are the process and programme stream. It also shows that during policy formulation there are dominant streams, helping to explain how problem definitions can be changed during the process (Howlett et al., 2015).

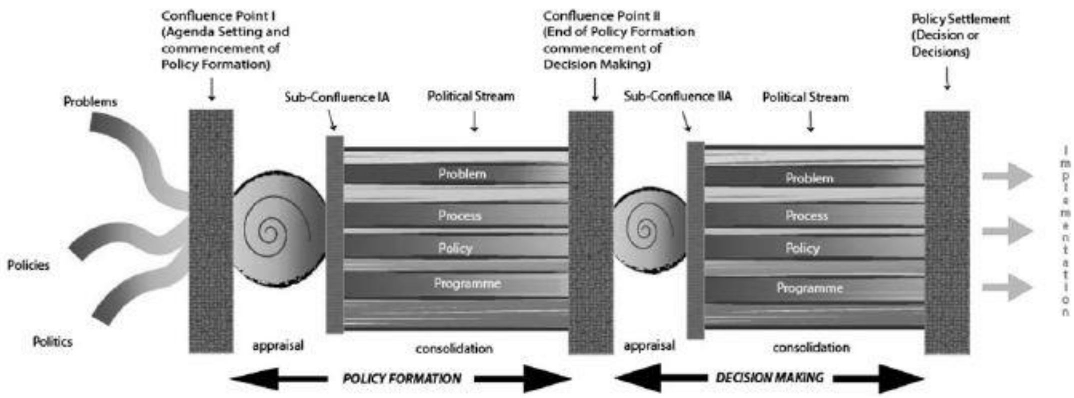

Figure 9 - Five stream confluence model with dominant political stream (Source: Howlett et al., 2015)

Zahariadis and Exadaktylos (2016) further look into the role of policy entrepreneurial strategies to explain why some adopted polies succeed and others fail to be implemented, highlighting ambiguity and conflict. They argue that coupling also takes place during the implementation phase, in which closely linked streams and specified conditions prompt decoupling and recoupling. They also argue that entrepreneurs alone do not cause policy reform, but also the different circumstances and actors during different stages of the policy process (Zahariadis and Exadaktylos, 2016). Highlighting the problem stream, this has been developed further by Knaggard (2015), who suggested the inclusion of the problem broker. This is the role that actors take to frame problems and make policy-makers accept them. They argue that problem framing influences policy entrepreneurs and thus also agenda-setting and decision-making (Knaggard, 2015).

Although several refinements and extensions have been made to the MSF over the years, in this study Kingdon's original definitions and design will be used. This is because the aim is not to have a deeper more detailed explanation of the policy process itself, but rather to find the links between the policy processes and the socio-technical developments of sustainability transitions.

2.7 Bringing together the MLP & MSF

As stated by Derwort et al. (2021) in their study of the German energy transition using the MLP and MSF, the combination of these two frameworks allows for the identification of policy-technology feedback links, influence of political decisions on technological development and different types of agency involved. The MSF describes policy changes as discrete events that take place at a time when the three streams are coupled and a policy window is open. It acknowledges that several policy ideas exist and go through a process of filtering based on criteria for survival, but it does not really explain where these policy ideas come from. The MLP on the other hand brings the perspective of the evolution of niche innovations and the way they challenge the dominant regime (Derwort et al., 2021). The MLP looks at transitions in an evolutionary way over a longer period of time, involving changes in technologies, institutions, infrastructures and practices. However, it does not include political struggles and decisions that impact the trajectory. The MSF on the other hand offers the perspective of decision points where policy outputs impact future ones by feeding back into the socio-technical system (Derwort et al., 2021). It can also be noticed that both the MLP and MSF contain the concept of "windows" that are presented under certain conditions and recognize the role of agency herein. The MLP emphasizes technological innovations developed by niche actors and the MSF includes policy innovations and lobbying by political actors and policy entrepreneurs (Derwort et al., 2021). The study by Derwort et al. (2021) shows that the combination of the MLP and MSF can be used to explain how sustainability transitions emerge from interaction between socio-technical and political dynamics. However, it does not address specific links between these two frameworks and how this can possibly be used for theory synthesis in future research.

2.8 Conclusion

This chapter first described what socio-technical systems and sustainability transitions are, based on literature study. Then the multilevel perspective on technology transitions and the multiple streams framework on policy change are discussed and their refinements and extensions over the years are also mentioned. Lastly, the ways in which these two frameworks show similarities and complement each other are discussed, based on the literature review and a previous study by Derwort et al. (2021). This reveals that the MLP and MSF can be used to explain how sustainability transitions emerge from interaction between socio-technical and political dynamics. To examine the links between these two frameworks, a case study will be conducted, which is discussed in the next chapter.

3. Case study background & methodology

In the previous chapter the theoretical foundation of this research was discussed. Before empirically analyzing the two theoretical frameworks, this chapter first introduces the case study of the Dutch transition to zero emission public transport buses and its relevance for the purpose of this study. Then the data collection and data analysis strategy is presented and the data validation strategy is discussed.

3.1 Case study introduction

Timespan

Although electric buses have been around since the early 19th century, improvement in battery technology and rising environmental concerns have sparked a rise in their market share globally from 2010. This is also the case in the Netherlands, where the first public bus transport companies started using electric buses in 2013 (CROW-KpVV, 2021). Before this time there were mostly diesel, hybrid and natural gas buses in the public bus fleet. An important change in the Dutch public bus sector was the Passenger Transport Act in 2000, which transferred the public bus authority from a national to a more regional level. This effectively changed the structure of authority in the Dutch public bus sector. What led to the adoption of this policy was not related to ZEBs or cleaner buses in general and thus will not be included here. The case study will therefore focus on the period between 2000 and 2022.

Geographical boundaries

The main focus of the case study is on a national level, as it analyses the Dutch national public bus fleet. While authority in the Dutch public transport sector is on a regional level, policies are implemented at a national level and the subsequent strategies that develop as a result thereof are different per region. Relevant events on the European level are also included in the analysis to identify causes that influenced the transition to ZEBs in the Netherlands. This is because the Netherlands is a member of the European Union and policy plays a major role in this case.

Zero emission buses in the Netherlands

There are three types of ZEBs in the Netherlands: Battery electric buses (BEBs), Hydrogen or Fuel cell electric buses (FCEBs) and trolley buses. FCEBs use a combination of compressed hydrogen and oxygen in fuel cells and batteries to power an electric motor (Brdulak et al., 2020). The fuel cells generate the energy for overall operation of the bus, while the battery provides peak power to the motor for rapid acceleration and gradients (Fuel Cell Electric Buses, 2022). All required energy is provided by hydrogen, which is stored on board. An infographic of a typical hydrogen bus is shown in Figure 10. BEBs use batteries, with plug-in charging, to power an electric motor (Brdulak et al., 2020). Figure 11 illustrates a typical electric bus.

Figure 10 - Van Hool fuel cell bus (Source: Fuel Cell Electric Buses, 2022)

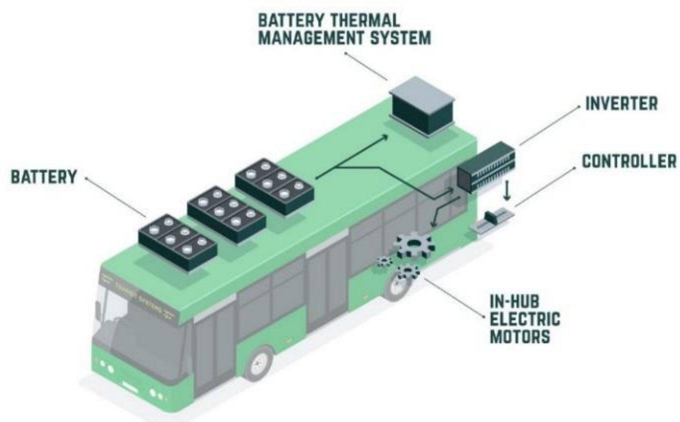

Figure 11 - Battery electric bus (Source: Transit Systems, 2022)

With the growing market for sustainable buses and advances in battery technology, ZEBs have seen improvements in cost competitiveness on a lifecycle basis. The initial costs do however remain high and therefore contracting and financing mechanisms play an important role in ZEB adoption (Brdulak, 2020). The electric vehicle supply chain is also starting to become more established and the availability of charging infrastructure is increasing in the Netherlands. This is an important factor contributing to the ZEB transition because of the low energy density of Li-ion batteries. As stated by Abdelwahed (2020), charging times for a depleted battery in a BEB range up to an hour, even with fast charging infrastructure. They have a limited driving range and need to be charged during the day. This is one advantage that FCEBs have over BEBs as hydrogen has a higher energy density than batteries, enabling longer ranges. This means that they can typically be refueled once a day, like diesel buses, which takes only around 7 minutes (Fuel Cell Electric Buses, 2022). However, there is a lot of innovation taking place to extend the driving range as well as decrease the charging and refueling time of both BEBs and FCEBs. The latest Ebusco 3.0 BEB has an expected range up to 575 km, which means only overnight charging will be needed (Ebusco, 2022).

Since 2016 the Dutch public transport system has added more than 1000 battery electric and hydrogen fuel cell buses to their bus fleet (Sustainable bus, 2020; Fuel Cell Works, 2019). With more than 20% of public buses now being electric, the transition to zero emission public transport buses in the Netherlands has become evident (Rijksoverheid, 2021; Sustainable bus, 2020). The current Dutch public bus fleet consists of around 5250 buses, of which 1310 (25%) are battery electric and 58 (1.1%) are hydrogen fuel cell buses (CROW-KpVV, 2022).

There have also been trolley buses in the city of Arnhem ever since 1949. These buses are powered by dual overhead wires, using spring loaded trolley poles (see Figure 12). Starting with around 193 trolley buses in 1950, today there are only 40 left in operation in Arnhem (Nederlandse Trolleybus Vereniging, 2022). It is the only trolley bus network left in the Benelux and one of the biggest in Western Europe. These buses will not be included in the case study, as they represent a very small share of the public transport bus fleet in the Netherlands.

Figure 12 - Trolleybus in Arnhem (Source: Indebuurt Arnhem, 2022)

Sustainable mobility policy

Under the Climate Act laid down in 2019 the Dutch government wants to reduce CO_2 emissions in the Netherlands by 49% in 2030 and 95% in 2050, compared to the 1990 levels (Rijksoverheid, 2022; Rijkswaterstaat, 2022). This resulted in the National Climate Agreement in 2019, which includes agreements for sustainable mobility. The Dutch Ministry of Infrastructure and the Environment is responsible for the implementation of plans set under this agreement. Already in 2016 the Dutch Ministry of Infrastructure and the Environment signed a "Zero Emission Regional Public Transport by Bus" administrative agreement with 14 transport authorities. It states that from 2025 onward all newly purchased public transport buses must use 100% renewable energy and from 2030 all public transport buses in operation must be fully emission free (International Energy Agency, 2020; Rijkswaterstaat, 2022). This came after the 2015 Paris Agreement, which is a legally binding international treaty on climate change (United Nations Framework Convention on Climate Change, 2022). Electric transport policy in the Netherlands is created in line with the Dutch polder model, which characterizes partnerships and consultation with private parties to develop supported policy (Netherlands Enterprise Agency, 2019). An example of this is the Formula E-Team, which is a national public-private partnership that brings together business, academia and government to advance e-mobility (Nederland Elektrisch, 2022).

