Electrification of Construction equipment

Master Thesis

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By

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Executive Summary

Motivating contractors and the government to cut emissions at infrastructure development sites is essential if we want to mitigate the consequences of climate change. However, little study has been done on how to quicken the shift to phasing out fossil fuel construction equipment on site. This study investigates the factors that slow down and speed up the shift to the use of electric equipment in the Dutch infrastructure industry. The findings came from research based on semi-structured interviews, desk research, and meeting notes from participant observation. The purpose of this study was to learn more about the transition process from the viewpoints of the government and contractors. Additionally, the influence of innovation and technology in the transition process was investigated. Not only the barriers but even the actions and drivers were also discussed to answer the main research question: *How can the transition of phasing out fossil fuel equipment on construction sites be accelerated?*

Before working on accelerating the transition, it was a must condition to understand the current situation. Semi-structured interviews were conducted in order to gather information about the barriers that hinder the transition and the counteractive actions that drive the transition to achieve the goal. LinkedIn worked as a foundation in finding respondents and then one respondent connected to another and nine interviewees were interested in sharing information and helping with this thesis. Respondents from BAM, Heijmans, ENI and Rijkswaterstaat were a part of this research. Interviews took place via Microsoft Teams and personal interviews. Teams had the feature of transcribing the complete interview in real-time. These transcripts went through manual thematic analysis to understand the different barriers, drivers and actions in this transition.

The lack of readily available electric machinery was the biggest technological obstacle. Contractors and government policy tools are both hampered by this. Limited fueling and charging options were another significant technological barrier. Currently, compared to the machines that are in use today that run on fossil fuels, the costs of zero-emission alternatives are too expensive to be financially viable. The fact that electric equipment is still in development and innovations are being introduced to the market gradually is the major reason for the poor availability and high investment prices. It was discovered that certain hurdles relating to the government, contractors, and technology and innovation were related through a cause-and-effect connection. The obstacle of contractor’s wait-and-see attitude appears to be linked to the barrier of the government's lack of a clear market strategy and clarity. The findings indicate that, in general, interviewees from the contractor and the government do not have the same perspective. Different obstacles and categories that delay the shift were ranked differently by each actor. This was discovered to constitute a barrier in and of itself.

By submitting bids for these emission reduction projects, contractors may hasten the shift and improve their competitiveness. Winning these contracts provides funding for new electric machinery and increases the competitiveness of future zero-emission initiatives. Additionally, according to the respondents, the government may exert more of a stimulating

influence than it now does. According to interviews, there are two distinct responsibilities for the government: major client and legislator/policy maker. As the primary customer, it is crucial that the government pushes the market to function as emission-free as feasible. When sufficient zero-emission equipment is widely accessible on the market, the respondents suggested that zero-emission might be included in the contract criteria. For instance, additional incentives might be made for the acquisition of technology that produces no emissions. Contractors must also do their part to hasten the transition to zero-emission construction sites. The little and medium-sized electric equipment that is now accessible might help contractors gain more expertise. The ability to use new equipment be taught to and trained in construction employees. In order to find new collaborations and project stakeholders and to encourage the development, accessibility, and delivery of early equipment, contractors might also proactively engage suppliers, manufacturers, and subcontractors.

The results of the interviews revealed that the government and contractors usually see this change differently. The employment of policy instruments by the government may encourage, coordinate, and enforce the private sector. Additionally, contractors might practice social responsibility and refrain from viewing the reduction of emissions at construction sites as merely a governmental issue.

Several limitations are faced in this research. The research used semi-structured interviews as a base to do this study, more case study research could have been done. Secondly, the research is limited to one country, The Netherlands. When inputs from other countries are input the results could have been more nurtured. The result of this study contributes by listing down the actions for acceleration. The actions combine both government and contractor sides to accelerate the transition to phasing out fossil fuel equipment on the construction site.

Contents

List of Figures

List of Tables

1. Introduction

1.1. Background and Context

Global warming has become a huge threat to the world, and it has been contributing to drastic climatic changes in recent years. This made all the world leaders focus on this issue and take action over this problem for a sustainable and greener environment. In 2015, The United Nations gathered 196 countries to sign the Paris Agreement to limit global warming to below 2 degrees Celsius, and push all the countries to reach global peaking of greenhouse gas emissions as soon as possible to achieve a climate-neutral world by 2050 (Paris Agreement, 2015).

The construction Industry is the heart of a country's economic and social development (Bellona, 2018). Facts say that the construction industry generates around 9% of the European GDP and provides 18 million jobs. On the other side, the building and construction sector emits 39% of energy and process-related carbon dioxide emission(International Energy Agency & Global Alliance for Buildings and Construction., 2019). This makes the industry a major contributor to the climatic changes happening.

In the construction industry, most equipment and machinery are still powered by fossil fuels, which tend to emit a tremendous amount of carbon dioxide and nitrox gases. World leaders are experiencing a rise in demand and cost for fossil fuels due to the political wars between countries, making fossil fuels more expensive.

The Netherlands is built below sea level and these climatic changes put the people under pressure. This led to the growth of social, political and environmental awareness toward a more sustainable society. The government focuses on reducing the CO_2 emissions. Not only the government, but other stakeholders also show interest in the reduction of the CO_2 emissions. Paris Agreement acknowledged both the private and public sectors to join hands and work toward a greener environment.

Eventually, such pioneering goals of the government will result in stricter electrification of electric equipment and machinery on the construction site. The importance of electrification keeps growing, but the pace of phasing out fossil fuel equipment is taking place very slowly. This makes it hard to achieve a completely electrified construction site by the end of 2030. Contractors tend to work traditional, while the electrification of equipment is in the rapid development phase. Contractors have a high degree of uncertainty which makes it difficult to invest. Also, the investment costs are almost thrice the price of fossil fuel equipment. So contractors are an intermediate party between the sustainable demands and regulations of the government and solutions offered by the market or manufacturer.

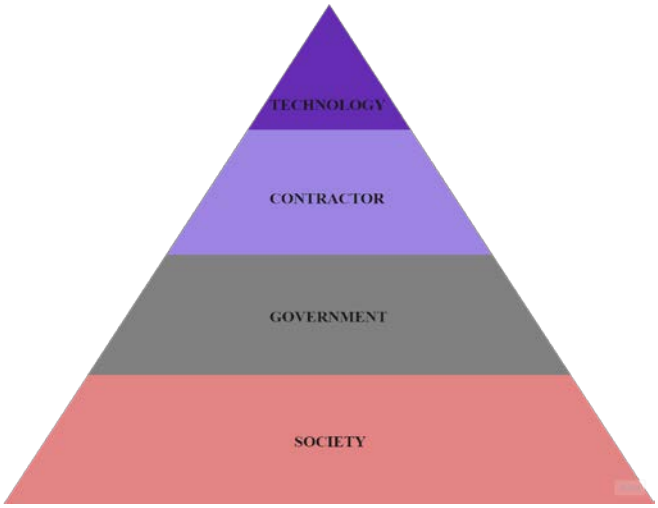

Figure 1 : Hierarchy in which a contractor is situated

Apart from the roles of the contractor and the government, the speed and direction in which the new technologies develop have an enormous impact on the transition of phasing out fossil fuel equipment. The technology for providing fully electric and battery-powered heavy-duty machinery requires further technological improvements (Bellona, 2018). Figure 1, demonstrates the hierarchy of the construction industry. Society plays a vital role in fast-growing social, economic and environmental awareness toward a more sustainable society. Government focuses on its ambitious goal of a zero-emission construction site by 2030. Contractors and construction firms act as intermediate players between market conditions and the government's sustainable goals. Finally, technology marks the market of existing and rapidly developing technologies.

1.2. Problem Analysis

The construction industry is a major user of the world's non-renewable resources which has been the most serious concern, because of the dependency of all human activities on them at present and also because of the current rate of depletion of these fossil fuels. Also, the amount of Green House Gas emissions made an impact on climate change. According to the Paris Agreement 2015, there has been pressure on the adaptability of renewable energy sources from fossil fuels to reduce Green House Gas emissions. Adding to this, the objective of making a circular economy in the Netherlands by 2050 and many other political issues that take place worldwide add more pressure on the construction leaders to shift from fossil fuels. There are some initiatives from different players at the current time to improve the use of these machines. However, there has not been a solid strategy to phase out fossil fuels, since every stakeholder works individually and lacks knowledge on how to get it done and the lack of urgency is reflected in the behaviour of the contractors.

1.3. Problem Statement

The identified problem leads to the following problem statement :

The transition speed of phasing out fossil fuel equipment and the complete electrification of the equipment on the construction site seems to be very low. We do not know how to speed up the process to attain a completely electrified construction site in 2030.

1.4. Research Gap

Table 1 : Literature studies

Literature	Methodology	Findings
(Karlsson et al., 2020)	Assessment of the potential for road development to reduce carbon emissions using literature study and scenario analysis	Decarbonization in road building needs to be implemented more quickly. Policy and procurement actions ought to be coordinated. Important potential include the electrification and hybridization of heavy equipment and transportation. Over-reliance on biofuels and cost efficiencies that cannot be scaled up are the main risks.
(Mamo Fufa et al., 2019)	Case studies that highlight the principal difficulties and potential from low-emission construction locations	To achieve fossil and/or emission-free building sites, stakeholders must work together openly and thoroughly, pay attention to the early planning stage, have defined goals, adhere to system boundary criteria, and use quantitative assessment techniques to prove reduction in emission.
(Anderson, 2019)	Case study to investigate the viability of waste-free and emission-free building sites.	Commercial aviation's decarbonization Jobs in construction will ultimately change. from fossil fuel to the electric industries production of equipment and power industry. Governments have the chance to open the way for inexpensive, wholesome, and safe zero-emission building.
(Aalbers, 2020)	Case study to accelerate the zero-emission of construction sites in Dutch Construction Industry.	Altering the competing market dynamics, enabling the policy environment and improving the attractiveness of various technologies. Additionally, contractors might exercise social responsibility and stop viewing emission control at construction sites as a purely governmental issue. Contractors might welcome the shift to more environmentally friendly building practices, such as reducing emissions at construction sites.
(Andresen et al., 2019)	Construction documentation were analyzed to determine the key takeaways	The significance of an integrated design, procedure, selecting locally sourced materials with low embodied carbon, having precise targets and accompanying evaluation techniques

	from the experimental zero-emission building projects.	
(Clarke et al., 2017a)	conducting interviews to ascertain the competence required for low-energy building.	The absence of learning on infrastructure sites and a deterioration in the breadth and quality of vocational education and training are obstacles. A radical transition road rather than market-based fixes can be used to solve this.

These studies demonstrate that there are broad obstacles and chances to get to zero-emission construction sites. The significance of governments and public procurement in advancing social goals like carbon reduction is one potential. The amount of literature already in existence has recognized the growing necessity to expedite this shift.

However, the topic of accelerating the shift to electrical construction equipment has received less attention.

There is still room for improvement in our comprehension of accelerating this change. Furthermore, earlier research lacked a summary of the major drivers and obstacles in the shift to electrified construction sites.

The Dutch construction sector does not demand the practice electric machines on site, which makes it difficult for contractors to successfully work toward phasing the fossil fuel machines . Which approach contractors should use to go toward phasing out fossil fuel equipment on construction sites is unclear at this time.

1.5. Research Questions

Summarizing the research gap that was analyzed by the literature study directs to the following main research question:

How can the transition of phasing out fossil fuel equipment on construction sites be accelerated?

To answer this main question there are a few sub-questions that needs to be discussed :

Q1. What are the barriers that slow down this transition of phasing out fossil fuel equipment on a construction site?

Q2. What are the drivers that accelerate this transition of phasing out fossil fuel equipment on a construction site?

Q3. What actions can accelerate this transition in electrifying construction equipment?