3.2 Case study relevance

The current transition to zero emission public transport buses in the Netherlands can be conceptualized as a socio-technical transition because it involves changes in technological, institutional, political and socio-cultural dimensions. The ongoing transition to ZEBs in the Netherlands is a leading example in Europe. In 2020 more than 80% of newly purchased buses in the Netherlands were zero emission, bringing the total share of ZEBs in the fleet well over 20%. This is a significantly higher percentage increase as compared to other European countries, which can be seen in Figure 13 (European Federation for Transport and Environment, 2022). There are many types of actors involved in the transition, like local bus manufacturing companies, local charging infrastructure and solutions providers, national and international electric transport partnerships and organizations, government institutions and policymakers. Next to the development of zero emission technologies, policy also plays a key role here. This makes it an interesting case to apply a combination of the MLP and MSF to, possibly providing a more comprehensive explanation of the developments over time as well as its success.

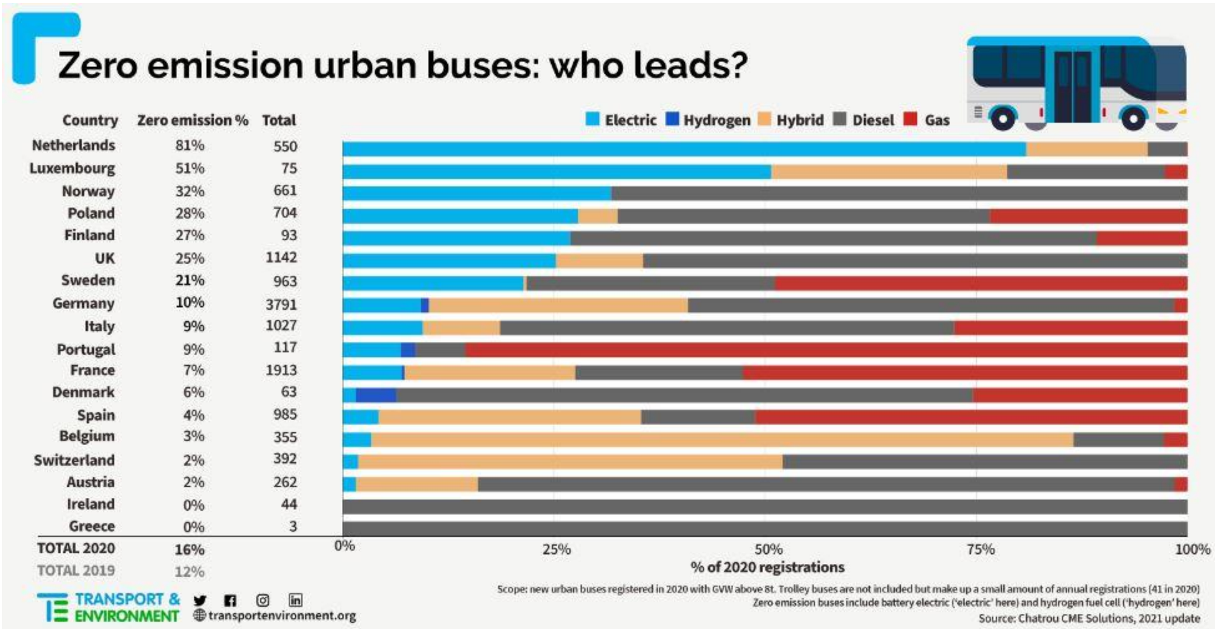

Figure 13 – Zero emission buses in Europe (Source: transportenvironment.org)

3.3 Data collection

The data collection strategy for the case study consists of desk research and interviews. The data sources used are a combination of academic literature, official reports, policy documents and interview transcriptions. Using a variety of sources to gather information about the case gives a broad perspective and can possibly also verify statements through data triangulation.

Desk research

A search for academic literature is done in Scopus, Google Scholar and Connected papers. Official government reports, public transport data, policy documents, bus company reports and tech-innovation reports about zero emission buses are also used. These gray literature resources are used to gather contextual information about ZEBs and sustainable mobility policy in the Netherlands which cannot be found in academic journals. Gray literature is often more up-to-date than academic research (Paez, 2017). However, it is not subjected to peer-review. This is also the case with interviews and must be considered in the interpretation of results of the case study.

Interviews

The interviews conducted for the case study are semi-structured, in order to guide the conversation in a specific direction while also allowing room for the interviewee to provide explanations or insights which might have been overlooked or excluded during desk research. Interviewees are selected to complement, elaborate on or verify data gathered from desk research and consist of a representative of a public transport authority, public transport government agency, bus manufacturing company, transport knowledge platform, public bus transport operator and a transport expert (see Table 1). Six interviews of about 30 minutes were conducted during the research project, in May/June. The interviews were conducted online.

The questions that were prepared for each interviewee beforehand were dependent on their area of expertise about the ongoing transition to ZEBs in the Netherlands. The invitation was sent in English and the interviews were conducted in English as well, unless the interviewee indicated a preference for Dutch. The interviews were then transcribed to be able to conduct qualitative data coding.

Interview code	Actor	Organization
I-1	Transport expert	Delft University of Technology
I-2	Public transport authority	Provincie Zuid-Holland
I-3	Transport Knowledge platform	CROW
I-4	BEB manufacturer	Ebusco
I-5	Ministry of Transport	Rijksoverheid & RWS
I-6	Public transport operator	GVB
I-7	Public transport operator	HTM

Table 1 – Anonymized list of interviewees

Ethics

Interviewees are given a consent form and checklist and asked for their permission to record and transcribe the interviews, as part of the Human Research Ethics rules of the TU Delft. The interview transcripts are not included in this report.

3.4 Data analysis

Qualitative data coding

The collected data is then treated and analyzed by means of qualitative data coding. Qualitative data coding is used to create and assign codes to categorize pieces of information found in the data sources. These codes can then be used to identify links, themes and patterns between pieces of information. The type of coding used here is a combination of what Holton (2012) refers to as substantive coding, which includes both open and selective coding procedures, and axial coding (Scott and Medaugh, 2017). In substantive coding the data is fractured, analyzed and labeled first through open coding. During open coding the data is closely examined to identify emerging categories and related concepts. Then, through selective coding, the data is linked to theoretical concepts (Holton, 2012). Axial coding is applied in order to organize the large amount of open coded data into more abstract concepts (Scott and Medaugh, 2017). The coding procedure is illustrated through an example in Figure 14. It shows how the "fuel cell electric bus pilot" and " battery electric bus pilot" labels used in the open coding step are categorized into "pilot projects with ZEBs" in the axial coding step and subsequently linked to "niche" in the selective coding step.

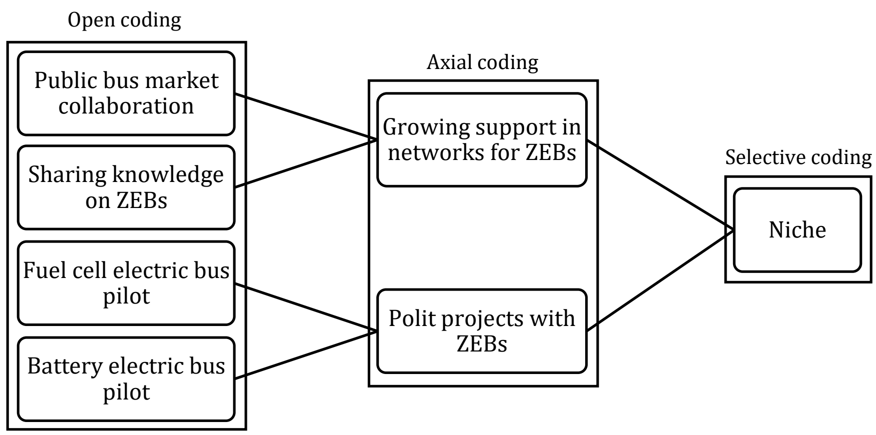

Figure 14 – Example of the coding procedure

Qualitative data coding will be performed using ATLAS.ti (ATLAS.ti Scientific Software Development GmbH, 2022), a well-known and widely available computer software for qualitative data analysis. In ATLAS.ti a coding scheme and syntax is used to ensure uniformity and clarity during the coding procedure. Table 2 shows randomly selected examples of the coding syntax used for each of the different steps of the coding procedure.

Open coding	oc-higher initial costs ZEBs
Axial coding	ac-public private partnerships for ZEBs
Selective coding	sc-PROBLEM STREAM

Table 2 - Coding syntax used in ATLAS.ti

The coding scheme is presented in Table 3. It shows the definitions of the codes in the selective coding step. These codes are connected to the different structural elements of MSF (problem stream, policy stream, political stream, policy window and policy entrepreneur) and the MLP (landscape development, socio-technical regime, technological niche and window of opportunity), linking the data to the theories. The definitions used here are based on the literature review in Chapter 2, with the added specification of focusing on an international level for landscape developments. This choice is made because in the case study the socio-technical regime is analyzed on a national level and landscape developments are considered to occur in an exogenous context (Derwort et al., 2021).

	Element	Definition
MSF	Problem stream	Conditions identified as problematic (through indicators, focusing events, and policy feedback) and for which action needs to be taken.
	Policy stream	Collection of proposals, ideas and alternatives available in policy communities that meet criteria of survival.
	Political stream	Institutional setting, balance of interests, national mood, pressure campaigns and political motivation directing the focus of policymakers.
	Policy window	Opportunity for advocates to push their policy proposal or attention to their problem through focusing events, a shift in national mood or created by the policy entrepreneur.
	Policy entrepreneur	Key actors trying to influence policy outcomes in their favor.
MLP	Landscape development	Technology external factors, slow changes and structural trends taking place on an international level.
	Socio-technical regime	Established technology, infrastructure, knowledge, culture, policy, networks, markets and user practices.
	Technological niche	Experimentation, pilots and radical innovation taking place in protective spaces.
	Window of opportunity	Destabilization of the regime due to internal tension or pressure from the landscape.

Table 3 - Selective coding scheme

Process tracing

The coded data is then analyzed using process tracing. It is a fundamental tool to analyze trajectories and causations of change (Collier, 2011; Beach and Pedersen, 2013). In this research process tracing is applied to arrange the data in a way that is in line with the expectations of the MLP and MSF (Derwort et al., 2021). The type of process tracing used here is what Beach (2017) and Beach and Pedersen (2013) refer to as explaining outcome process tracing, in which causal mechanisms are traced to provide an explanation of historical events.

The sequences of events are interpreted first through the lens of the MLP and then through that of the MSF. This means that the ongoing transition to ZEBs and the key policy changes are reconstructed over time and causes of changes or outcomes are assessed. This is done by labeling the coded data according to the year that the events took place, which then shows a trajectory of events. An example of this is illustrated in Figure 15. It shows how first in 2009 projects with ZEBs were being executed by different stakeholders to learn about the operational aspects of the technology. Then in 2012 the market started to pick up on this trend by, for example, further developing batteries and charging infrastructure. This led to a growing support in networks for ZEBs in 2016. Process tracing allows for a comparison of the way the two theories explain the trajectory of the transition and potentially could provide a more complete picture of the coevolution between technological and policy changes.

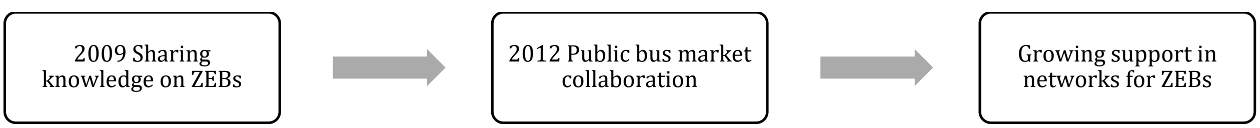

Figure 15 - Example of the process tracing procedure

3.5 Validation

Data validation

Assumed causal relations between events are tested and verified by using various sources. For example in Figure 15 excerpts relating to "growing support in networks for ZEBs" are found in Ministry of Infrastructure and Water Management (2020), Bakker and Konings (2018), Netherlands Enterprise Agency (2019) and Kok et al. (2017). Different types of data sources (policy documents, interviews and scientific literature) are used as much as possible for data triangulation to contribute to the internal validity of the research.

Research validation

During the research it is attempted to address selection bias by selecting interviewees from different organizations involved in the public bus market in the Netherlands, while also accounting for the difference in opinion that may be present. The coding procedure is explained in detail, however, it is acknowledged that there are certain levels of subjectivity in this method. For example when defining the elements in the selective coding step or by overlooking information when labeling the data in the open coding step. The reliability of the research is shown by using a clear and well-structured coding syntax and labeling the coded data by year to explain the trajectory of events.

Validation of results

The external validation of the results is to be conducted by means of three semi structured interviews. One interview will be conducted with a postdoctoral researcher whose research field is governance and sustainable development and has used both the MLP and MSF in scientific article publications. A second interview will be conducted with a professor of science and technology policy. The third interview will be with a senior researcher whose research includes sustainability transitions and transformation pathways. They will be asked specific questions on the results of the case study and its implications for possibly linking the two theories in the future. Next to this, they will also be asked about their opinion regarding the use of the combination of the MLP and MSF to explain sustainability transitions and the propositions for theory synthesis generated in this study. Lastly, room will be given for any feedback on elements which might have been overlooked during this study.

3.6 Conclusion

In this chapter first the case study of the ongoing transition to zero emission public transport buses in the Netherlands is introduced and its relevance for the purpose of this study is discussed. Then the case study methodology, the data collection and data analysis strategy, is presented. Lastly, this chapter discussed the validation strategy for the used data, the research design and the results that are generated. In the next chapter the case study is conducted by applying the multilevel perspective.

4. Explaining the transition to ZEBs using the MLP

In this chapter the Multilevel perspective is used to describe the ongoing Dutch zero emission public bus transition. As stated by Geels (2002), there are phases in sustainability transitions. Currently, ZEBs are well on their way to replacing diesel buses in the Dutch public bus regime. This chapter discusses the developments on the landscape, regime and niche levels that have influenced this ongoing transition, which is illustrated in Figure 16.

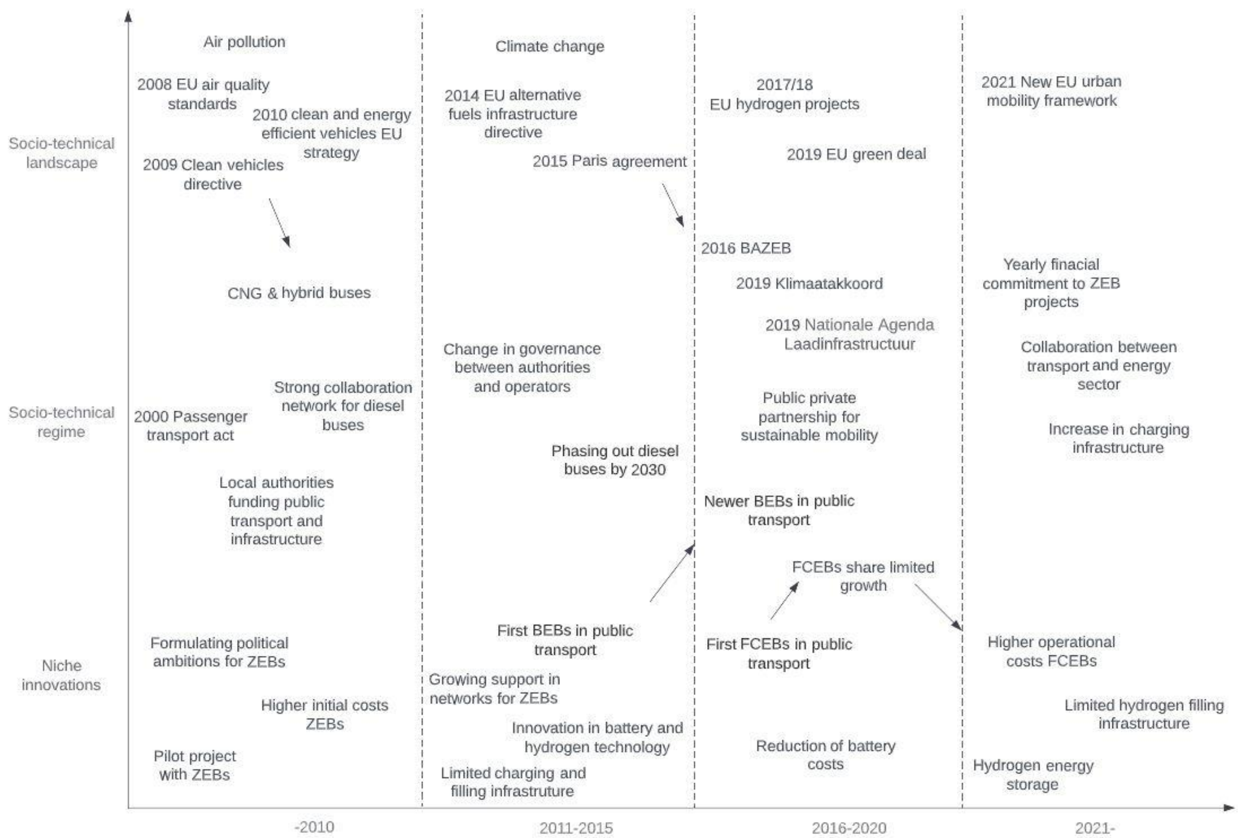

Figure 16 – The ongoing transition to ZEBs from the Multilevel perspective

4.1 Landscape developments

As a member of the European Union, the Netherlands is part of a broader political and economic regime in Europe. Together with other member states they agreed to follow several EU policies over the past years, which include the development of sustainable mobility. This was a result of increased concern about traffic congestion and air pollution in Europe. In 2008 the EU implemented the EU

Directive 2008/50/EC on ambient air quality and cleaner air for Europe, which sets air quality standards for national governments that must not be exceeded (European Parliament and Council of the European Union, 2008). One of the goals was to reduce the environmental impact of traffic by supporting cleaner technologies for mobility, like hybrid drive, hydrogen, natural gas and biogas (Ministry of Transport, Public Works and Water Management. 2010). This prompted the EU Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles in 2009 (European Parliament and Council of the European Union, 2009), which was revised in 2019 to set national targets for public procurement of zero emission vehicles. In 2010 the Clean and Energy-efficient Vehicles EU strategy was developed to stimulate the procurement of clean and energy-efficient vehicles through grants and support by the European investment bank (European Commission, 2010).

In order to provide the long-term security needed for investment in the technology of cleaner vehicles and improve coordination in the development of alternative fuel infrastructure, the Alternative Fuels Infrastructure Directive was set in 2014. It required member states to create national policy frameworks (NPFs) for the development of publicly available fueling and charging infrastructure for cleaner vehicles (European Parliament and Council of the European Union, 2014). As a result of the Conference of the Parties of the United Nations Framework Convention on Climate Change (COP21) in Paris, the 2015 Paris Agreement was signed by 196 Parties, including the Netherlands. The goal of this agreement is to reduce greenhouse gas emissions in order to limit global warming to well below 2 °C, compared to preindustrial levels (United Nations Climate Change,2015). Under this agreement falls the Declaration on Electro-Mobility and Climate Change and Call to Action, as the transport sector is one of the major contributors of greenhouse gas emissions. In this declaration members commit to an increase of electro-mobility (United Nations Climate Change,2015).

In 2017 and 2018 the JIVE1 and JIVE2 (Joint Initiative for hydrogen Vehicles across Europe) projects were initiated by the European Union to support large scale deployment of hydrogen vehicles and infrastructure. These projects contribute to knowledge development and cost reduction of hydrogen technologies (Fuel Cell Electric Buses, 2020; Ministry of Infrastructure and Water Management. 2020). To make the EU's economy more sustainable and turn climate and environmental challenges into opportunities for policy through several initiatives, the European Green Deal roadmap was presented in 2019 (European Commission, 2019). This was used as a basis for creating the New EU Urban Mobility Framework in 2021, which highlights the use of zero emission vehicles to reduce greenhouse gas emissions and air pollution in urban context (European Commission, 2021).

The Netherlands is not only following this clear European trend towards sustainable mobility, but also a front runner in the case of ZEBs in public transport.

4.2 The socio-technical regime

The concept of sustainability was first mentioned in the context of transport policy in 1991 in the Dutch Second Transport Policy Plan (V&W, 1991) (Annema and van Wee, 2009). After growing road congestion and studies in the 1990's showed that the CO_2 emissions caused by traffic had increased significantly since the 1980's, the government coalition wanted to create a shift from cars to more use of public transport (Passenger Transport Executive Group. 2010; Social Economic Council, 2001). This led to The Passenger Transport Act in 2000, which had the aim to increase the use of public transport, especially in urban areas, and the degree of cost coverage of by passenger revenues. This decentralized and restructured the organization of public transport into exclusive public transport operating concessions of max. 8 years for bus and/or regional train services. Competitive tendering of these concessions was introduced to incentivize transport operators to be creative in their proposals, except for in the 3 largest cities of Amsterdam, Rotterdam and The Hague. It also put provinces and city regions, instead of the Ministry of Transport, in charge of funding the transport operators (Rijksoverheid, 2000; Passenger Transport Executive Group. 2010). Over the next 10 years there was a strong collaboration network in the market for diesel buses. Bus manufacturers were building buses fit for 8-10 years of operation, compatible with the concession periods, as transport authorities were demanding new buses for every new concession. There was close interplay in the diesel bus regime (I-1). With developments of the technology during this period and a focus on improving air quality with cleaner vehicles, hybrid electric and compressed natural gas (CNG) buses were implemented as well (Ministry of Infrastructure and Water Management, 2010; I-1).