1.6. Structure of Research

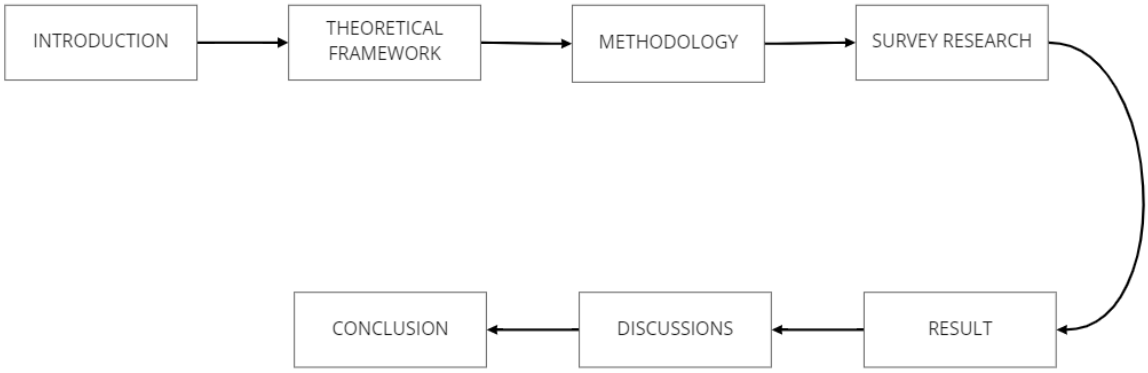

Figure 2 : Research Structure

This research is organized in the manner as follows. First, an explanation of the study's theoretical foundation is provided. It presents two transition theories that serve as the theoretical framework for this study. Second, the research's methodology is described. For instance, this concerns the particular survey research selections. The research's findings are then illustrated in chapter four. Chapter five discusses these findings. The research's primary findings are presented in chapter six, along with suggestions for more study.

2. Theoretical Background

This section is dedicated to explaining the two main concepts of this research: Construction Site and Transition. The major focus of this research is on phasing out the fossil fuel equipment on the construction site. So construction site is explained as a concept. This replacement of fossil fuel equipment with electrical equipment is called transition, and the socio-technical transformation is discussed.

2.1. Socio-Technical Systems and Transitions

One of the major reasons to step into this transition was the climatic changes happening worldwide. To encounter this system transition needs to take place. Also, this theoretical concept is chosen since the construction sites are visualized as a socio-technical system. This theory will be contributing to understanding the problem more in-depth with construction sites and answering the sub-research questions.

Socio-technical system transition aims at understanding the technological and social changes by analyzing the cause that enables or inhibits them and by offering policy recommendations on how to steer sociotechnical systems (PapaChristos). The socio-technical system incorporates technology and humans, clusters and deeply locks them together in many elements(Geels, 2002).

The socio-technical system consists of three basic interacting elements (van Rijnsoever & Leendertse, 2020) :

- Actors
- Institutions
- Infrastructure

The actors the main element of the socio-technical transition since they exchange resources and form networks. They develop patterns, produce products and provide services. The actors act under an institution which is the set of rules and regulations imposed by the government. This regime is continuously reproduced by actors that adhere to the rules. Thirdly, the physical resources that are needed at a minimum for the socio-technical system to function are the “Infrastructure” (van Rijnsoever & Leendertse, 2020).

The advantage of categorizing the transition into the socio-technical system is that the co-evolution of technology and society becomes the focus of attention. It also involves a dynamic process of mutual adaptations and feedback between technology and the user environment (Geels, 2004). Figure 3; focuses on bridging the gap between the user and technology and the co-evolution between them.

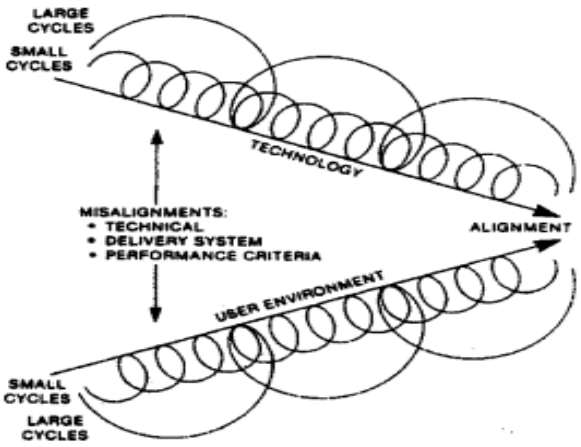

Figure 3 : Co-evolution of technology and user environment (Geels, 2004)

2.2. Construction Sites as a Socio-Technical System

A construction site is filled with many different elements, such as the main infrastructure on the site, storage places of materials, construction equipment and machinery, and offices and facilities for staff to work all day. An overview of construction activities is illustrated in the figure 4.

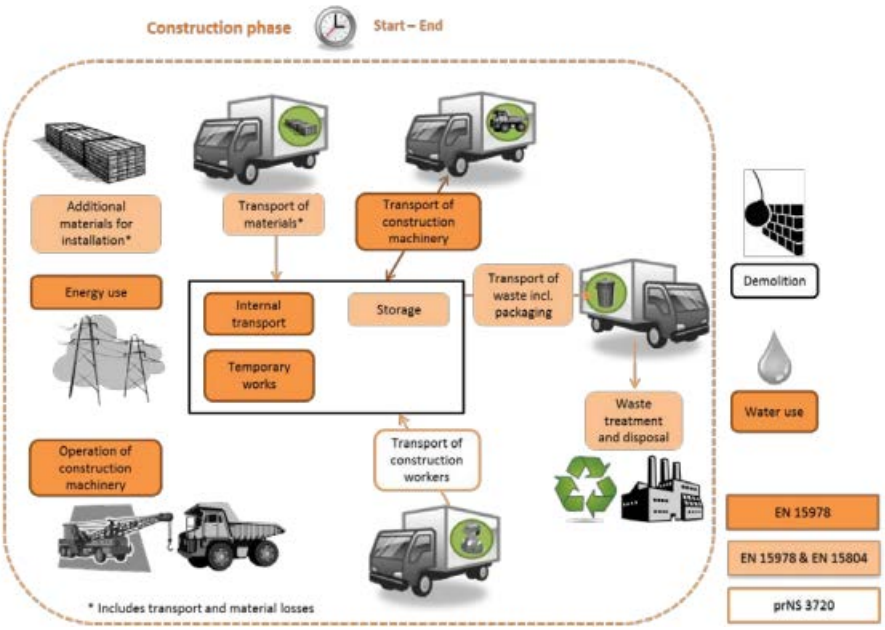

Figure 4 : Boundary for construction activities at the site (Fufa et al., 2019)

A construction site is referred to as a socio-technical system because they consist of all the three basic elements of the socio-technical system mentioned by (van Rijnsoever & Leendertse, 2020). A socio-technical system of a construction site is illustrated in the figure 5.

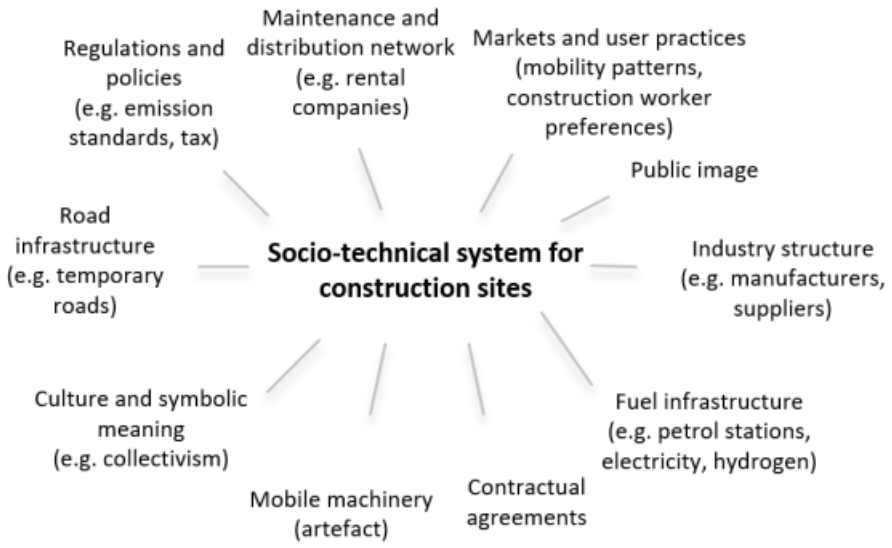

Figure 5 : Socio- technical system for construction sites from (Geels, 2002)

In this research, barriers and drivers will be found that deals with these different elements of the construction sites as a socio-technical system.

2.3. Multi-Level Perspective (MLP) Framework

The multi-level perspective (MLP) is used as one of the core frameworks of this research to get an in-depth understanding of the transition. The concept deals with three different perspectives from the views of the Government, the contractors, Technology and innovation. Sub-question one and sub-question two are about understanding the barriers and drivers from the three different perspectives mentioned above.

The multi-level perspective is a theoretical framework that conceptualizes the overall dynamic pattern in the socio-technical transitions (Geels, 2011). The biggest strength of this framework is that it is a relatively open framework allowing researchers to ask new kinds of questions (Geels & Schot, 2010). MLP is used to understand the struggles faced by the system when it is transforming in various domains such as socio-cultural regime, user and market regime, policy regime, science regime and technological regime.

The MLP has two fundamental dimensions: Scale and time. From the views of MLP, the transition appears to be a non-linear process from three analytical levels such as :

1. Niches: The micro-level element which is unstable, consisting of entrepreneurs and innovators.

2. Socio-technical regime: A meso-level element where the social networks are much larger. The actors are coalesced into a stable and have articulated rules and more structuring effects.
3. Socio-technical landscape: The macro-level part of the system, an exogenous broad structure that provides gradients for action.

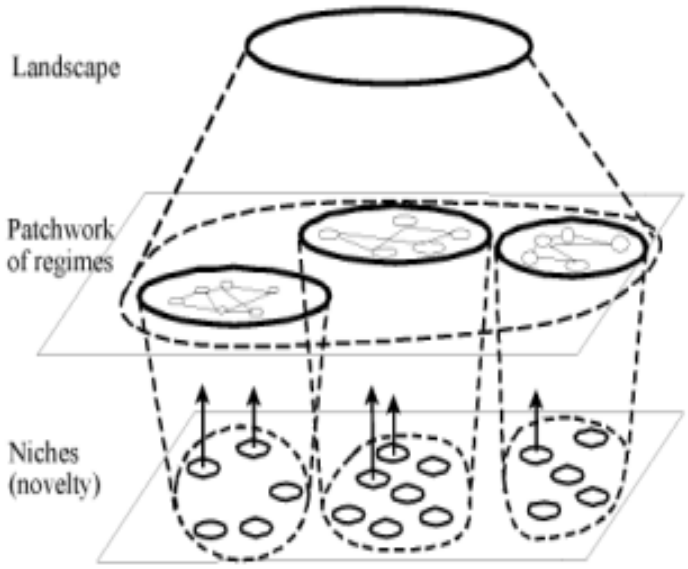

Figure 6 : Multi-level perspective (Geels, 2002)

Transitions are mainly about the change with stability involved in it. Also, the systems do not change exponentially but incrementally over time. This can be well explained by the economic, social and political mechanism that results in stability. Niches innovation which are happening in an unstable environment want to break out but instead, they are struggling in that system.

The regime level is where most of the interest is concentrated. It addresses the issue of how current regimes transition from one system to another. In the end, transitions are about both stability and change. The issue is that the current system is antiquated, dependent on its current course, and resistant to change.

Systems change more gradually throughout time rather than drastically. Stability-producing economic, social, and political mechanisms can be used to explain this. In terms of economics, this may include entrenched interests, sunk costs, scale benefits, and vested interests. Political power and social cognitive habits both play a significant impact.

Speciality inventions are the focus of the micro level. These dramatic niche inventions are the beginnings of sustainability shifts. These are the peripheral innovations that are emerging. The innovations want to succeed, but they are having trouble doing so in a firmly entrenched system.

This framework can act as a link between the various academic fields researching different facets of transitions and system improvements. We employ a preliminary framework that comprises the multi-phase and multi-level concepts as two transitional ideas (Loorbach & Rotmans, 2006).