A change in governance, regarding the tendering process of bus concessions, between public transport authorities and public transport operators took place over the years, because rapid technological developments demanded more flexibility in the tendering of concessions. The PTAs needed to find ways to deal with the uncertainties that new technologies bring and incentivize PTOs to innovate in the services they provide. PTAs are constantly improving the interaction with PTOs in the tendering process, allowing flexibility for the bus market to develop and provide the best solutions for public transport services (Veeneman, 2018; I-2; I-5). The change in governance of the bus concessions and adjusting of tendering requirements created institutional support for creating a new ZEB regime and effectively disrupted the old diesel system by sending a clear signal that diesel buses were to be gradually replaced by 2030 (Ministry of Infrastructure and Water Management. 2020).

The phasing out of diesel buses, supported by the national government and public transport authorities, became even more evident with the signing of the “Zero Emission Regional Public Transport by Bus” administrative agreement (BAZEB) in 2016 (Rijksoverheid. 2016). This agreement set fixed targets and dates for the replacement of all diesel buses in the public bus transport fleet, stating that by 2025 all newly purchased buses need to be zero emission, and by 2030 all buses in operation need to be zero emission. The agreement was signed by the Ministry of Infrastructure and Environment and all public transport authorities (Rijksoverheid, 2016; Bakker and Konings, 2018; Netherlands Enterprise Agency, 2019). After the first BEBs were implemented for public transport in 2013, now newer BEBs, that used pantograph charging en route (also called opportunity charging), were deployed (CROW-KpVV, 2021). With more than 20% of the total public bus fleet now being BEBs and the commitments set by the BAZEB agreement, BEBs have effectively broken out of the niche market, entered the regime level and are in the process of replacing diesel buses. More public private partnerships for sustainable mobility were entered into, like the Formula E-Team to accelerate the roll-out of electric transport, and collaborations between public transport authorities, cities, grid operators and charging infrastructure companies to determine the best charging solutions and roll-out strategies (Netherlands Enterprise Agency, 2020; Netherlands Enterprise Agency. 2019; I-1). After the first FCEBs started being deployed in the regular public transport service fleet in 2016, they only saw limited growth in the following years due to higher costs (CROW-KpVV. 2021; I-3). In 2019 the National Climate Agreement (Klimaatakkoord) was presented, with the aim to reduce greenhouse gas emissions in the Netherlands by 49%, compared to 1990 levels, by 2030 (Government of the Netherlands, 2019). This is to be achieved through commitments in five sectors, one of which is the mobility sector. The BAZEB was used as input regarding the further development of the public bus sector (I-2). One of such commitments is an increase in development of charging infrastructure, which resulted in the 2019 National charging infrastructure agenda (Netherlands Enterprise Agency, 2020). There is also a focus on setting more urban zero emission zones, investing in hydrogen infrastructure and sustaining public private partnerships (Government of the Netherlands, 2019).

With the signing of the BAZEB agreement yearly financial commitments to ZEB projects have been agreed upon. For example, the Dutch government allocates a yearly budget of €10 million from 2019 till 2025 to the organization of financing instruments for ZEBs and in 2020 the Ministry of Infrastructure and Water Management launched a subsidy scheme to stimulate the deployment of ZEBs (CROW-KpVV, 2021; Ministry of Infrastructure and Water Management, 2020; I-3). The increasing demand for charging capacity also prompted more collaboration between the transport and energy sector (I-2; I-6). In 2021 the EU research and innovation initiative 2ZERO was established.

This partnership of industry and research members promotes and facilitates research and innovation of zero emission vehicles (2zero, 2022). Currently all active public transport operators in the Netherland, GVB, RET, HTM, EBS, Arriva, Transdev, Keolis and Q-buzz, have ZEBs in their fleet (see Figure 17).

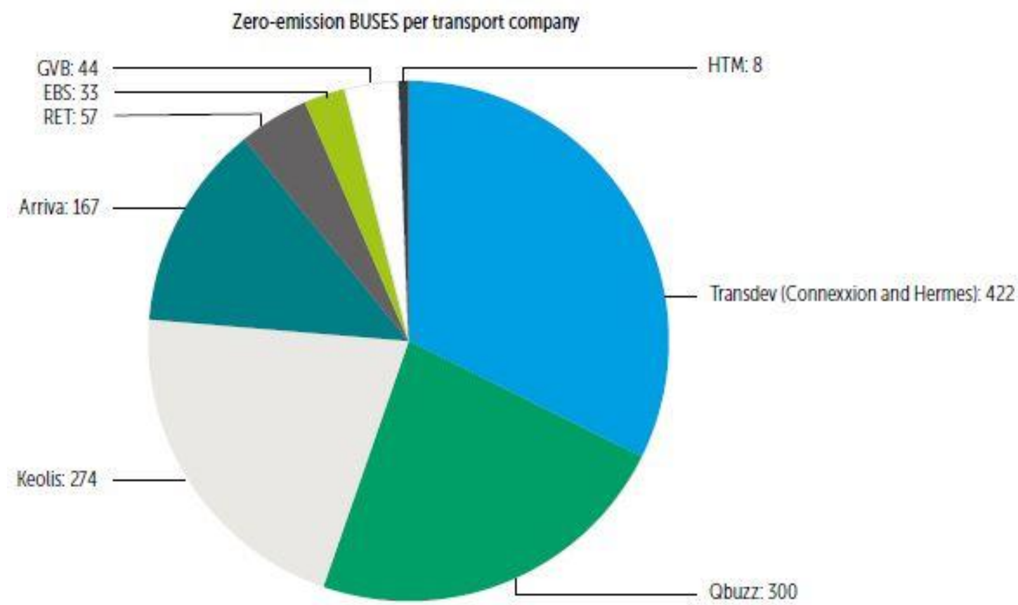

Figure 17 – Zero emission buses per transport operator (Source: CROW-KpVV, 2021)

4.3 Niche development

In 2003 the city of Amsterdam conducted a pilot project with FCEBs, as part of the European CUTE project and in 2009 a pilot project with BEBs was conducted in the city of Den Bosch (Bakker and Konings, 2018). A Green Deal Zero Emissie busvervoer pilot project was established in 2012 between the Ministry of Infrastructure and Water Management, the Province of North-Brabant and the Zero Emissie Busvervoer foundation to support local governments and market parties in investing in ZEBs and charging and fueling infrastructure (Rijksoverheid, 2016; I-3). The cost of purchasing ZEBs were significantly higher than diesel buses, which made such pilot projects necessary on the niche level (Bakker and Konings, 2018; Kok et al., 2017; I-1; I-7). These pilots were used, amongst other things, to formulate political ambitions for ZEBs in order to give a strong signal to the market (Ministry of Infrastructure and Water Management. 2020; I-1).

Meanwhile a growing support developed in networks for ZEBs. In 2009 the Dutch organization for electric transport (DOET) industry association was established by entrepreneurs in support of electric transport. They facilitate knowledge sharing, internationalization and access to subsidies and also organize political lobby (Dutch organization for electric transport, 2022; Netherlands Enterprise Agency. 2019). In the same year the ElaadNL partnership was also established by Dutch electricity and gas grid operators for knowledge development and innovation of charging infrastructure (ElaadNL, 2022; Netherlands Enterprise Agency. 2019). AutomotiveNL, a partnership between the automotive industry, mobility sector and automotive education sector, was created in 2011 to encourage the development of a strong network in the sector (Dutch Mobility Innovations, 2022; Netherlands Enterprise Agency. 2019). The Netherlands also has two local electric bus manufacturers, VDL and Ebusco, who supply the majority of electric buses used in the Dutch public bus transport fleet (see Figure 18). While VDL was already, and still remains, a big player in the diesel bus market, Ebusco is a young company that is fully focused on sustainable emission-fee transport. There are companies working on charging solutions and smart charging, like Ecotap, Greenflux and Viriciti, EV chip manufacturers, like NXP, energy storage companies, like Alfen and battery technology companies, like LeydenJar Technologies (Netherlands Enterprise Agency. 2019). A growing collaboration in networks for ZEBs developed internationally as well, with the Netherlands being a member of electric transport partnerships like the Transport Decarbonisation Alliance, Hybrid and Electric Vehicles Technology Collaboration Programme, Electric Vehicle Initiative (Netherlands Enterprise Agency, 2022). In 2015 the Netherlands co-founded the Zero-Emission Vehicle (ZEV) Alliance with several other countries to accelerate global zero emission vehicle adoption (Netherlands Enterprise Agency. 2019). After several pilot projects, the first BEBs were deployed by PTOs on a regular and commercial basis in 2013. These buses were charged via the mains and via induction (CROW-KpVV, 2021; Bakker and Konings, 2018; I-1).

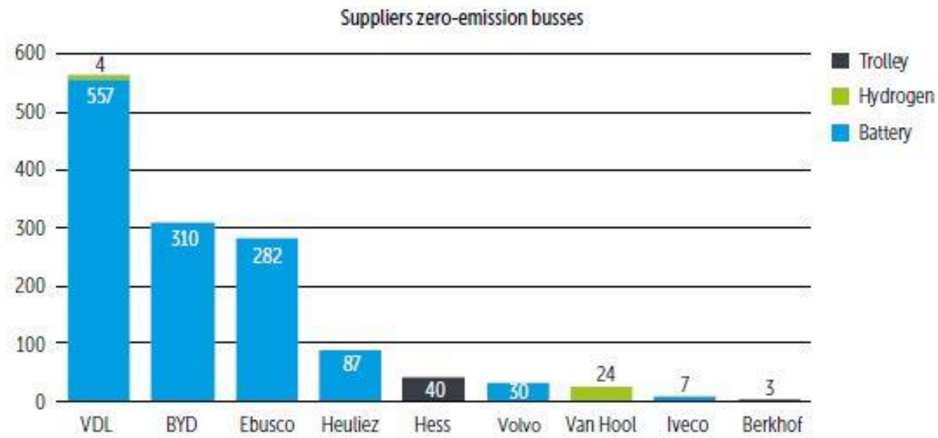

Figure 18 – Manufacturers of zero emission buses used in the Netherlands (Source: CROW-KpVV, 2021)

In 2016 the first FCEBs were deployed commercially for public transport (CROW-KpVV, 2021). During this time a lot of research and innovation was taking place in battery and hydrogen technology through grants from the EU (European Commission, 2010). This resulted in the reduction of battery costs (Bakker and Konings, 2018; I-2). There was, however, limited charging and fueling infrastructure available, which made it very challenging to operate the ZEBs (I-1; I-3). Currently the share of BEBs in the public transport fleet is around 20% and keeps growing, while the share of FCEBs is very limited due to higher purchasing and operational costs as well as limited availability of hydrogen filling infrastructure (CROW-KpVV, 2021; I-2; I-3; I-4; I-7). However, there is still the possible advantage of using hydrogen for energy storage and to decrease the load of the electric grid, which is increasingly becoming an issue (CROW-KpVV, 2021; I-2; I-5). There are also networks supporting hydrogen vehicle development and use, there are subsidies available for hydrogen projects and some industry professionals still see future possibilities for FCEBs (Fuel Cell Electric Buses. 2020; Fuel Cell Works; I-4; I-7).