2.3.1. Multi-Phase Concept

According to the multi-phase notion, transition paths that change from one dynamic equilibrium to another are highly non-linear and involve multiple phases. Generally speaking, we assume that a transition occurs through the following stages :

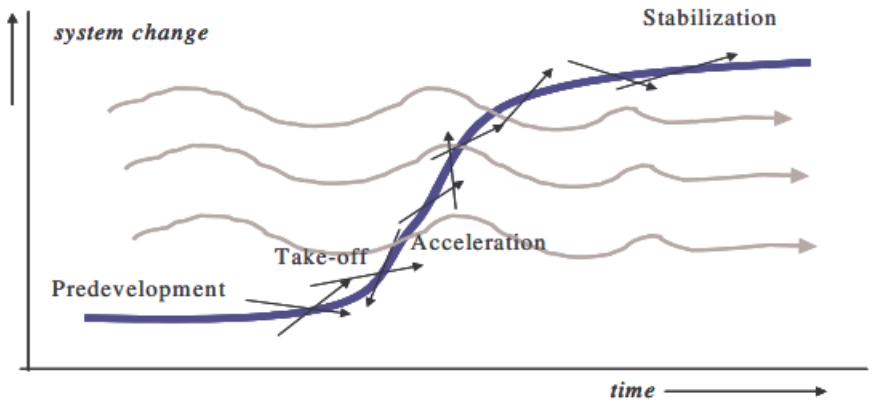

Figure 7: Various Transition Phases (Loorbach & Rotmans, 2006)

1. A pre-development stage in which there is a lot of experimenting at the individual level but little discernible change at the systems level;

2. A take-off phase, during which the process of change starts to intensify and the system's state starts to alter as a result of various surprises or innovations that reinforce one another.

3. An acceleration phase in which institutional, sociocultural, economic, and ecological changes are implemented and accumulate to produce evident structural changes.

4. A stabilization phase in which the rate of social change slows and a new dynamic equilibrium is attained.

Radical innovations are all coming from someplace, and it is possible to follow their evolution throughout time. Innovations first appear on the margins and are unable to compete in established markets right away. When compared to existing technologies, the price performance characteristics of innovations are initially substantially lower. When

innovations perform better and are valued by, for example, major clients, this changes. How may these beneficial niche breakthroughs gather steam overtime to topple the current system? The central conundrum of transition studies is that.

2.3.2. Dynamic Multi-Level Perspective

It is possible to combine the multi-level and multi-phase concepts more dynamically. (Geels, 2004) conceptualized time using a similar four-phase method.

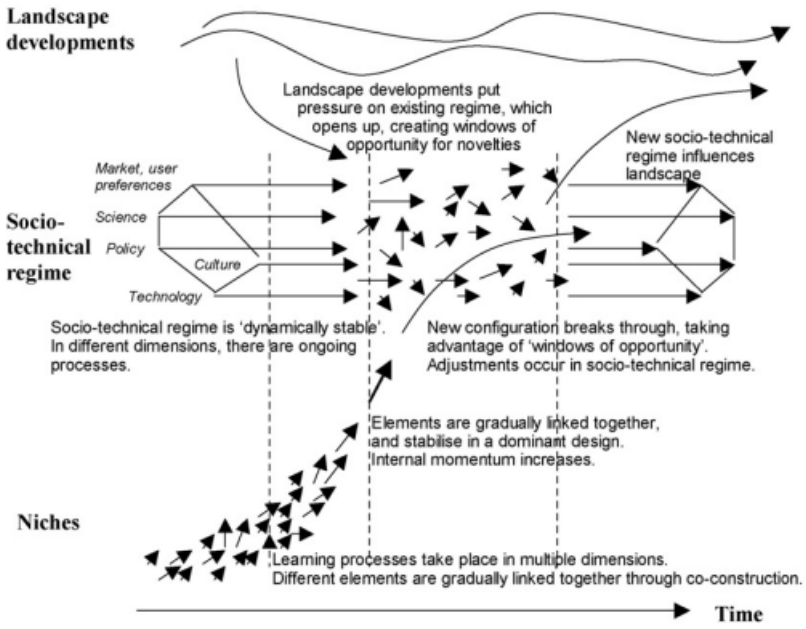

Figure 8 : Dynamic Multi-level perspective on transitions (Genus & Coles, 2008)

Typically, radical innovation happens at the micro level in niches, either as a result of landscape changes or in a bottom-up manner. Niche markets can serve as safe havens for experimentation or as a platform for the development of social networks that promote radical innovations.

Figure. 8 shows graphically how the various scale levels are developing over time. There is a lot of trial and error as radical innovations emerge. The niches are very diverse, but there are also a lot of failures. Niche inventions are up against the current system. This regime is not completely dormant; rather, it is gradually evolving. Typically, the larger landscape level develops considerably more slowly.

The emergence of radical innovations in narrow niches is discussed in the first phase. There is an extended time of exploration, learning, network development, and vision articulation. The system then progressively stabilizes. There is greater consensus over the direction to be taken, and visions, prices, and performance all improve.

The second and third phases then begin to suffer. How do new ideas spread and integrate into the current system? Usually, this also includes forces coming from beyond the government, such as tools of policy. Deep-seated lock-ins and route dependencies are often resolved by doing this. Due to these forces, the regime is made more flexible, which gives niche ideas a better chance of becoming more broadly adopted and displacing the current system.

2.3.3. Research Application of MLP

The meso, micro and macro levels of the MLP are connected to the three views of this study. The notion of the landscape is influenced by the rising sense of urgency in society to address climate change (Aalbers,2020). Both the government and the contractors understand the regime from a meso-level viewpoint. The study's primary interests are in the government and contractors, just as the MLP's primary interests are in regime transitions. The niche innovations are conceptualized from the framework from the technology and innovation standpoint.

2.3.4. Transition paths

(Geels & Schot, 2010) enumerate four distinct transition routes :

- Technological substitution: new, specialized developments appear, and substitution mostly affects the technological realm. One technology is used more frequently, whereas another technology is used less frequently.

- Transformation Pathway : current actors gradually change their orientation. A changed system without a replacement is the result of this long-term, incremental change in a regime.

- Reconfiguration Pathway : radical ideas appear in specialized markets and are integrated into current systems. The architecture of the system may alter as a result of partial substitution in the systems. Instead of overturning the current administration, new and old actors form partnerships.

- De-alignment and re-alignment : Significant topographic pressure shocks the system. The system starts to break down and become unstable. This makes room for the development of specialized innovations, which prompts a fresh repositioning of the regime.

These transitional routes are intriguing since they show that there are several methods to make a change.

2.3.5. Limitations of MLP

The theoretical MLP framework has a number of drawbacks. (Geels, 2011; Geels & Schot, 2010) addressed these drawbacks and enumerated the objections.

- Lack of agency - The MLP framework pays little attention to actors and their role in politics and power. According to (Geels & Schot, 2010), social actors actively participate in the multi-level alignments and trajectories, giving them agency. The MLP accommodates agency through constrained rationality and interpretative. However, other forms of agency, such as power conflicts, culturally discursive activities, and logical decision-making, are still in their infancy. Insights from business studies and strategic management might also be useful for the framework.

- Operationalization and regime specification - This relates to the issue of identifying the subject of analysis and establishing boundaries. The frameworks don't specify how precisely or broadly a certain issue should be defined. The regime may include empirical issues with various levels of detail. What appears to be a regime transition at one level may really be a gradual adjustment at a larger lever. The concept also emphasizes how one regime's transition takes place. Other interactions between several regimes require further focus.

- Bias in favor of bottom-up change models: The MLP favors regime changes that start in niches and work their way up. This understates the impact of the terrain on the socio-technical regime that works at the bottom of the social hierarchy.(Geels & Schot, 2010) identified the four transition paths in an effort to combat this prejudice.

- Heuristics, epistemology, and explanatory approach - The framework is also seen as having an explanatory and theoretical approach. The MLP, on the other hand, is an open platform that enables analysts to pose specific queries regarding processes and patterns.

- Methodology - It has been argued that historical case studies shouldn't employ secondary data sources. The framework's consideration of the reliability of the data sources lacked depth. In contrast to methodical research, the transition studies focused more on exploration and visualization. Nevertheless, creative interpretation is always a part of studying complicated processes like transitions.

- The socio-technical landscape level was criticized for being a residual category because it is a level of the technological environment. More theorization is required at this level, and the idea may be made more dynamic.

- Hierarchical levels vs. flat ontologies - The notion of hierarchical levels was criticized since society is not always portrayed as a multilevel entity. But doing so could compromise the framework's empirical operationalization, generality, and correctness .

2.4. Transition Theories

Different transition theories are founded on the socio-technical systems theory that was previously discussed as well as the multi-level viewpoint. The following are the top four transition theories: 1) Transition Management 2) Innovation systems 3) Sustainable Market Transition 4) Small Wins (translated from (Het Brien, 2021)). Out of the four commonly used theories, this part tries to justify the selection of the transition theory of sustainable market transformation for further discussion in the next section. On the basis of scale application, actor application, advantage, and disadvantage, Table 2 contrasts the four theories. The Sustainable Market Transformation and Innovation Systems theories are the two that place a lot of emphasis on private businesses. Due to their lack of this particular focus and their perceived ability to provide a more general viewpoint, the other two theories—Transition Management and Small Wins—were not selected. While the scope of this study does not simply focus on innovations, the innovations systems (TIS-model) is particularly focused on them (Aalbers, 2020). This influences the notion of sustainable market transformation. The Sustainable Market Transformation theory's key benefit is that it emphasizes stakeholder actions, particularly those of private businesses. This is quite consistent with the study's goal.

Table 2: Transition Theories

Theory	Scale Level	Actors	Advantage	Disadvantage
Transition Management	Applicable on all scales	Applicable to all actors	Offers the most broad perspective	Less detailed in the analysis of the market movements and innovations
Innovation systems (TIS-model)	Regional, national and international sectors	Government and companies	Provides a deep understanding of the success of innovation	Less focus on other aspects besides innovation
Sustainable market transformation	Regional, National and international sectors	Government, companies, NGOs, financial and knowledge institutions	Focus on interventions of stakeholders	Less focus on the broad societal transition process
Small wins	Applicable in any scale	Applicable to any actor	Focus on small and meaningful steps	Less focus on deeper underlying transition problems

2.5. Sustainable Market Transformation

Sustainable market transition is built through the understanding of the path-dependent nature of the socio-technical system and the nature of interactions among the actors involved and the assumption of every market transformation there are underlying reasons why sustainability issues happen. According to the system theory, the dynamics of the system are explained in terms of a causal loop. These causal loops are self-reinforcing mechanisms that create a specific path to action leading to a lock-in, a process already highlighted when considering path dependence at the market level(Vergne & Durand, 2010). There are many stakeholders taken into account because businesses are not the only ones facing these significant sustainability issues. It is a multi-stakeholder problem, not just one that affects one corporation.

2.5.1. Introduction

The sustainable market theory seeks to identify actor behavior patterns that result in unsustainable results. According to (Lucas Simons & Andre Nijhof, 2021), transitions can be sped up if this behaviour is noticed. The motivations behind this behaviour should be understood in particular. This holds true for all parties involved in the building business, including public and private entities. By examining the obstacles to the change, this unsustainable behaviour was also discovered later in the investigation.

It is stated that changing systems is a multi-year, multi-phase process that must go through many stages. Every stage has unique qualities (Lucas Simons & Andre Nijhof, 2021). Understanding where the theoretical model places the change process can help you determine what the government, a private party, or any player in the construction sector has to do. System change is considered to be an organizational problem amongst industry stakeholders. Understanding which actor should do which action at which time is crucial (Lucas Simons & Andre Nijhof, 2021). In a multi-stakeholder setting, the stakeholders should organize their interactions.