4.4 Window of opportunity

Looking at the type of interaction between the landscape, regime and nice level it can be seen that before 2010 there was pressure from the landscape on the diesel bus regime due to increased traffic congestion and air pollution. At this time ZEBs had not yet been sufficiently developed yet, with high costs and short driving ranges. As a result incremental innovation was taking place in the regime level, replacing some diesel buses with CNG & hybrid buses to reduce air pollution. This resembles a transformation pathway (Geels and Schot, 2007). As indicated by Geels and Schot (2007) it is possible that a transition starts with one path and later shifts to another. This can also be seen in this case, where from 2015 on there was again pressure from the landscape on the diesel bus regime due to international commitments to reduce greenhouse gas emissions drastically by 2030. At this time ZEBs, particularly BEBs, in the niche level had seen significant improvements in the battery technology and supporting charging infrastructure. As a result they were able to break through and are now in the process of replacing the existing diesel bus regime. This shows more similarities with a technological substitution pathway (Geels and Schot, 2007).

4.5 Conclusion

In this chapter the ongoing transition to ZEBs in the Dutch public bus sector has been analyzed from the multilevel perspective. The developments on the landscape, regime and niche levels have been discussed, explaining how ZEBs have come to be well on their way to replacing diesel buses in the Dutch public bus regime. Lastly, the windows of opportunity that can be seen in the case study are discussed. In the next chapter the multiple streams framework is applied to analyze key policy changes in the ongoing transition to ZEBs in the Netherlands.

5. Explaining the transition to ZEBs using the MSF

In this chapter the Multiple streams framework is applied to the ongoing Dutch zero emission public bus transition. Policy making is an important driver to implement the changes that are required for sustainability transitions to develop. Up to now two policies have been adopted in the Netherlands regarding the transition to ZEBs. These are the "Zero Emission Regional Public Transport by Bus" administrative agreement in April, 2016 (BAZEB) and the "National Climate Agreement" in June, 2019 (Klimaatakkoord). This chapter discusses these key policy changes around sustainable mobility that influenced this ongoing transition through the lens of the MSF (see Figure 19 and Figure 20).

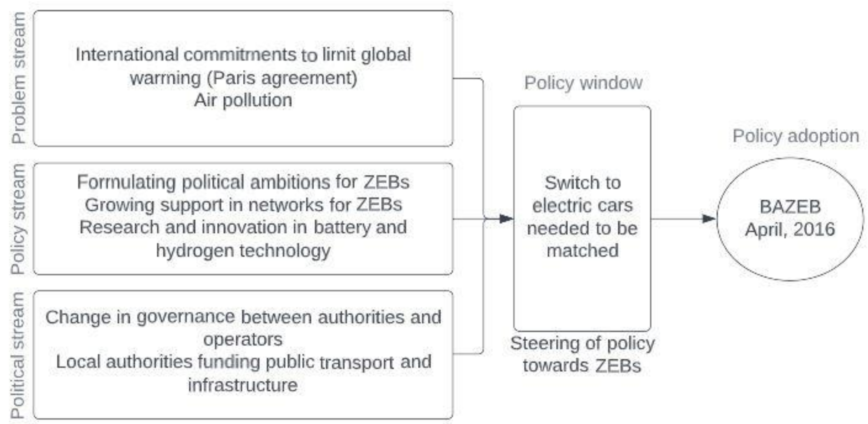

Figure 19 – BAZEB explained using the Multiple streams framework

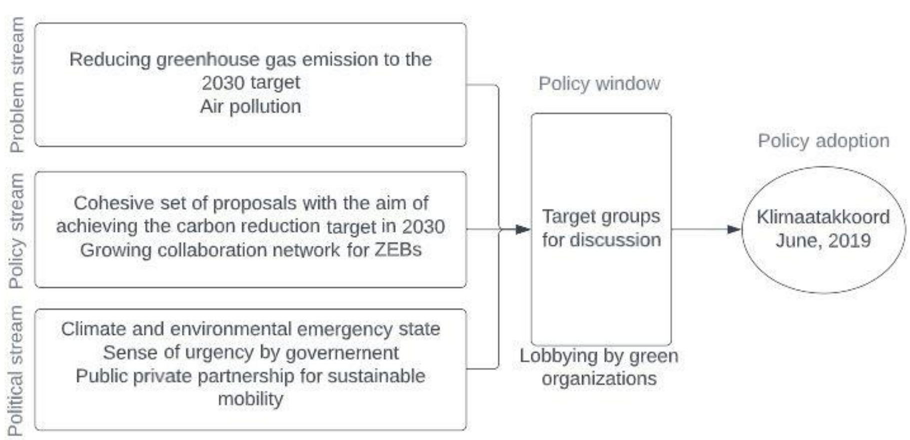

Figure 20 – Klimaatakkoord explained using the Multiple streams framework

5.1 The BAZEB

The problem stream

The problem streams of the BAZEB and the Klimaatakkoord both basically contain the same two key issues: increasing air pollution and environmental damage as a result of the growing greenhouse gas emissions. A study in 1995 showed that CO_2 emissions from traffic had increased by 40% in ten years (Social Economic Council, 2001). One of the factors that contributes to the identification of problems by policymakers, according to Kingdon, are indicators. Since then the Dutch mobility policies have shifted towards a strategy to reduce traffic congestion and promote sustainability in order to improve air quality and reduce environmental damage (Passenger Transport Executive Group, 2010). A report by the European Environment Agency in 2012 showed that the period between 2002–2011 was the warmest on record in Europe and that action needed to be taken to prevent further damage to the environment (European Environment Agency, 2012). Through international events like the COP21 in Paris in December 2015, even more political attention was directed towards rising greenhouse gas emissions. With the establishment of the 2015 Paris Agreement, the Netherlands also made an international commitment to limit global warming, under which falls a Declaration on Electro-Mobility and Climate Change and Call to Action (United Nations Climate Change,2015). In doing so there was now legally binding commitment to reduce greenhouse gas emissions in the Netherlands in several sectors, including the mobility sector, putting it high on the agenda.

The policy stream

In the public bus sector attempts to reduce emissions were first made by introducing "cleaner" alternatives to diesel buses, which are the hybrid electric and compressed natural gas (CNG) buses we still have in the Netherlands today (Ministry of Transport, Public Works and Water Management, 2010). Since 2005 EU standards have been set for particulate matter in emissions as a guideline for improving air quality (IQAir, 2022). Several pilot projects were also set in motion from 2003 with FCEBs and from 2009 with BEBs (Veeneman, 2018). Gradually, as the technology developed further, the wish grew from having buses with lower emissions to having buses with zero emissions (Ministry of Infrastructure and Water Management, 2020). In 2011 the Stichting Zero Emissie Bus was set up by the ministry and local governments to formulate ambitions for ZEBs that could be backed by policy and would send a strong signal to the market (Ministry of Infrastructure and Water Management. 2020; I-7). This resulted in a growing support in networks for ZEBs in the form of collaborations, discussions and presentations to share knowledge and develop proposals. At the same time there was also a lot of research and innovation taking place in the development of battery and hydrogen technology, improving the technical feasibility of ZEBs. The 2010 Clean and Energy-efficient Vehicles EU strategy supported this kind of research and innovation through grants and support by the European investment bank (European Commission, 2010). A guideline for nitrogen dioxide was also set by the EU in 2010 to improve air quality (IQAir, 2022). In 2011 the Dutch government made the 2011-2015 Action Plan to accelerate the market introduction of electric transport, which also highlighted the necessity of studying the possibilities of electric drive using batteries for public transport, by means of inductive charging, or using hybrid or fuel cell buses (Rijksdienst voor Ondernemend Nederland, 2011).

The political stream

In 2000, with the Passenger Transport Act in 2000, the public bus authority was transferred from a national to a more regional level, effectively changing the structure of authority in the Dutch public bus sector and giving local and regional policy makers more control. With rapid technological developments taking place and an increased focus on sustainability in national and local governments, changes in the governance between public transport authorities and public transport operators occurred. More flexibility was introduced in the competitive tendering process for public bus concessions and the interaction between PTAs and PTOs also changed (Veeneman, 2018; I-2). This increased flexibility combined with the fact that local authorities are responsible for funding public transport and infrastructure made it easier for local policy makers to steer the transition towards ZEBs and incentivize PTOs to participate (Passenger Transport Executive Group, 2010; I-5).

The policy window and policy entrepreneur

What mostly led to the opening of a policy window in the case of the BAZEB policy adoption was the perception of transitioning to electro-mobility on a whole. The switch to electric cars had already begun to gain momentum and needed to be matched in the public transport sector, in the eyes of the national government (I-1; I-5). Because there was now a legally binding commitment to reduce greenhouse gas emissions in the Netherlands, an opportunity presented itself for policy change in the public bus sector. The national government together with local transport policymakers, taking the role of policy entrepreneurs, started steering policy proposals towards the implementation of more ZEBs and in essence eventually decided to set a definitive goal with fixed dates. This was done to also provide certainty to the ZEB market and stakeholders (I-1; I-5; I-7).

5.2 The Klimaatakkoord

The problem stream

As previously stated, the problem stream of the Klimaatakkoord contains basically the same two key issues as that of the BAZEB: increasing air pollution and environmental damage as a result of the growing greenhouse gas emissions. While air quality has been steadily improving in urban areas in Europe since 2011 (see Figure 21) as a result of several efforts to reduce traffic congestion and promote sustainability, the World Health Organization stated that pollution was still above the recommended levels in 2019 (World Economic Forum, 2022). Several indicators and events were also showing that more action needed to be taken to prevent further damage to the environment. A study by the European Environment Agency mapped out different greenhouse gas emissions scenarios and climate models in 2016, stressing the importance of reducing emission (European Environment Agency, 2016). In March 2019 protesters from all over Europe took the streets, including in Amsterdam (see Figure 22), demanding that politicians be more aggressive in combating global warming (Politico, 2019; RTL Nieuws, 2019).