2.5.2. Four-Loop Model

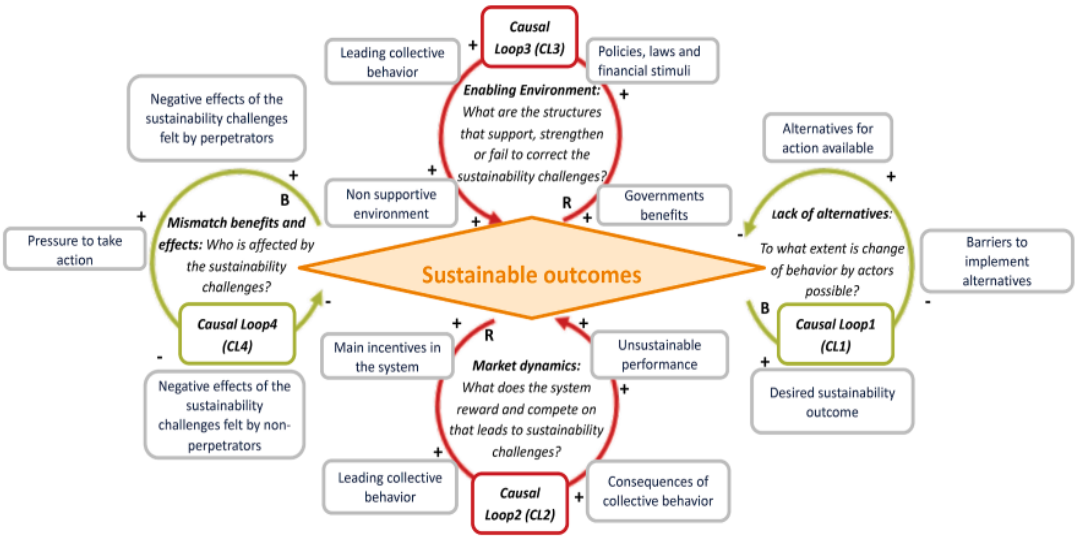

Figure 9: Four Loop Model (Nijhof et al., 2022)

Four loops leading to unsustainable results have been identified in order to better understand the system of the construction industry. Each loop has a related question. Figure 9 illustrates these four possible loops in detail. These inquiries are addressed in the context of the building sector, which is significant since it includes zero-emission building sites. Violent loops in the model are fuelling a downward trend. Understanding these self-reinforcing cycles in the construction sector can shed light on why the shift to zero-emission building sites is moving so slowly.

Loop 1: Causal Loop 1 – CL1:

A balancing loop of alternatives or conditions to change. What are the alternatives and how attractive they are? Theoretically, a lot of alternatives are possible, but they are expensive, uncertain or there are not many manufacturers. Contractors are not familiar with the alternative practices or the new technique, since there is no expertise in a completely electrified construction site. However, these options are lacking in an unsustainable and small market, leaving the actors involved with no choice but to continue with their current practices.

Loop 2: Causal Loop 2 – CL 2:

A reinforcing loop of market dynamics. What does the market compete on? Manufacturers are reluctant to produce machines for the Netherlands because of the small market and number of projects. This makes them move slowly and safely towards producing more electrified equipment for the industry. There are currently no incentives provided in the

market for the transition to take place. The dominant culture in the construction sector is to aim for the lowest price, safety, fastness and as few risks as possible (Simons & Nijhof, 2021). Contractors that behave accordingly, will be successful and win the contract, leading to insufficient investment costs for bringing in the electric machines to the site. Clients are currently starting to focus on the most sustainable projects with the most emission reduction. On the whole, the complete sector is focused on reducing cost, staying away from risks or outsourcing to others. Such collective behaviour has consequences in terms of actions taken by market actors which lead to unsustainable outcomes (Nijhof et al., 2022).

Loop 3: Causal Loop 3 – CL 3:

A reinforcing loop of enabling environment. What are the policies and their context of it? The Dutch government has an interest in the construction sector, which is efficient, provides jobs that are cheaper and leads to investment. This makes the Netherlands competitive and this also applies to the construction market. This makes the Government blind to the social values of the environment. The policy, financial incentives, legislation and how people are educated generally aim to keep projects cheap, efficient and unsustainable. In this way, a construction sector is created in which the winning contractors are those with the lowest costs and lowest risks, and who have become good at externalising costs (Aalbers, 2020).

Loop 4: Causal Loop 4 – CL 4:

A balancing loop of the mismatch benefits and effects. Who is affected? Contractors and governments are not personally affected. Contractors are only indirectly affected when the projects come to a standstill, which happened in 2019 when they were not allowed to build anymore because of the emission. The Dutch government is concerned about the NOx crisis.

The leading vicious loops in the construction sector today are depicted in Figure 10. The maintenance of these vicious cycles can be attributed to the building industry's delayed transformations. It is because the underlying system's deeper causes and incentives for unsustainable behaviour are impeding transformations.

These loopholes have been kept open by governments, the corporate sector, and all other building industry partners (Lucas Simons & Andre Nijhof, 2021). The performers concede that there is a problem, but they contend that others must take the initiative. While the government waits for the market mechanism to function and more zero-emission equipment to be used on building sites, private parties are waiting on the government. Due to the phases that the change process goes through, there is no easy way to break these loops (Lucas Simons & Andre Nijhof, 2021)

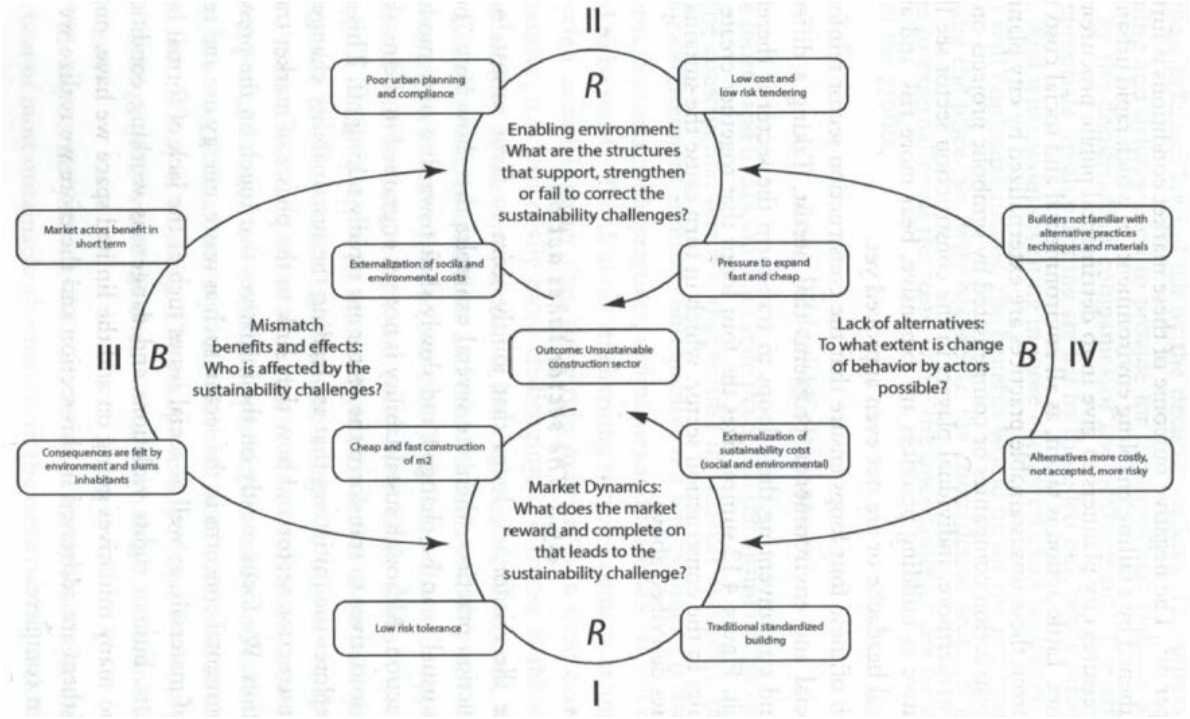

Figure 10 : Four loop model applied to the construction sector that leads to an slower paced transition (Simons & Nijhof, 2021)

Later on in this research, the acceleration measures are designed to break these loops and produce an upward trend rather than a downward trend.

2.5.3. Strategy : Sustainable Market Transformation

The acceleration actions aim to break these loops which tend to form a slow transition to a sustainable outcome. Sustainability is not a linear path to a single goal but a complex process, consisting of distinct phases toward system maturity(NewForesight Insight, 2018). It is argued that every market goes through four market phases, such as Inception, First Mover, Critical Mass and Institutionalization Phase. Figure 11, illustrated the identical transition pattern towards a more sustainable system, known to be the Sustainable Transformation Curve or the “S-Curve” (NewForesight Insight, 2018).

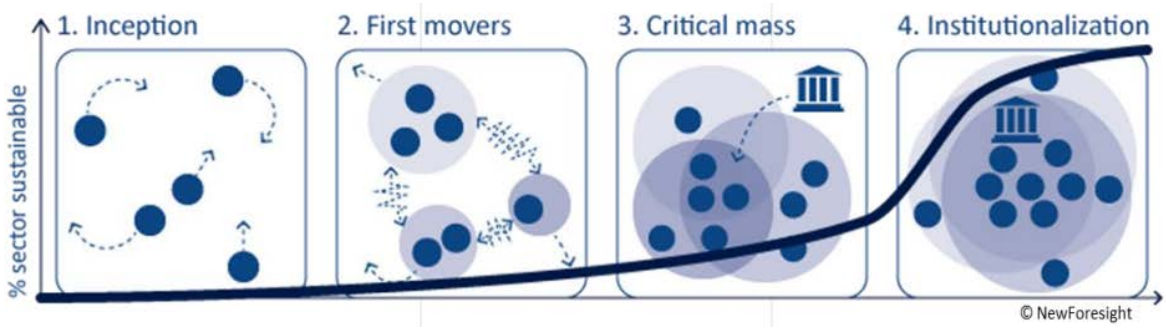

Figure 11 : Sustainable Transformation Curve (NewForesight Insight, 2018b)

Phase 0: Denial

His phase appears before any of the other phases begin, hence it is not visibly shown in figure 11. The construction industry operates as usual, and the vicious cycles continue. Long before it was thought to be an issue, the need for emission reduction was well acknowledged. This lasted up to a critical point. The industry awoke later, and a sense of urgency developed. Denial is frequently a sector's initial response. This urgency was brought about in the Netherlands by the 2019 nitrogen problem.

Phase 1 : Inception - raising urgency and pursuing practical solutions through projects and innovation

Phase one sees the sectors launch new initiatives and pilot programs. Finding out what requirements solutions should satisfy is the goal here. The purpose of this phase is to learn about the technology that can help the industry accomplish its objective of reducing emissions at building sites.

Phase 2 : Competitive advantage – through using innovation and competition, developing new business models

The second phase concerns the early adopters who will implement these novel solutions initially. Construction sites may now use zero-emission machinery thanks to contractors. To gain a competitive edge, these pioneers must be honoured and recognized. This might be a prize, improved networks, access to technologies, or a better reputation. Additionally, it's critical to progressively influence individuals who choose not to participate. Private businesses want to stand apart from their rivals, not do the same thing as them. In this stage, businesses innovate, develop new business models, and invest more resources because they want to defeat their rival. Although the loops have not yet been closed. Although the loops have not yet been closed, the industry has already moved from denial to competition after completing pilot projects and learning.

Phase 3 : Pre-competitive Collaboration: Facilitating Scaling via Multi-Stakeholder Coalition and Platform Collaboration

Phase three calls for the sector to facilitate scale through coalitions and platforms made up of various stakeholder groups. The sector's top decision-makers begin to exchange ideas with one another about their vision, the structural role of the government, and the role of the corporate world. A clear picture of what zero-emission building sites in the Netherlands should now be formed as the participants start to agree on what they want to accomplish.

Phase 4 : Institutionalization - establishing laws and forceful self-regulation to provide a level playing field

The turning point has been achieved in phase four. To guarantee a fair playing field by law and forced self-regulation, political leadership is required. Everyone has had enough time to become used to emission reduction techniques. This indicates that some parties may withdraw, but the industry has advanced. After then, fresh waves of market transformation will begin to emerge. Market innovations and changes are ongoing in a sustainable market transition.

2.5.4. Theoretical Acceleration

Everyone can cooperate to speed up this transition if the key stakeholders understand what to do in each step (Lucas Simons & Andre Nijhof, 2021). This acceleration may be explained using the analogy of cycling. If everyone is kept together, the peloton will move, but at a set speed. People continue to stick together, so there is no incentive to speed up. The peloton has to be broken up in order to speed up. But this goes against the idea that there should be no barriers to admission and no fair playing fields. The best question to address from a strategic standpoint is: Under what circumstances may boundary behaviour be recognized and acknowledged? The peloton is split apart in this way. The peloton must then be reassembled by scaling up. An organized harmonica movement is what is needed. Create a sense of urgency, identify the problems and their remedies, disperse the peloton, speed it up, bring it back together, scale it up, and institutionalize it. This movement is a market transformation ploy.