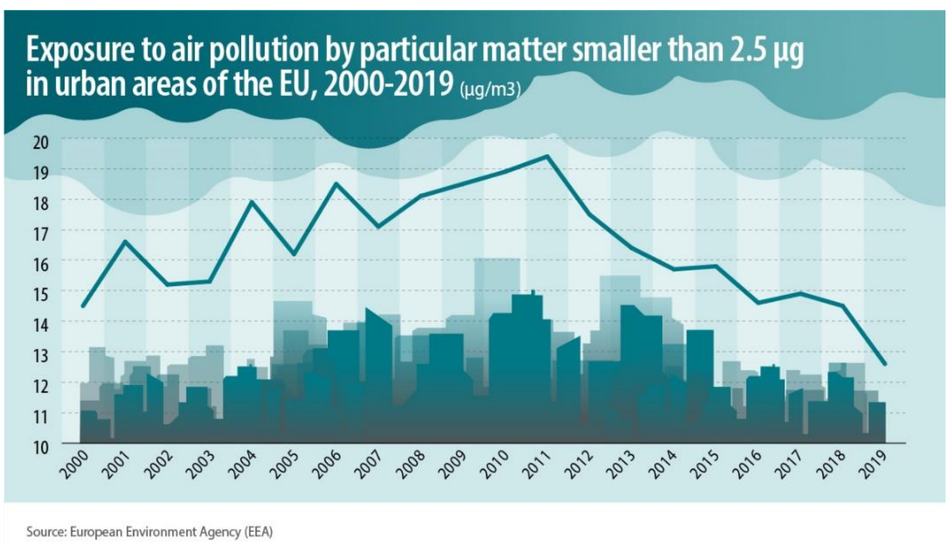

Figure 21 - Air pollution in urban areas of the EU (Source: Eurostat, 2021)

Figure 22 – Climate change protest in Amsterdam (Source: Milieudefensie/Twitter)

The policy stream

As a result of the growing networks for ZEBs, supported by the BAZEB agreement, by 2019 there were many proposals available with the aim of achieving the carbon reduction target in 2030 (Government of the Netherlands, 2019; I-5). This also showed a growing collaboration of different stakeholders for the further implementation of ZEBs. It became clear that zero emission was not just an advice anymore, but the way to go forward. This was evident in the 2019 EU Green Deal, which provided a roadmap to cut pollution and reduce greenhouse gas emissions (European Commission, 2019). Stakeholders also used their network for sharing knowledge about the application of zero emission vehicles in, for example, the heavy transport industry (I-1; I-2; I-6). The EU standards for air pollution differ from those of the World Health Organization, because they are based on economic feasibility. A plan to further reduce the standards by 2.5 times has been proposed, but has not yet been put in practice (IQAir, 2022).

The political stream

Around 2019 there was a clear message on the EU level announcing a climate and environmental emergency state (European Commission. 2019). This was one of the reasons for the creation of the European Green Deal roadmap in 2019. It prompted a sense of urgency on the Dutch government as well to take increased action (I-5). With also the climate change protests sending a clear message to policy makers, the national mood was shifting towards taking more action to combat climate change (RTL Nieuws, 2019). At this time there were already a lot of public private partnerships for ZEBs in the Netherlands, which is known as the Dutch polder model (Passenger Transport Executive Group, 2010). This provided a lot of support from stakeholders to take further action regarding climate change (Government of the Netherlands, 2019). On a local level, governments also advocate and implement local strategies and projects to fight climate change and improve the sustainability of public transport, like the Rotterdam Urban traffic plan, presented in 2017 by the local Alderman for Mobility (Gemeente Rotterdam, 2017). Citizen in the Netherlands advocating climate change action also put pressure on the national government, like with the Urgenda Climate Case in 2015, making climate change an important political issue and inspiring other climate cases around the world (Urgenda, 2019).

The policy window and policy entrepreneur

In the case of the Klimaatakkoord a policy window was present when there were many discussion events with more than 100 target groups, as this policy change was not only to set requirements and commitments in the mobility sector, but for many other sectors as well (Government of the Netherlands, 2019). What led to these discussions could arguably be the change in national mood caused by the increasing pressure from citizens on the national government to take more climate change action and the message on the EU level announcing a climate and environmental emergency state. However, a clear link was not found in the data sources used for this case study. Looking at the role of policy entrepreneurs here, it can be seen that there was a lot of lobbying taking place by green organizations and electric transport organizations during this period (Netherlands Enterprise Agency, 2019; I-5; I-7). How they exactly managed to influence the policy outcome was not able to be determined from the data sources used for this case study.

5.3 Conclusion

In this chapter the relevant policy changes in the ongoing transition to ZEBs in the Dutch public bus sector have been analyzed from the perspective of the MLP. The developments in the problem stream, policy stream, political stream, the policy window and policy entrepreneurs have been discussed for the BAZEB and the Klimaatakkoord, explaining the adoption of these key policy changes. The next chapter will discuss the case study results and the implications for elaborating on the theories as well as future theory synthesis.

6. Discussion of case results and implication for theories

In this chapter the results of the case study and the implication for the theories are discussed. Based on this, proposition for theory synthesis is generated, after which external validation is conducted.

6.1 Insights from applying the two frameworks to the case study

The Multilevel perspective

By using the Multilevel perspective to describe the ongoing Dutch zero emission public bus transition the following insights were observed:

Around 2008 policies started be created at the EU level to improve air quality in Europe. This was to be achieved in part through cleaner and more efficient vehicles. It led to the increased deployment of CNG and hybrid buses in the Netherlands. Meanwhile pilot studies were carried out with ZEBs, which were still very expensive in terms of initial and operation costs. However, the technology was improving and policies started to be drafted to support this development. After several pilot projects, the first BEBs were deployed by operators on a regular and commercial basis in 2013. From then on the share of BEBs in the public bus fleet has gradually increased. This was accompanied with innovation in battery technology, more flexibility in tendering requirements of bus concessions and growing support in networks for ZEBs. At the same time it was becoming clearer that diesel buses were to be phased out by 2030. With the signing of the 2015 Paris agreement an increased urgency was created to reduce greenhouse gas emissions, as it was a legally binding commitment of each member. One of the sectors that needs to contribute to this commitment is the mobility sector, including public transport. A national policy that followed this development was the BAZEB in 2016, in which the government and all public transport authorities agreed that all new buses purchased in 2025 will be zero emission and by 2030 the entire public bus fleet needs to be zero emission. This gave a clear signal to the market and resulted in an increase in public private partnerships for sustainable mobility. Due to development of battery and charging technology, newer BEBs that used pantograph charging entered the market. The first FCEBs were deployed by operators on a regular and commercial basis in 2016. However, contrary to the BEBs, their growth was only limited. This is because of the higher initial and operational costs of FCEBs as compared to BEBs and the limited availability of fueling infrastructure. It makes it more attractive for an operator to choose for BEBs, especially considering the increasing driving range of newer models. A few FCEBs continue to operate in the public bus fleet, mostly due to support from EU level hydrogen projects. The interest to develop hydrogen technology remains to be seen, although still at the niche level, as it may perhaps also be used for energy storage in the near future. The establishment of the Klimaatakkoord in 2019 resulted the 2019 National charging infrastructure agenda, leading to an increase in investments in charging infrastructure. It can be seen that more collaboration is needed with the energy sector, due to the increased electricity demand created by ZEBs. With yearly financial commitments to ZEB projects and more partnerships for sustainable mobility on local, national and international levels, the prospects for ZEBs, and in particular BEBs, looks very promising.

The Multiple streams framework

By using the Multiple streams framework to analyze policy change regarding the ongoing Dutch zero emission public bus transition the following insights were observed:

The first key policy adoption in the Netherlands to stimulate the transition to ZEBs was the BAZEB in 2016. Looking at the different streams that led to this, it can be seen that the problem stream contained two key issues: increasing air pollution and environmental damage as a result of the growing greenhouse gas emission. This was first tackled by introducing "cleaner" alternatives to diesel buses, which are the hybrid electric and CNG buses we still see in the Netherlands today. Meanwhile in the policy stream a growing network was developing in support of ZEBs, a lot of research and innovation taking place in the development of battery and hydrogen technology and political ambitions in the form of policy proposals for these technologies were being formulated. In the political stream more flexibility was introduced in the competitive tendering for public bus concessions and the interaction between public transport authorities and public transport operators also changed. With the switch to electric cars already having begun to gain momentum and the perception of the national government that this needed to be matched in the public transport sector a policy window was created. As local authorities are responsible for funding public transport and infrastructure it was easier for the national government together with local transport policymakers to steer the transition towards ZEBs and incentivize operators to participate. This led to the adoption of the BAZEB in 2016. The second key policy adoption in the Netherlands regarding the transition to ZEBs was the Klimaatakkoord in 2019. Looking at the different streams that led to this, it can be seen that the problem stream contained basically the same two key issues as that of the BAZEB: increasing air pollution and environmental damage as a result of the growing greenhouse gas emission. In the policy stream a growing collaboration in networks for ZEBs was present, supported by the adoption of the BAZEB. Because of this many proposals were available with the aim of achieving the carbon reduction target in 2030. This network was also used for sharing knowledge about the application of zero emission vehicles in, for example, the heavy transport industry, creating more collaboration.

Meanwhile in the political stream a sense of urgency was created by the Dutch government to take increased action, emphasizing a climate and environmental emergency state. With the many public private partnerships for ZEBs there was strong support from different stakeholders, which was then used in discussion events, together with a lot of lobbying by green organizations and electric transport organizations. This resulted in the adoption of the Klimaatakkoord in 2019. How these organizations exactly managed to influence the policy outcome was not able to be determined from the data sources used for this case study.

Comparing the findings

When comparing the findings from the application of the MLP and MSF to the case of the ongoing transition to ZEBs in the Netherlands, certain similarities and complementarities can be seen. Problems like increasing air pollution and environmental damage as a result of the growing greenhouse gas emissions are mentioned in the problem stream and on the landscape level. Formulating political ambitions for ZEBs, growing support in networks for ZEBs and research and innovation in battery and hydrogen technology are mentioned in the policy stream and in the niche level. The change in governance between authorities and operators and the fact that local authorities are funding public transport and infrastructure are mentioned in the political stream and in the regime level. The declaration of a climate and environmental emergency state is mentioned in the political stream and on the landscape level. The steering of policies towards ZEBs was done by the policy entrepreneur and arguably took place in the niche level through the formulation of political ambitions for ZEBs and the growing support in networks for ZEBs. When applying the MLP, there is no mention of the perception of the government to match the switch to electric cars in the public transport sector. This is important because it basically led to the decision to set a definitive goal with fixed dates, to provide certainty to the ZEB market. It also does not address how policies were being steered towards ZEBs, resulting in the adoption of the BAZEB in 2016. There is also no mention of how the growing collaboration in networks for ZEBs helped to generate a coherent set of proposals with the aim of achieving the carbon reduction target in 2030. This was then used during events with target groups for discussions. It also does not address the lobbying by green organizations and electric transport organizations, which contributed to the adoption of the Klimaatakkoord in 2019. These developments are explained better using the MSF. When applying the MSF, there is no mention of the pilot projects that took place concerning ZEBs, which contributed to a growing support in networks for ZEBs. It also does not address the higher costs of ZEBs, the reduction of battery costs or the limited availability of charging and fueling infrastructure. There is no mention of the different results in market share growth of BEBs and FCEBs after initial implementation. It also leaves out the growing need for collaboration with the energy sector, regarding the electricity demand and grid capacity. These developments are explained better using the MLP.