This procedure will push market participants who are at the rear of the pack to join the train right away or risk being eliminated from the market. A party runs a danger of failing if it takes the initiative and innovates excessively. To speed up transitions, risk-taking leading behaviour should be encouraged. This may also be accomplished, for example, by forming clever alliances with rival businesses.

It is crucial to understand what each stakeholder does at when moment during the different phases in order to accelerate the process (Simons & Nijhof, 2021).In the stakeholder matrix, an outline of what the key players should perform at each phase is provided. In Figure 12 , this stakeholder matrix is shown. It gives insight of the roles that the industry and the government should ideally take in the various phases.

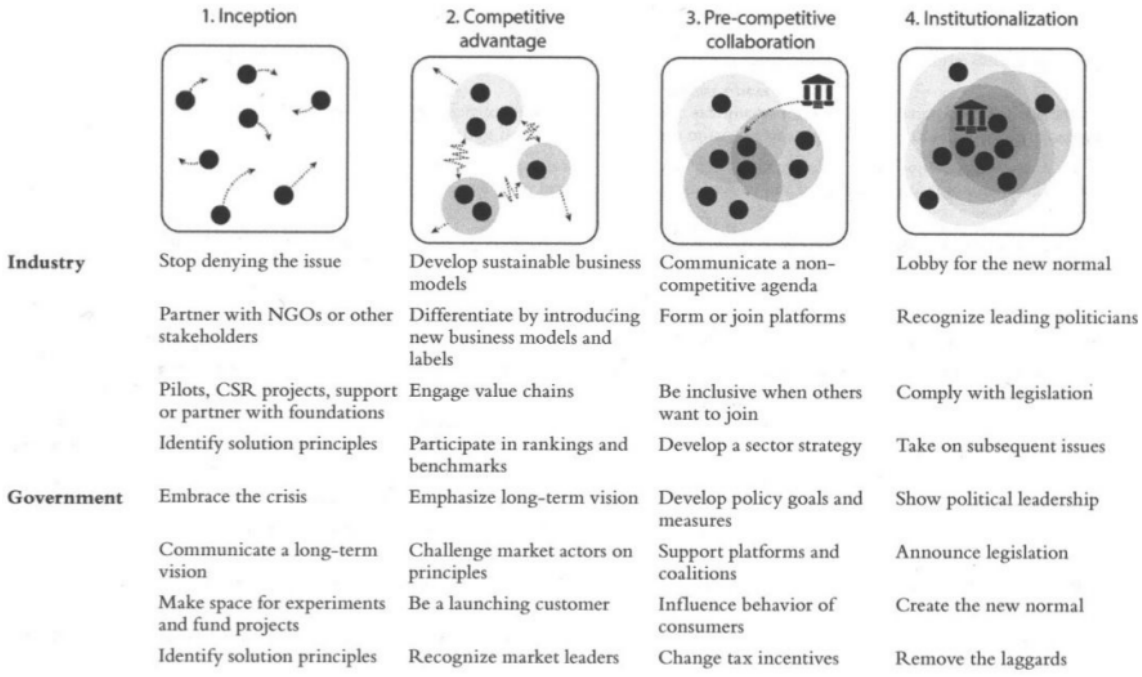

Figure 12 : Industry and Government stakeholder matrix (Simons & Nijhof, 2020)

2.5.5. Limitations

According to (Simons & Nijhof, 2021) the following are the primary market transformational assumptions:

1. Any concern with sustainability might trigger a complete market revolution.
2. There are usually four stages to this change.
3. Since each step influences the market circumstances of the following phase, none of these phases may be omitted.
4. Each market participant has a unique function to play in each phase.
5. The game can only be adjusted if it is apparent who should do what and when; otherwise, resistance may be anticipated; buddies in one phase will turn into foes in the next.

Theoretically, just some of the assumptions are addressed. For instance, consider stakeholder salience theory, deliberative democracy theory, evolutionary economics, viable systems theory, and neo-institutional theory.

The underlying assumptions do, however, need to be theoretically strengthened more. The stakeholder matrix per sector and the comprehension of the particular functions played by different market participants may yet be improved. There may be some performers missing, depending on the area of interest. The idea does not offer guidance on how to inspire each stakeholder to take the appropriate action.

For the impact of market changes to be observed in practice, longitudinal study would be required. This is required to determine whether the theory actually produces solutions that meet the sustainable development goals.

2.6. Barriers and Drivers

2.6.1. Theoretical Barriers and Drivers

A framework for classifying transitions is shown in figure 13. Each phase has its own obstacles to overcome and chances to advance to the next level. Different theoretical obstacles and motivations apply depending on the stage of the transition. For instance, changing from competition to collaboration while transitioning from phase two to phase three. For example, adopting a "wait and see" mindset and failing to actively participate to fostering a collaborative environment is a barrier that prevents this. Companies don't trust each other enough, which is another hurdle. Companies won't actually collaborate if they continue to operate in the competitive phase. If the government does not show that it is prepared to change or does not take the initiative to alter the political climate, the competition phase can also be hampered. Here, there are opportunities for advancement, such as developing a workable business case strategy and offering rewards for desirable behaviour. In addition, the philosophy promotes defining roles and duties clearly, ensuring scalability, and maximizing synergy. Stakeholders must establish trust, be transparent, and unite on a plan and a shared vision.

Figure 14 illustrates the Market Transformation Matrix, which helps to identify the four market transformation phases and builds upon the prior framework. This matrix lists the key change agents, primary opponents to change, drivers of change, level of awareness, readiness to collaborate, and hurdles for each phase. For instance, the growing understanding that sustainability may be used as a competitive advantage is a catalyst for change in phase two. During this phase, standard organizations and early adopter businesses are the main change agents. First mover advantages, long-term marketing, and media pressure are seen as drivers at this stage. This matrix may be used as a road map for stakeholders to recognize both opportunities and priorities at each step of the transformation process.

How to characterize the transitions

Phase 1 to phase 2: from PR problem to competitive opportunity

The actual impact of the projects in phase 1 remains limited and fragmented. New crises drive public awareness of the problem or companies identify a competitive opportunity; accelerating the transformation process. The transition can be slowed down when emerging practices don't create sufficient value for first movers, or when organizations that benefit from phase 1 successfully resist the move towards competitiveness.

By sparking the competition on sustainability between frontrunner companies, change agents can smoothen the path towards phase 2.

Barriers

- Emerging practices do not create sufficient value for first movers
- When organizations that benefit from phase 1 successfully resist, undermine or lobby against new practices

Opportunities for progress

- Create best practices/standards that give a competitive advantage to first movers
- Spark competition by gathering positive attention for first movers and build pressure on laggards

Phase 2 to phase 3: from competition to collaboration

While efforts in phase 2 are more effective than in phase 1, they are still unable to address all negative systemic feedback loops. While added value of standards diminish, due to the saturated label-market, the realization grows that structural sustainability issues are not being solved.

The move towards collaboration requires a growing awareness of the need for joint action in tackling the systemic issues affecting the sector as a whole. This marks a shift in industry thinking away from "how can we beat our rivals at sustainability?" to "how can we effectively organize the path towards a sustainable sector?".

To make collaboration a success, stakeholders need to open up, build trust and align behind a common vision and strategy that has a viable business case.

Barriers

- Companies that start to work together have a 'wait and see' attitude and do not actively contribute to grow the collaborative, non-competitive movement
- Companies, NGOs, and standard organizations can successfully resist and undermine collaboration between actors
- Companies don't trust each other sufficiently; then they won't really collaborate and instead stay in the competition phase
- This phase can also fail if governments do not provide leadership and demonstrate their willingness to change the policy landscape to institutionalize better practices
- Lack of resources to make the change mainstream

Opportunities for progress[1]

- Bring industry leaders together to create a common, inclusive approach towards a sustainable sector; from standards and certification to sustainable transformation
- Develop a compelling Theory of Change and consistent, actionable strategy to align stakeholders
- Articulate clear roles and responsibilities to maximize synergy, ensure scalability and share costs
- Build a viable business case approach, creating incentives for desired behaviour
- Co-create a shared framework for M&E and reporting to ensure accountability
- Organize sector-wide learning to drive continuous improvement

Phase 3 to phase 4: joint action towards a sector tipping point – things are markedly improving.

But the work is not done yet: some stakeholders resist the transition, while unsustainably behaving companies profit from the improving industry image.

Frontrunner companies that lobby to institutionalize the new normal are held back by governments unwilling to change or by NGOs and standard-setting organizations feeling left out. It is therefore essential to align as much of the industry with the vision and actively lobby for institutionalization.

Barriers

- Governments are unwilling to make institutional change
- There is effective lobbying against transformation of the sector

Opportunities for progress

- Convene the critical mass of industry leaders willing to align with and contribute to this new vision
- Ensure a consistent message to all stakeholders and clear, fact-based lobbying towards policy makers

Figure 13 : Characterising Transition (NewForesight Insight, 2018)

Elements	Phase 1: Inception	Phase 2: First mover	Phase 3: Critical Mass	Phase 4: Institutionalization:
Triggers for change	- A publicly visible **crisis** raises awareness, and leads to public pressure to act	- Problems in the sector persist, but there is increasing realization that sustainability can be leveraged as a competitive advantage	- Industry actors realize that the problem will not be solved by competing organizations and isolated efforts, and **efficiency can be found in collaboration** - **Increased awareness** that sustainability issues cause supply chain risks and threaten business models	- **Harmonized initiatives** - Joint capacity building - **Institutionalization** - Involvement of national governments and international bodies
Initial response and level of awareness	- Initial projects start when **public pressure** offer a significant **reputational risk** - Problems are misunderstood resulting in **isolated projects** only addressing visible symptoms	- More should be done to address problems, otherwise they will persist - First Movers realize that they can benefit from **first-mover-advantages** and **marketing sustainability** - Laggards maintain a low profile hoping that attention to the topic fades	- High awareness of the severity of the problems as it threatens business continuity with the level of supply chain risks, and **limited results of previous efforts** - There is a need for the industry and national governments to collaborate, invest and **change the rules of the game**	- High level of awareness of the **interconnectedness** of the sector - How do we **organize ourselves** to change the rules of the game?
Willingness to collaborate with others	- There is a low level of confrontational relationships with industry competitors - There is **growing willingness to cooperate** on projects with those who have credibility, for shared resources and recognition	- **Willingness to collaborate is growing** and other (non-competitors) players can become partners	- Companies are aware that they **need to collaborate**, though they are still relatively suspicious in the beginning, as they remain competitors in the marketplace: there is a need to clarify competitive vs non-competitive issues	- Level of **willingness to collaborate is high**; however, when regulation becomes effective, competitive behavior increases again
Drivers	- To avoid reputational damage - **Quick fixes** proposed as solutions - The focus is on storytelling and **marketing**—'being seen to act'	- NGO campaigning and **media pressure** continues; lawsuits appear - First Mover advantages include marketing & CSR promotion, whereas laggards experience limited pressure to change	- Longer term vitality of the sector - Securing sustainable sourcing - Efficiency of sustainability efforts - **Sharing risks and costs** - Collaboration increases influence on key stakeholders	- Compliance with standards becomes a qualifier for doing business
Limitations to impact & barriers to change	- Projects are **fragmented and competitive** with limited, temporary scope and impact - Projects are **not scalable**, with no real exit strategy, resulting in problems resurfacing due to the root causes not having been addressed	- Farmer change is mainly driven by premiums, expensive **certification programs** and NGO capacity building support for farmers; however, programs can only reach a certain number of farmers and resource use is inefficient due to proliferation, fragmentation, and **competition of standards** - At some point, the **added marketing value declines**, while the costs of the programs continue to rise	- To **build trust** between the parties to collaborate and **share knowledge** can be challenging, as well as determining where the industry works together and where it competes	- Despite having moved the sector on a particular issue, **new issues have already been identified**, progress on which is generally at the start of the curve
Main change agents	- NGOs, media, outsiders, concerned individuals, leveraging public pressure	- First mover companies - Standard organizations	- Neutral **convening platforms** and industry representative groups - Leading **industry groups** in which former competitors work together - At this point, **governments may follow** and support	- Industry lobbies for **level playing field** - Governments and trade organizations protect the rules - **Law enforcement** and **monitoring**
Main opponents to change	- Beneficiaries of the business-as-usual scenario, often industry, the financial sector, and (local) gov'ts	- Project owners of the first phase of market transformation - NGOs who resist working with the industry out of ingrained distrust - NGOs or capacity builders with vested interest in the booming 'projects industry'	- Resistance or heel-dragging may come from key change makers of previous phase (standard organizations, NGOs, companies), who perceive a threat to their central role as key change-makers; - National governments may resist change as they are expected to commit to something they have not been involved in creating	- Laggard companies, national governments - Standard organizations

Figure 14 : Market Transformation Matrix (NewForesight Insight, 2018)

2.6.2. Barrier and Driver Categories

To get a better understanding of the barriers and drivers, a literature study was performed to help categorise them related to the infrastructure transitions. There are four different categories, a) Institutional/ Regulatory, b) Social/ Cultural, c) Economic/ Market/ Financial and d) Technological (derived from (de Jesus&Mendonça,2018)). The higher techno-economic trajectories might be seen as having "harder" components (de Jesus & Mendonça,2018). The "softer" aspects are more related to cultural and legal concerns. The "drivers" are elements that support or facilitate the shift to zero-emission building sites. The difficulties that prevent the shift to zero-emission building sites are the "barriers". Table 3 illustrates these four categories and their definitions.

Table 3 : Classification of barriers and drivers

Category	Description
Institutional/ Regulatory	The lacking legal system, institutional framework and misaligned incentives.
Social/ Cultural	The rigidity of business routines.
Economic/ Market/ Financial	Need for large capital investment, transaction costs, uncertainty return and profit.
Technological	Lack of technical support and training.

There is a dearth of academic research on the acceleration of the shift to complete electrification of construction site. The researcher searched beyond the purview of this issue since internal driver categories for the transition at construction sites had not yet been covered by prior studies. The literature on green building demonstrates parallels between emission reduction at construction sites and serves as an important backdrop for our study. Internal drivers may be categorized into three more categories to provide a better understanding of what motivates private reducing behaviour. 1) Business; 2) Project; and 3) Personal (Darko et al., 2017). Corporate drivers refer to the organizational advantages of emission reduction initiatives and go beyond the scope of individual projects (Darko et al., 2017). Benefits throughout the building period are a concern for project drivers. Individuals are inwardly motivated to increase their efforts to reduce emissions, based on dedication and personal conviction (Darko et al., 2017).

Table 4 provides examples of various internal drivers' definitions.

Table 4: Internal Drivers

Category	**Description**
Corporate	Drivers based on the capture of professional value and organizational advantages
Personal	Drivers based on dedication and values
Project	Drivers based on perks during construction

Contractors are also externally influenced by governments in addition to the internal ones. First off, the majority of the time, their main client is the government. Second, the government enacts laws and creates policies. An extra classification may be used to better comprehend these external forces from the government's perspective. Governments may view policy tools as outside forces (Olubunmi et al., 2016)Three alternative classifications were used to group these policy instruments: 1) Cooperation and communication, 2) Law enforcement, 3) Incentive programs (adapted from (Mees et al., 2014)). When seen from a multi-level perspective model, these driving mechanisms from the policy instruments affect contractors from the top down. The definitions of the external drivers are listed in Table 5.

Table 5 : External Drivers

Category	**Description**
Communication and Cooperation	Encouraging and collaborating with the business sector to reduce emissions
Law Enforcement	Utilize authority to compel emission reduction
Incentive Programs	the use of (monetary) incentives to reduce emissions

2.7. Theoretical Framework

The following theoretical framework was created especially for this study to integrate the previously outlined hypotheses from earlier studies on transitions. Figure 15 serves as a demonstration of this theoretical framework.

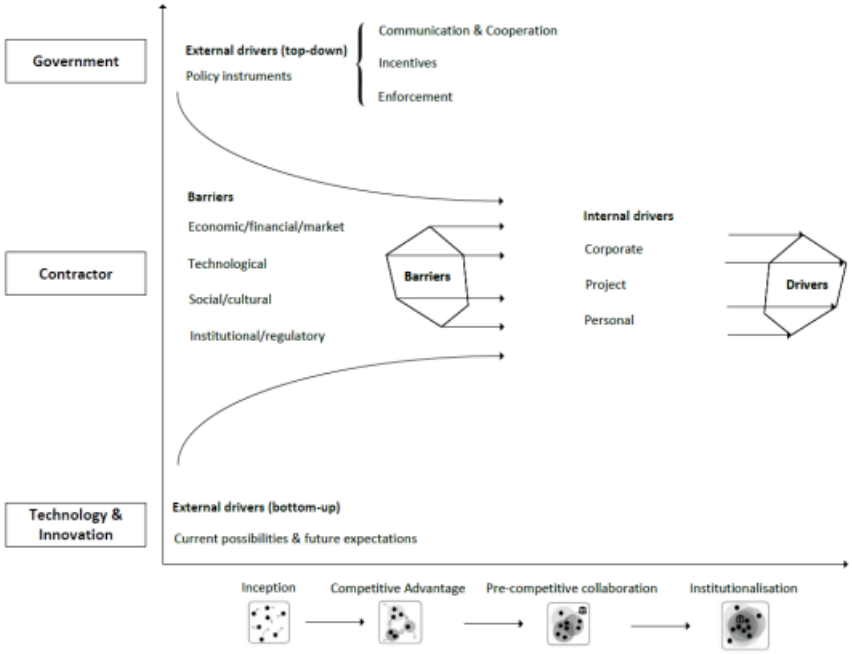

Figure 15 : Theoretical Framework

During the interviews, the framework begins by identifying empirical drivers and impediments. For three distinct perspectives—government, contractor, and technology & innovation—barriers and drivers are identified. The multi-level perspective theory included these three viewpoints. Contractors and the government are both a component of the dictatorship. When this perspective is inserted into the theory of the multi-level perspective, technology and innovation become a part of specialized innovations. According to this notion, construction sites and contractors are a component of the government that is currently ensconced. Barriers for each of the three views were broken down into four groups: 1) Economic 2) Technological 3) Social/Cultural 4) Institutional/Regulatory.

The framework distinguishes between internal and external drivers within the drivers. The government's external drivers are tools for policy. The three categories of policy instruments are as follows: 1) Cooperation and communication 2) Incentives 3) Enforcement. The government's policy tools have the power to exert pressure on the contractor regime. Contractors are being driven top-down by these external pressures.

The possibilities and expectations for technology and innovation in the future serve as the external drivers for this perspective. External possibilities and expectations for the future

motivate contractors from the bottom up. According to the multi-level perspective theory, specialized innovations begin to take hold while radical ideas begin to make their mark.

Contractors are specifically driven ahead by internal drivers. These internal factors for private companies were separated into three groups 1) Corporate 2) Project 3) Personal.

The sustainable market transformation theory by (Lucas Simons & Andre Nijhof, 2021)was also incorporated into the framework. The many stages of sustainable market transformation (inception, competitive advantage, pre-competitive collaboration, and institutionalization) are presented at the bottom of the framework as a visual representation of this. For progress to be made and momentum to be maintained, each phase necessitates a unique set of actions. To progress through the phases, there are theoretical hurdles and drivers in each one. Finally, these conceptual obstacles and motivators were contrasted with the actual obstacles and motivators discovered during the interviews. A list of actions for acceleration was created using this pattern matching of the theoretical and empirical barriers and drivers, according to the researcher.

This framework served as the foundation for structuring the research's outcomes later on. The interview questions were created via the scientific lens of the theoretical framework.

3. Methodology

This chapter goes into further detail about the research design. The primary research methodology was a qualitative case study. The theoretical framework developed in the preceding chapter served as the foundation for the research design. This theoretical foundation served as a prism through which the research was designed. Semi-structured interviews and secondary data sources were used to collect the data. The survey research was selected because it examined the opinions and expertise of many stakeholders on construction sites in the context of real-world settings.

3.1. Theoretical Background

The theoretical foundation served as a scientific prism through which the study, interview questions, and coding themes were created. The framework and sub-questions 1 and 2 can be connected directly because the framework was used to classify the barriers and drives. Greater knowledge of transitions and market change was provided by the theoretical foundation, which also assisted in the analysis of the interview data. Comparing empirical data with the theoretical framework was done using the semi-structured interview data. To build an acceleration plan, the third sub-question was addressed using the theory that supports the theoretical framework.

A theoretical framework aids analysts in developing their problem-solving skills (Michael E Porter, 1991). The multi-level viewpoint and sustainable market transformation theory made up the bulk of the theoretical underpinning for this study (Loorbach & Rotmans, 2006; Lucas Simons & Andre Nijhof, 2021). The theoretical foundation gave contractors more insight into the tools and procedures required to hasten the shift to zero-emission construction sites. The activities required for this transition were made clear by breaking down its evolution. The three diverse perspectives—government, contractor, and technology & innovation—were created by the multi-level viewpoint to provide a deeper knowledge of transitions and create the conceptual framework for the study (Geels, 2002). The sustainable market idea directed the analysts' focus on locating pertinent issues and queries. This made it easier to spot intriguing mechanisms and trends.

3.2. Literature Research

The literature review was the first step of the investigation. To create a thorough understanding of the body of knowledge already available on the subject, a narrative review was conducted (Bryman, 2016). Due to the multidisciplinary character of the research, this strategy was chosen. It addresses issues including innovation, infrastructure development, and zero emissions. Comparatively to systematic reviews, a narrative review is less narrowly focused, has a broader reach, and promotes the multidisciplinary character of the study. A systematic review methodology would be more thorough, less biased, and would improve the study's dependability. The more information you have on the subject, the more likely you are to find fresh papers that are pertinent to the research.

The most crucial terms were abundantly used in scientific search engines including Google Scholar, Scopus, Web of Science, and ScienceDirect. Since no single journal will cover the large study field, keyword search is preferred over journal search (Alan Bryman & Emma Bell, 2012).

A list of the scientific papers that were used in the investigation. The distinct headings in the literature list have a special relationship to the three separate research viewpoints government, contractor, and technology & innovation and the research's primary focus was electrification of construction sites. A few generic articles are included in the literature list to start. Then, examples of the papers that serve as the basis of the literature for zero-emission building sites are provided. These articles are included under the headings “emission free equipment on construction site”, "emission reduction in construction" and "low or zero-emission construction sites. Additionally, there are articles on the technology & innovation subject that is linked to this theme. Finally, papers that were utilized to create the research approach. Additionally, there are articles on the technology & innovation subject that is linked to this theme.

3.3. Survey Research

3.3.1. Selection of Research Design

(Hollweck,2016) listed five distinct ways to do research: case study, experiment, survey, and archive analysis. The study's research questions heavily influence the optimal strategy to use (Hollweck, 2016). The focus of this study will be on current occurrences rather than past ones because it has no control over behavioural events. Then a poll or a case study are your only two options. Therefore, a case study, survey, or a combination of the two would be the advised strategy. However, there are several reasons why the survey technique was chosen.

A survey is a type of descriptive study that collects primary data via oral or written interviews with a sample of respondents who are thought to be representative of the target population (T. Mathiyazhagan & Deoki Nandan, 2010).

First off, the survey research strategy was used for this study because it offers rich, qualitative, and in-depth data. Qualitative research offers in-depth comprehension of challenging problems and fresh subjects. Additionally, it enables analysts to collaborate closely with data sources such as interviews, which helps to gradually reveal unanticipated results. Instead of attempting to explain, qualitative research aids in better understanding. Because of this, qualitative research was the best method to use for this study, which sought to explore how contractors might hasten the transition to the electrification of construction sites. Quicker data collecting than alternative techniques. comparatively cheap data collecting, survey results that are sampled probabilistically can be quite accurate, accessibility to a diverse group of participants, it is more morally superior than experimentation, to ensure ecological validity, it makes use of the techniques, resources, and environment used in the research of the real-life scenario that is being investigated. Also, it is the only method for getting data on a respondent's past and is the sole technique

that allows for the collection of generalized data from practically any human group (T. Mathiyazhagan & Deoki Nandan, 2010).

Surveys are among the most widely used research tools because they may be used to gather information and explain naturally occurring phenomena that exist in the actual world. They provide a means for academics to gather a ton of data in a comparatively simple and rapid manner, which helps us in understanding the real-world practices of electrification of the construction equipment in the Dutch infrastructure.