6.2 Implication for elaborating the current theories

From the case study it can be concluded that there are similarities between certain elements of the MLP and MSF. These are between the problem stream and the landscape level, the policy stream and the niche level, the political stream and the regime and landscape levels and the policy entrepreneur and the niche level (illustrated by the solid lines in Figure 23).

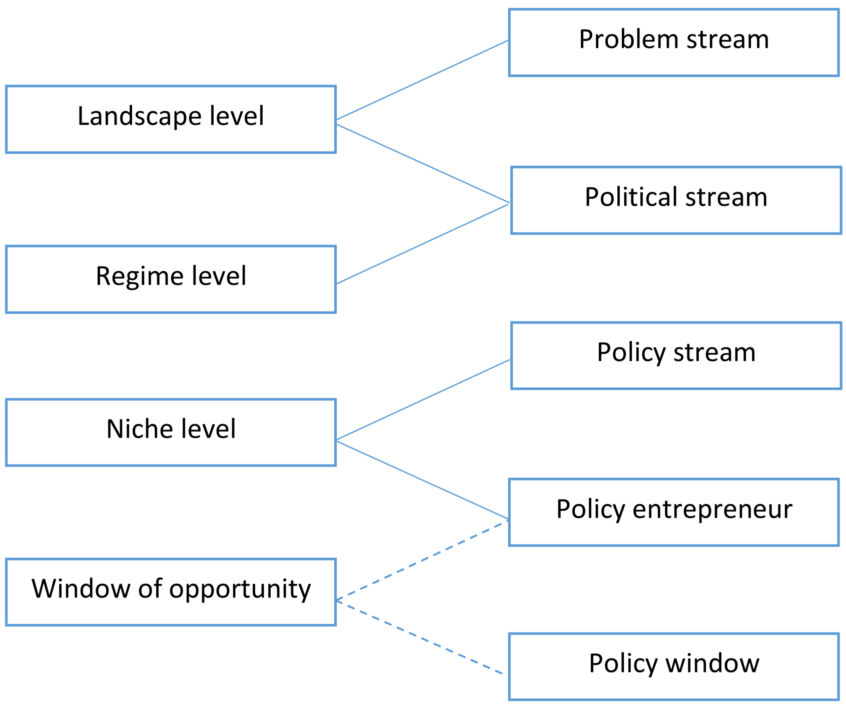

Figure 23 - Links between the MLP and MSF based on the case study results

It can also be seen that when using the MLP there are elements missing in the narrative which are addressed when using the MSF. These are the events that would be placed in the political stream, policy window and activities carried out by the policy entrepreneur, like pressure campaigns, discussion events and influence from key actors that want to guide the policy process in a particular direction that favors them. From the case study is can also be concluded that when using the MSF there are elements missing in the narrative which are addressed when using the MLP. These are events that happen on the niche level and incremental changes in the socio-technical regime, like experimentation in protective spaces, changes in costs and supporting infrastructure and collaboration in the regime. This demonstrates that by using both the MLP and MSF to analyze sustainability transitions, it is likely to expand the explanatory potency of the trajectory.

These links have been discussed in interviews with three researchers from different universities in other countries. An interesting point of view from one of the three sources used for external validation is that the MLP should not be used for the explanation of sustainability transitions, as its structure of the landscape, regime and niche level and their interactions do not accurately resemble the development of transformative change in reality. On the contrary, interviews conducted with the two other researchers showed that the links between the MLP and MSF resulting from the case study are possible and could be useful for future theory synthesis. These researchers do stress the importance of defining the boundaries of the elements of the MLP and MSF when looking at links and complementarities between the frameworks. They also emphasize the need for conducting case studies in other countries and sectors to add more validity and further specify the proposed links.

6.3 Proposition for theory synthesis

Based on the comparison of the case study results of applying the MLP and MSF and the implications for elaborating on the theories, it can be argued that the combination of these frameworks provides a more in depth narrative of the development of a sustainability transition. The two frameworks show similarities and complementarities. The MLP gives a more elaborated overview of the different aspects of sustainability transitions, while the MSF is very focused on how policy change is induced. Therefore the following is proposed: For future theory synthesis it would be beneficial to include elements of the MSF that are missing to the MLP. Considering that these elements consist of events in the "policy window" and activities carried out by the "policy entrepreneur", a link could be drawn to the "window of opportunity" in the MLP (illustrated by the dotted lines in Figure 23). This is because the window of opportunity does not occur in a specific instant, but is rather a dynamical change that takes place through interactions during the transition. This link can be drawn by extending the definition of the window of opportunity to not only entail the destabilization of the regime due to internal pressure or pressure from the landscape, but to also include discussion events and the influence of key actors that are aiming to influence policy outcomes. While the MLP does recognize the role of agency as technological innovations developed by niche actors (Derwort et al., 2021), it does not address agency in the form of lobbying by political actors and policy entrepreneurs. Another important element missing from the MLP is the importance of the effects of policy change on transformative change, which is arguably always necessary in the case of sustainability transitions, as well as on future policy changes. Addressing these missing elements contributes to the main criticisms on the both the MLP and MFS. The first being that the MLP treats policy changes black as box outcomes, and the second being that the MSF treats technological changes as mere exogenous events. Including discussion events and the influence of key actors that are aiming to influence policy outcomes in the definition of the window of opportunity contributes to the explanation of policy change and transformative change.

6.4 Conclusion

This chapter discussed the results of the case study from applying the MLP and MSF and the similarities and complementarities that can be observed. Then the implication for elaborating on the theories are addressed. Based on this, a proposition for future theory synthesis is generated and external validation of the results is conducted. In the next chapter the research findings, limitations and recommendations are presented.

7. Conclusion

In this chapter the research findings are presented, first by answering the sub research questions. Then the main research question of this study is answered. Subsequently, the limitations of the study are discussed and recommendations regarding future research and policy making are given.

7.1 Research findings

Sub research question 1

What is socio-technical regime change through the Multilevel Perspective?

A socio-technical system is a network of physical components, legislative components, organizations, resources, culture and knowledge that interact in order to achieve societal functions. Dominating structures in society are referred to as the socio-technical regime, or the "deep structure" of rules that coordinate the activities between actors and keep the existing socio-technical system stable. The shift from one socio-technical configuration to another is what is referred to in the academic body of literature as a socio-technical transition or regime change. It involves changes in technological, institutional, political and socio-cultural dimensions, with many types of actors during a considerable timespan. As technology plays a major role in modern society, socio-technical regime change is also referred to as a technology transition. Sustainability transitions are purposeful socio-technical transitions towards a sustainable society. The MLP describes technology transitions as consisting of three levels: technological niches, socio-technical regimes and the landscape developments. A transition, or regime shift, takes place due to internal pressure in the regime or when developments in the landscape put pressure on the existing regime so niche innovations can break through, causing a "window of opportunity".

Sub research question 2

What is policy change through the Multiple Streams Framework?

In sustainability transitions governance plays an important role, as there are long-term goals and different actors need to coordinate and work together to achieve them. Transitioning to a more sustainable regime requires not only necessity, but also feasibility and benefits for the broad range of actors and institutions involved. This is why policy changes political actors and regulatory and institutional support play a major role in the context of sustainability transitions. The MSF, developed by Kingdon in 1984, describes a policy process as consisting of three parallel processes: the problem stream, the policy stream and the politics stream. When these largely independent streams are coupled as a result of focusing events in the problem stream or due to activities of policy entrepreneurs at the right point in time, during a “policy window”, policy shift takes place.

Sub research question 3

How can the transition to zero emission public transport buses in the Netherlands be analyzed using the MLP?

Around 2008 policies started be created at the EU level to improve air quality in Europe. It led to the increased deployment of CNG and hybrid buses in the Netherlands. Meanwhile pilot studies and demonstrations were carried out with ZEBs, which were still very expensive. After several pilot projects and technological and policy developments, the first BEBs were deployed by operators on a regular and commercial basis in 2013. From then on the share of BEBs in the public bus fleet has gradually increased along with innovation in battery technology, more flexibility in tendering requirements of bus concessions and growing support in networks for ZEBs. At the same time it was becoming clearer that diesel buses were to be phased out by 2030. With the signing of the 2015 Paris agreement an increased urgency was created to reduce greenhouse gas emissions, including in the public transport sector. A national agreement that followed this development was the BAZEB in 2016, in which the government and all public transport authorities agreed that all new buses purchased in 2025 will be zero emission and by 2030 the entire public bus fleet needs to be zero emission. This gave a clear signal to the market and resulted in an increase in public private partnerships for sustainable mobility, development of battery and charging technology and newer BEBs that used pantograph charging entering the market. The first FCEBs were deployed by operators on a regular and commercial basis in 2016. However, contrary to the BEBs, their growth was only limited due to higher costs and limited availability of fueling infrastructure. This makes it more attractive for an operator to choose for BEBs, especially considering the increasing driving range of newer models. A few FCEBs continue to operate in the public bus fleet, mostly due to support from EU level hydrogen projects. The interest to develop hydrogen technology remains to be seen, although still at the niche level, as it may perhaps also be used for energy storage in the near future. The establishment of the Klimaatakkoord in 2019 resulted in the 2019 National charging infrastructure agenda, leading to an increase in investments in charging infrastructure. It can be seen that more collaboration is needed with the energy sector, due to the increased electricity demand created by ZEBs. With yearly financial commitments to ZEB projects and even more partnerships for sustainable mobility on local, national and international levels, the road in the next few years for ZEBs, especially for BEBs, looks very promising in the Netherlands.

Sub research question 4

How can the transition to zero emission public transport buses in the Netherlands be analyzed using the MSF?