In his 1973 classification, Kerlinger distinguished several different forms of surveys, including (i) personal interviews, (ii) mail questionnaires, (iii) panel surveys, (iv) telephone calls, and (v) observations. Personal interviews and postal surveys are two of them that investigators believe to be the most common. The data collection used in this research is personal interviews. It was chosen because this sort of research can take on a variety of shapes, from a strictly formal interview to an open-ended or unstructured interview in which the interviewer switches up the questions they ask to gain a deeper knowledge of the topics they are researching.

The survey study's goal was to learn how contractors might hasten the transition to electrification and accomplish it on job sites. The analytical units aided in identifying which barriers prevent contractors from reducing emissions at building sites and if transitional opportunities were being taken advantage of. It will also be taken into account how the contractor provided the sustainability standards substance and how the clients perceived their projects. Interviews with relevant parties regarding how they handled the tender's sustainability criteria, with an emphasis on construction-related emissions, were to be conducted. The replies were selected based on the theoretical context. Respondents were picked from the government, contractor, and technology and innovation perspectives of the multi-level viewpoint. The primary obstacles and motivators for the initiatives were revealed by this, shedding light on both the driver and barrier parts of the process. They were questioned about the lessons that may be taken away.

3.3.2. Selection of Interview Type

The interview is a crucial method of data collection that involves verbal exchanges between the researcher and the subject. In exploratory and descriptive research as well as survey approaches, interviews are frequently employed. There are several methods for conducting interviews, ranging from utterly unstructured, allowing the subject to speak freely about whatever they like, to extremely organized, with only direct questions allowed for subject replies (Mathers et al., 2002).

In every qualitative study, interviews may be classified according to their implementation style and desired purpose. Interviews can be classed as formal or casual depending on their nature (Adhabi&Anozie,2017). In light of our study, interviews are broadly grouped according to their place in qualitative studies and are classed depending on how formal they are. Thus,

- Structured: With the use of structured interviews, the interviewer is able to ask every participant identical questions in the same manner. A schedule of questions that is extremely well-structured is employed, very much like a questionnaire. The questionnaire's questions will have been prepared in advance, maybe with the aid of pilot research to make them more precise.

- Semi-Structured: Open-ended questions depending on the subject areas the researcher intends to cover are used in semi-structured interviews. Although the open-ended nature of the inquiry clarifies the subject under examination, it also gives the interviewer and subject the chance to go further into particular subjects.

- Unstructured: The interviewer crafts subsequent questions in response to the interviewee's prior response with the intention of talking about a small number of subjects, perhaps only one or two. Even though there are just one or two subjects mentioned, they are well-explored (Mathers et al., 2002).

The best aspects of both structured and unstructured interviews were integrated into the semi-structured interview. The semi-structured interview made sure that the primary subjects of interest were addressed while preserving the option to drive the conversation in other ways. Additionally, it made it possible for the interviewers' comments to be objective. The semi-structured interview format was used since it was thought to be the most appropriate for this study.

The drawback of unstructured interviews is that they are typically time-consuming, lasting up to an hour. They are also more challenging to analyse than other interview styles due to the unstructured interviewing method's tendency to produce broad and in-depth themes (Stuckey, 2013).

3.3.3. Selection of Interview Questions

The researcher must choose a subject that is personally appealing to them in order for the research question to be completely guided by that subject. As a result, the researcher must also rely on open-ended questions to clarify the participant's proper response. Importantly, the researcher must start with the fundamentals. To emphasize the effectiveness of the entire process, key elements include a proper introduction of both the speaker and the issue, as well as the development of a strong rapport. Accordingly, the researcher will start by asking simple questions before moving on to more difficult ones. Even after taking into account all significant considerations, the interview shouldn't go too long. The interviewer should be authoritative, but not to the point where the subject becomes tense.

Five suggestions were made by (Carter McNamara, 2022) for good interview questions. Make sure the following for the interviews:

1. All phrasing is open-ended.

2. As neutrally as feasible, questions are worded.

3. A single question is posed.

4. Questions are expressed clearly

5. Questions that begin with "Why" are hesitant.

These suggestions were followed in the interview questions. The responses of the respondents were not guided by specific directions Nevertheless, if the responder was unable to respond, they were asked whether they recognize opportunities that might hasten the shift to zero-emission building sites.

The interviews were done in English and the audio files were made into transcripts. Some interviews took place via Microsoft Teams, so with an inbuilt feature, the transcripts were made automatically by teams. Each interview took around an hour to complete. Some paraphrasing was required in order to concisely and clearly express the respondents' responses.

3.3.4. Selection of Respondents

The interviewees were divided into three groups based on their responses. The many viewpoints from the theoretical multi-level perspective constitute the foundation from the response of the respondents. List of people was first collected from the help of various professors and students of the faculty. LinkedIn played an huge role in connecting with people who were interested in this topic and connecting to people who was not on the initial list. The interview was conducted with people, who were not a part of the list in the initial stages.

Respondents from Rijkswaterstaat who were interested in the subject of phasing out fossil fuel equipment in construction sites were chosen. Governmental entity representing the macro level in the theoretical framework is Rijkswaterstaat. Heijmans and BAM respondents who, from the contractor's viewpoint. This group relates to the conceptual regime level of the contractor viewpoint. A subcontractor, a project developer, and a consultant business From TNO and ENI were also chosen. These group gave more context to the theoretical framework's conceptual niche innovations from the perspective of technology and innovation. Due to the fact that they are the next-to-last actor in the contractor supply chain, subcontractors have a direct relationship with specialized advances. In this study, manufacturers are not specifically taken into account. Also, respondents were selected on basis of English speaking capability, since the researcher hardly could speak or interview in Dutch.

3.3.5. Thematic Analysis

Thematic analysis is a qualitative data analysis technique that entails reading over a data collection (such transcripts from in-depth interviews) and looking for patterns in meaning to extract themes. In the process of creating meaning from data through thematic analysis, a researcher's own experience plays a major role. In the field of psychology and other disciplines that employ qualitative research techniques, thematic analysis is frequently utilized. Six steps were followed to do this thematic analysis.

1. Familiarizing the data : Since most of the interviews took place via Microsoft Team, the interview was transcribed automatically with the Teams feature. The other interviews were collected as an audio file and they were transcribed using a Google software. The transcripts are read and close attention are paid to any themes or patterns that emerge in the data collection.

2. Coding the data : The transcripts of the organized data are coded after becoming familiar with the data in the previous phase of the theme analysis. Since thematic analysis deals with non-numeric data, it is crucial for the study to mark and label the text with the pertinent points and keywords so that the researcher may utilize them to produce a useful analysis. From one research to the next, different codes are utilized for the research. Therefore, the researcher's knowledge and expertise are what they use to code the text in order to facilitate analysis. Depending on the researcher's preference, it may take the shape of numbers, colour codes, keywords, abbreviations, etc.

3. Highlighting the themes: The “Theme” in “thematic” refers to this. One of the crucial phases of the thematic analysis is highlighting the topics. Studying the codes and keywords discovered in the previous stage is involved, as is classifying the material into several topics. The topics that were identified in this stage act as a road map for the study. Therefore, it is crucial that the researchers take their time analyzing the data and emphasizing the pertinent topics.

4. Reviewing the Themes: Once the themes have been determined, it is crucial to evaluate them and make sure that they are appropriate for the research's main goal. The researcher can further develop the chosen themes at this stage and make any necessary modifications.

5. Defining and naming the themes: Once the topics for the study have been determined, it is crucial to characterize them and provide clear criteria that will make it easier to classify the data into each theme. Since the data used in the thematic analysis is non-numeric in nature, it is essential to establish criteria to prevent incorrect interpretation of the data. It speeds up the process and helps to minimize human mistakes.

6. Writing the Report: The last stage of theme analysis involves carefully studying the classified data and drawing pertinent conclusions. Here is where the researcher's knowledge and expertise are put to use. It requires a lot of work to thoroughly analyze

the transcribed material and pinpoint the implications. Because of this, the researcher must proceed with extreme caution.

3.3.6. Survey Research Limitations

Any study's limitations relate to possible flaws that are typically outside the researcher's control and are strongly related to the research design that was selected, restrictions on the statistical models that were used, financing restrictions, or other variables (Theofanidis & Fountouki, 2018).

The researcher may only have access to a narrow geographic region, which would prevent them from getting a broad range of replies while examining survey respondent responses. As a result, the sample would not have been representative in quantitative studies, nor would data saturation have been obtained in qualitative research. The methodology for data analysis is another possible weakness. For instance, most qualitative approaches cannot be accurately duplicated (such as in controlled experimental settings) and hence cannot be directly confirmed. Regarding quantitative statistical analysis, the majority of models can quickly identify the correlation between two or more variables, but not necessarily causation.s

4. Results

4.1. Introduction

Answering the first sub-question, which seeks to identify obstacles preventing the shift to usage of electrical equipment on building sites, is the initial task of this chapter. The second sub-question, which sought to determine the factors accelerating the shift to electric equipment construction sites, was next addressed. Finally, the third research topic is addressed, where a set of activities for acceleration were created in light of the first two sub-questions and the theoretical framework. An answer to the primary study topic was found by responding to these sub-questions. The findings shed light on what motivates contractors on the inside and what the government may do to externally encourage, enable, or compel private electrification of the site.

4.2. Barriers

The first sub-question is the focus of this section.

"What are the barriers that slow down this transition of phasing out fossil fuel equipment on a construction site?"

First, section 4.2.1 outlines the obstacles that were discovered from a government standpoint. Second, section 4.2.2 explains the obstacles from the standpoint of the contractor. In section 4.2.3, the technology and innovation perspective was also discussed.

4.2.1. Government

Table 6 : Main barriers that hinder the transition from the Government's side

S. No	Barrier	Category
1.	Lack of Internal Collaboration	Institutional/Regulatory
2.	Lack of Proactiveness	Social / Cultural
3.	Limited budget	Economic/ Financial / Market
4.	No incentives	Economic/ Financial/ Market
5.	Risk-Aversion	Social/ Cultural
6.	Lack of big market	Technological
7.	No clear financial strategy	Economic/ Financial/ Market
8.	Mistrust	Social/ Cultural
9.	Priorities in Tender	Institutional/ Regulatory
10.	Missing policies	Institutional/ Regulatory

In order to determine the obstacles impeding the government's shift to electrified construction sites, interviews were analyzed. The primary obstacles to the transition are summarized in the table from the viewpoint of the government.

The findings indicate that the barrier that was cited most frequently from a government viewpoint is the absence of international coordination. There is some international cooperation among European nations, but it is on a very limited scale. "The Dutch market isn't that big. Prices of major European manufacturers may not decrease as demand for zero-emission machinery rises in the Netherlands ". There is no guarantee that as Dutch demand for zero-emission machinery grows, global manufacturers will raise their supply. Right now only Netherlands and Scandinavian countries are focusing on the use of electric machines in construction sites

According to the findings, the hurdle that was cited most frequently from a government standpoint is the absence of international collaboration. There is some cross-border cooperation among the European nations, but it is too limited. Only Netherlands and other Scandinavian countries are currently focusing on electrifying the equipment on the construction site. A little portion of the Dutch market exists. Prices from major European manufacturers might not decrease as the Netherlands increases its demand for machinery with no emissions. There is no guarantee that manufacturers with a global focus would raise their supply of zero-emission devices when Dutch demand for them rises.

Additionally, respondents said that in Dutch public infrastructure auctions, sustainability is still not given enough emphasis. Sustainability is now just a deciding element in 35% of Dutch infrastructure contracts. Although sustainability standards are becoming increasingly significant, many tenders still place a strong emphasis on the lowest price . Notably, respondents from the government did not share the perception that this was a barrier; only respondents who were contractors did. Contractors also added that the top level government (Rijkswaterstaat) is currently bringing in sustainability and electrification to the tendering criteria in addition to the pre-existing quality of work criteria in the tendering. Whereas, the smaller government organizations such as municipality works do not focus on sustainability or environment factors yet.

Additionally, technological limitations such as the lack of zero-emission equipment and technology that is currently in development impede the government's procurement plan. All of the government responders highlighted this hurdle, which is thought to be quite important.