The first key policy adoption in the Netherlands to stimulate the transition to ZEBs was the BAZEB in 2016. It can be seen that the problem stream contained two key issues: increasing air pollution and environmental damage as a result of the growing greenhouse gas emission. Meanwhile in the policy stream a growing network was developing in support of ZEBs, a lot of research and innovation taking place in the development of battery and hydrogen technology and political ambitions in the form of policy proposals for these technologies were being formulated. In the political stream more flexibility was introduced in the competitive tendering for public bus concessions and the interaction between public transport authorities and public transport operators also changed. Which political actors specifically were responsible for this was not able to be determined from the data sources used for this case study. With the switch to electric cars already having begun to gain momentum and the perception of the national government that this needed to be matched in the public transport sector a policy window was created. As local authorities are responsible for funding public transport and infrastructure it was easier for the national government together with local transport policymakers to steer the transition towards ZEBs and incentivize operators to participate. This led to the adoption of the BAZEB in 2016. The second key policy adoption in the Netherlands regarding the transition to ZEBs was the Klimaatakkoord in 2019. The problem stream contained basically the same two key issues as that of the BAZEB. In the policy stream a growing collaboration in networks for ZEBs was present, supported by the adoption of the BAZEB. Because of this many proposals were available with the aim of achieving the carbon reduction target in 2030. This network was also used for sharing knowledge about the application of zero emission vehicles in, for example, the heavy transport industry, creating more collaboration. Meanwhile in the political stream a sense of urgency was created by the Dutch government to take increased action, emphasizing a climate and environmental emergency state. Discussion events were held and strongly supported by different stakeholders due to the many public private partnerships for ZEBs. Combined with a lot of lobbying activities by green organizations and electric transport organizations, it resulted in the adoption of the Klimaatakkoord in 2019. How these organizations exactly managed to influence the policy outcome was not able to be determined from the data sources used for this case study.

Sub research question 5

In what way do the MSF and MLP complement each other in explaining the transition to zero emission public transport buses in the Netherlands?

When applying the MLP, there is no mention of the perception of the government to match the switch to electric cars in the public transport sector. It also does not address how policies were being steered towards ZEBs, resulting in the adoption of the BAZEB in 2016. There is also no mention of the growing collaboration in networks for ZEBs, which helped to generate a coherent set of proposals with the aim of achieving the carbon reduction target in 2030. This was then used during events with target groups for discussions. It also does not address the lobbying by green organizations and electric transport organizations, which contributed to the adoption of the Klimaatakkoord in 2019. These developments are explained better using the MSF. When applying the MSF, there is no mention of the pilot projects that took place with ZEBs, which contributed to a growing support in networks for ZEBs. It also does not address the higher costs of ZEBs, the reduction of battery costs or the limited availability of charging and fueling infrastructure. There is no mention of the different results in market share growth of BEBs and FCEBs after initial implementation. It also leaves out the growing need for collaboration with the energy sector, regarding the electricity demand and grid capacity. These developments are explained better using the MLP.

Main research question

After answering the sub research questions, the findings in this study can now be used to answer the main research question, which is:

How can the ongoing transition to zero emission public buses in the Netherlands be explained using the Multiple Streams Framework and the Multilevel Perspective?

The MLP gives a more elaborated overview of the different aspects of sustainability transitions, while the MSF is very focused on how policy change is induced. The case study revealed that the two frameworks show similarities and complementarities. The similarities are between the problem stream and the landscape level, the policy stream and the niche level, the political stream and the regime and landscape levels and the policy entrepreneur and the niche level. When using the MLP there are elements missing in the narrative, that using the MSF would be placed in the political stream, policy window and activities carried out by the policy entrepreneur. Respectively, these are elements like pressure campaigns, discussion events and influence from key actor that want to guide the policy process in a particular direction that favors them. The MSF on itself, being very policy changed oriented, excludes events that, when using the MLP, are placed on the niche level and certain incremental changes in the socio-technical regime. Respectively, these are elements like experimentation in protective spaces, changes in costs and supporting infrastructure and collaboration in the regime. Based on the results of this study it can be argued that the combination of the MLP and MSF provides a more in depth narrative of the development of a sustainability transition. Therefore it is proposed that for future theory synthesis it would be beneficial to include elements of the MSF that are missing to the MLP. Considering that these elements consist of events in the "policy window" and activities carried out by the "policy entrepreneur", a link could be drawn to the "window of opportunity" in the MLP. This link can be drawn by extending the definition of the window of opportunity to not only entail the destabilization of the regime due to internal pressure or pressure from the landscape, but to also include discussion events and the influence of key actors that are aiming to influence policy outcomes. While the MLP does recognize the role of agency as technological innovations developed by niche actors (Derwort et al., 2021), it does not address agency in the form of lobbying by political actors and policy entrepreneurs. Another important element missing from the MLP is the importance of the effects of policy change on transformative change, which is arguably always present in the case of sustainability transitions, as well as on future policy changes. Including discussion events and the influence of key actors that are aiming to influence policy outcomes in the definition of the window of opportunity contributes to the explanation of the development of policy change and transformative change, addressing policy-technology feedback.

7.2 Limitations

As is the case with any research project, this study also has limitations, which need to be addressed.

The first limitation is in regards to the definitions of the elements in the theoretical frameworks. Both the MLP and MSF provide definitions of elements in the theories that are relatively abstract and could be interpreted differently by different researchers. For example, when studying the ongoing transition to ZEBs in the Netherlands it could be decided to position national policies in the regime level or in the landscape level. According to the definition of the landscape level given in the theory this should contain technology-external factors and structural trends that emerge and change slowly over time and occur on the macro level, including broad political coalitions. According to the definition of the socio-technical regime given in the theory this should contain the dominating and stabilized structures, rules and practices that enable and constrain existing systems on the meso level, including policy. By these definitions a national agreement like the BAZEB could be seen as the result of incremental innovation in the policy regime, but it could also be seen as a technology-external factor that happens on the landscape level, which in turn puts pressure on the regime level. In this study this was addressed in the selective coding step by giving clear definitions to the codes used to link the data to the theories. However, these definitions could differ depending on the researcher, which must be considered when interpreting the results. This was also an important stressing point that resulted from interviews with experts.

A second limitation is related to the data sources used for the case study. The documents that were used for desk research were publicly available. Some information needed regarding the MSF, like information about lobbying activities and political discussions is not very well documented in publicly available reports and documents and may require alternative sources. This was tackled by using interviews to collect the missing data. However, with data gathered from interviews there also needs to be accounted for subjectivity and selective bias of the interviewees. A way to deal with this drawback was to select interviewees from different sides of the public bus market. It is important to note here that the quality of interviews are also dependent on the researcher's level of experience with interviewing techniques. Lastly, the interviewees were also not always able to provide all information needed, like the role of specific political actors that encouraged policy changes. This is an important drawback of using interviews for data collection when relying on referrals within the organizations for a candidate that is suitable to discuss the topic and willing to participate.

A third limitation has to do with the data analysis procedure used in this study. With open coding in Atlas.ti there is always the possibility that a different researcher would assign different codes to quotations. This would then trickle down to the next coding step where different categories could emerge. As mentioned by Scott and Medaugh (2017) axial coding can also limit theoretical insights by being too structured. This is because it can force the data into categories, rather than letting categories emerge from the data. Although process tracing has been proven to be one of the most valuable methods to analyze causal inferences, it also has its tradeoffs (Beach, 2017). One of these is that the degree to which each element is defined theoretically and then traced empirically, affects the strength of the causal inference that can be made. However, defining each element of complex systems in high detail would require tremendous analytical sources. This was dealt with in this study by applying a less deep version of process tracing, as the definitions used in the selective coding step were only detailed enough to be able to structure and link the data to the theoretical frameworks. It does however mean that the causal relations found here are less strong.

A fourth limitation is the use of a single case study to generate proposition for linking the two theoretical frameworks. Because the results in this study are derived from conducting a single case study, it allows for a lower degree of external validation. The links between the MLP and MSF that became evident by conducting a case study on the ongoing transition to ZEBs in the Netherlands might not be valid when the case study is applied to, for example, a different country where the political or public bus transport system is different or where the degree of technological development in the local bus market is lower. This is also an issue when using process tracing in individual case studies, because the results are less generalizable (Beach, 2017). A way to deal with this limitation is through an attempt at external validation by conducting interviews with experts familiar with both of the frameworks and asking for feedback on the results of the study.

7.3 Recommendations for future research and policymakers

The first recommendation for future studies is to apply the combination of the MLP and MSF as is done here, to other cases. This will allow for further validation of the benefits of using the MLP and MSF together to explain sustainability transitions. Other case studies could for example focus on the ZEB market it different countries, which have different characteristics than that of the Netherlands. Case studies should also be conducted in other sectors, like the energy sector, agricultural sector or health sector. The more divers the collection of case studies using the combination of the MLP and MSF is, the apparent the benefits and challenges of linking them will be. This will help validate, or perhaps even invalidate, the proposition generated in this study to synthesize these two frameworks and possibly create a new conceptual framework. It will also address an import limitation that the process tracing method used in this study has, by complementing this with a comparative method using different case studies.

The second recommendation for future studies is to consider the effects that socio-technical regimes have on each other. As mentioned by Geels (2011), and can also be seen in the case of ZEBs in the Netherlands, battery electric vehicles link the transport and electricity systems. The rising deployment of BEBs is demanding an increase in grid capacity and charging infrastructure in the Netherlands. This has an effect on both the bus transport system and the electricity system. From the case study it was revealed that in certain instances public transport authorities and public transport operators were ready to deploy more BEBs for public transport, but could not do so because the local demand on the electric grid was too high and would cause issues with availability of charging capacity. At the same time the Dutch government wants to accelerate the transition to electric vehicles as well, which would create even more electricity demand. Therefore it is important to consider the positive and negative effects that the changes in relating socio-technical regimes have on each other and these relations should be studied further.

The third recommendation for future studies is regarding the analysis of sustainability transitions using multiple theoretical lenses. This study showed how the combination of the MLP and MSF can provide a more comprehensive narrative for the ongoing transition to ZEBs in the Netherlands. This combination of frameworks was also used by Derwort et al. (2021). It does not mean to say that these two frameworks are the only suitable combination for this purpose. Using multiple frameworks to explain complex phenomena is becoming increasingly popular in science. For example, Markard and Truffer (2008) combine the technological innovation systems approach with the MLP and Schmid et al. (2020) combine the Advocacy Coalition Framework with policy feedback theory. Studying the ongoing transition to ZEBs in the Netherlands using a different combination of theories, for example the MLP with the Advocacy Coalition Framework, could reveal interesting insights as well.

A fourth recommendation is for policymakers and stakeholders in regards to the deployment of FCEBs. The case study showed a clear difference in the percentage and rate of the deployment of FCEBs as compared to BEBs. This is not only the case in the Netherlands, but also in the rest of Europe. Despite several initiatives in the landscape level and in the niche level, the diffusion of FCEBs to the socio-technical regime remains a struggle. With the growing demand load of the electric grid, it would be not only smart but perhaps necessary to push alternative fuel drivetrains, like fuel cell electric vehicles, into further development. Policymakers need to develop a political support base to create necessity, design suitable policies and allocate resources to stimulate the development the FCEB market. They also need to include several stakeholders, like PTOs and bus manufacturers, in the policymaking process, which has proven to be successful in the case of BEBs in the Netherlands. It is important to avoid an ad hoc approach and facilitate cooperation of the market for hydrogen technologies, because this can support not only the deployment of FCEBs, but also other hydrogen vehicles and hydrogen energy storage solutions.

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