A constrained budget and a lack of a defined finance plan also pose challenges for the government. There is no agreement on which parties must fund which portion of the required investments. Contractors are looking on the government to foot the bill for the necessary transitional expenditures. While the government looks to the business sector for innovation and funding.

Another element noted by respondents is the unpredictability brought on by public clients' political dependence, such as Rijkswaterstaat, which depends on national political choices. According to the respondents, conflicting policies make it harder for the public to trust its clients.

The national governments and decentralized governments disparate sustainability goals represent another impediment. Larger customers like Rijkswaterstaat, according to the responder, are frequently less progressive than smaller, decentralized administrations. Because of this, contractors are unsure of what to anticipate from clients at various levels of government.

Last but not least, the survey showed that the government exhibited risk aversion even as it put out a tender because of the 2019 incident of stopping all the construction works in the Netherlands. In terms of implementing technologies that had not yet reached their full potential, they were not yet prepared to take chances. This lack of risk-taking in the tender value went counter to their ambitious project goals, which hindered the changeover process.

4.2.2. Contractors

Table 7 : Main barriers that hinders contractors from this transition

S. No	Barrier	Category
1.	Lack of Capital investment	Economic/ Market/ Financial
2.	Lack of expertise	Social/ Cultural
3.	Sceptical attitude	Social/ Cultural
4.	Uncertainty in future	Social/ Cultural
5.	Diversity in Knowledge	Social/ Cultural
6.	Lack of awareness	Social/ Cultural
7.	Internal resistance to change	Social/ Cultural
8.	Contractor- Government relation	Institutional/ Regulatory
9.	Cultural differences	Social/ Cultural

The findings of the interviews are examined in this part to determine what obstacles, seen from the perspective of the contractor, impede the transition to no fossil-fuel construction equipment. An overview of these barriers as a consequence of the interview analysis is provided in Table 7.

Most respondents said they are attempting to strike a balance between the high prices of zero-emission technology, which sometimes appear imbalanced compared to the hazy future advantages. Contractors don't take full use of the chances that are available as a result.

Respondents went on to say that there isn't much long-term investment. Long-term investments are less important to contractors than short-term earnings. It was claimed that contractors' investment attitudes are being hampered by unclear government policy implementations and the quick emergence of new technology. Contractors sometimes postpone making essential expenditures because of the high level of uncertainty around the development of new technology. This results in businesses adopting a wait-and-see mindset, waiting for the market to continue to develop rather than taking the initiative to begin the shift. The recovery of investments is also impacted by this uncertainty. It was claimed that recouping expenditures in zero-emission equipment on a single project is challenging.

In comparison to other European nations, respondents said that the Netherlands is more progressive when it comes to reducing emissions in building. Companies that are globally focused or have an international board with less progressive goals are hampered by this. Companies confront cultural variations when making investment decisions for emission reduction at building sites.

Overconfidence was suggested as another obstacle. People in the workplace frequently believe they are already doing a good job while making tiny improvements, even when their real influence is minimal. In that regard, overconfidence adds to a slower rate of change.

Additionally, it was shown that contractors lack information regarding zero-emission construction sites. A aspect that was mentioned included both real knowledge and awareness. According to a respondent, The construction companies hold the knowledge very close to their chest and not let it out, because of the goal to be the first in the market and make huge profits. This unhealthy competition lets down the whole construction industry and leads to lack of knowledge being shared.

The change is slowed considerably by gaps in contractor and client knowledge. The expectations and vision of the contractor and the customer in this transition are significantly out of sync. The conventional separation of the roles of client and contractor appears to be another impediment.

This position is still frequently uncooperative. The conventional barrier between the client and contractor is still present in the majority of infrastructure projects, despite the gradual emergence of more cooperative. The shift to zero-emission building sites is slowed significantly by the conventional, frequently uncooperative role separation between the customer and the contractor.

It was said that contractors are not inherently motivated to integrate zero-emission technologies into their typical business model and that there is a desire to continue with present working practices. It is remarkable that a responder who did work for a contractor was the only one to bring up this point.

It was discovered that certain hurdles relating to the government, contractors, and technology and innovation were connected through a cause-and-effect connection. Contractors' wait-and-see attitude is related to the government's absence of a clear market strategy and direction. The findings indicate that, in general, interviewees from the contractor and the government do not have the same perspective. Different transition-slowing impediments were selected differently in both orientations. This was discovered to constitute a barrier in and of itself.

4.2.3. Technology & Innovation

Table 8 : Main barriers that hinders the transition from technology & innovation perspective

S. No	Barrier	Category
1.	Lack of availability	Technological
2.	Limited energy infrastructure	Technological
3.	High Investment Cost	Economic/Market/Financial
4.	Development of Technology	Technological
5.	Lack of contractual Capacity	Institutional/ Regulatory
6.	Depreciation of existing equipment	Economic/ Financial/ Market
7.	Technology Choice	Technological

Interviews were analyzed to find out which obstacles hinder the transition to electrifying construction equipment from a technology and innovation viewpoint, similar to the government and contractor perspectives in the earlier sections. A summary of these barriers emerging from interview analysis is provided in Table 8.

The lack of readily available zero-emission equipment was the obstacle that was noted the most. Survey research also revealed that the construction sector must prepare for the reality that in the next years, there will only be a small supply of zero-emission construction equipment accessible (translated from (ENI,2020)). Numerous responders brought up this obstacle, which is seen to be quite important. The changeover is slowed greatly by both the lack of charging infrastructure. It is necessary that there be adequate electricity to charge electrical devices.

In addition to the lack of equipment and charging stations, the costs of zero-emission equipment are currently too costly to be competitive with the machines that are currently powered by fossil fuels. This was seen as a major obstacle by several responders. The fact that innovations are being slowly introduced to the market and that zero-emission construction equipment is still in development is the major reason for the poor availability and high investment prices.

The depreciation of current equipment was cited as another hurdle. Construction organizations must cope with the reality that the depreciation of their present equipment is still occurring over a lengthy period of time. Regular construction equipment is typically replaced six to eight years or 10,000 working hours after it is first (translated from (ENI, 2020). One or two new pieces of equipment are often purchased by contractors each year. Currently, contractors must replace their whole machinery park within a few years, which seems to be unrealistic for the contractors to do.

It was also suggested that one obstacle to this change was achieving economies of scale. According to (Loorbach & Rotmans,2006), “There are numerous positive sustainable contributions on project-level, but little meaningful progress is done on sector-level”. Small innovative sustainable initiatives struggle to achieve significant economies of scale. Initiatives often only apply to certain projects or niches of the construction industry, not to the whole sector.

Due to the lack of new equipment, the majority of the electric equipment is also retrofit. The lengthy procedure of retrofitting an outdated piece of equipment is a factor in the transition's sluggishness.

Last but not least, there isn't a single evident technological orientation or direction in which a zero-emission building site should be moving. Future building projects may be dominated by electrification and the advancement of hydrogen. Another barrier to starting investments was highlighted as the choice of technology creating uncertainty.

The responders mostly concurred on most technological impediments, in contrast to the contractor and governmental barriers in the previous sections. It is noteworthy that there is agreement on this issue but not on how the government and the contractor should participate in the transition.

4.3. Drivers

The second sub-question is the focus of this section,

“What are the drivers that accelerate this transition of phasing out fossil fuel equipment on a construction site?”

First, the drivers discovered from a government perspective are described in section 4.3.1. Second, section 4.3.2 explains the obstacles from the standpoint of the contractor. In section 4.3.3, the technology and innovation perspective was also discussed.

4.3.1. Government

Table 9 illustrates the drivers from a government perspective.

Table 9 : Drivers from Government's perspective

S. No.	Driver	Category
1.	Award Criteria	Incentives
2.	Tender Requirements	Enforcements
3.	Subsidy	Incentives
4.	Public-private Cooperation	Communication and Cooperation
5.	Tighten up laws and regulations	Enforcement
6.	Offer perspective to the market	Communication and Cooperation
7.	Align decentralized governments	Communication and Cooperation

The findings demonstrate that the most frequent relevant factor in the whole research dataset is the award criteria for successful projects. The client should include emission reduction at construction sites in every tender in order to truly accelerate this shift. Also by adding the type of equipment that needs to be used in the construction site. Particular focus must be placed on unique tender awarding based on zero-emission equipment, rather than primarily on the lowest price or project completion time. This is not always simple to do in reality. It's crucial to provide a clear tender assessment.

Another factor that was frequently noted by respondents was the demand for zero-emission equipment in contracts. This might be demonstrated, for example, by requiring a certain electric equipment percentage for the entire project or specific project components.

In addition to award standards and contract specifications, respondents frequently mentioned subsidies as a factor. This may take the form of Dutch subsidies or financial assistance from the EU. Particularly, subsidies aid in filling the financial gap left by currently unproductive initiatives. The advent of investors that encourage the shift to electrical equipment on construction sites is another change in the financial sector. In addition, a few banks began providing loans and leases for the purchase of zero-emission machinery.

The trailblazer strategy, in which the government recognizes sustainable leaders, was another motivator. It may be invigorating when the government puts the market to the test by choosing initiatives with a high level of innovation. When contractors win these contracts, they have the opportunity to spend more on zero-emission machinery, pushing the boundaries of what is possible in the field of zero-emission construction. This fosters innovation, increases competitive advantage, and advances contractors.

Another factor cited was a need for more extensive public-private partnership. Long-term and more cooperative contracts can promote cooperation. Contracts for innovation partnerships, performance agreements with learning spaces, and two-phase agreements are only a few examples of the various cooperation agreements. Compared to typical contracts, these options provide more room for implementing innovations in projects.

In connection with overseas operations, another driver was discovered. International producers and suppliers are more inclined to advance with their production lines and expand their capacity when global governments generate aggregate demand. Second, by establishing direct contact with major global suppliers and manufacturers, governments and contractors may encourage them to adopt more zero-emission manufacturing lines.

The transition paths taken by the government must also be in line with the current regulations. Consistency in policy is crucial to boosting public confidence in the administration. It is crucial that the government establishes the proper priorities. Not every location can experience change at once. Urban regions and natural areas should undergo the change first, per an ENI report from 2021.

Laws and regulations that are more stringent might push contractors to lower emissions at building sites. At the moment, government incentives are the sole means of encouraging emission reduction; laws are not yet in place to compel it. An example of a driver for zero-emission equipment was the suggested quicker phase-out of outdated diesel equipment. Old diesel equipment is to be outlawed by 2025, therefore conveying clearly and with certainty. Contractors will eventually phase out the outdated diesel equipment as a result. As a further possibility to enforce emission reduction, the adoption of a carbon tax by legislation, in which the government places a price on carbon emissions, was mentioned.

The goals of decentralized governments (provinces, municipalities, and regional water bodies) must also be in line. The national government is more credible when the goals of decentralized administrations are consistent. This also prevents emissions from being transferred to public consumers who have lower ambitions for emission reduction. Tools for uniform computation are currently being created. The whole Dutch MKI database is include zero-emission equipment. Future creation of more unified public policy across all levels of government may benefit from these technologies.

Last but not least, clients with a long-term outlook increase the likelihood that construction firms will be eager to spend. "Explain how zero-emission will develop throughout the organization over the next five to ten years" (translated from (ENI, 2021)).

4.3.2. Contractors

Table 10 provides examples of the drivers that were discovered from a contractor's perspective.

Table 10: Drivers from Contractor's perspective

S. No.	Driver	Category
1.	Personal Dedication	Personal
2.	Knowledge of Electrical Machines	Corporate
3.	Growth of awareness and knowledge	Personal
4.	Value Creation	Project

5.	Achieving the tender requirements	Project
6.	Skill development of construction workers	Project
7.	New partners	Project

The chart shows that contractors' primary motivator was identified as competitive advantage. By winning the tender for creative emission reduction projects, which enables the financing of zero-emission equipment, this competitive advantage is attained. Without contracts, Contractors won't acquire the equipment. Contractors are primarily focused on making money and on making a profit. This explains the emphasis on corporate financial drivers. It seems that contractors typically only gain an indirect understanding of the benefit of emission reduction initiatives through customer evaluation.

The familiarity and experience with zero-emission machinery was identified by respondents as a key factor. The proper use of zero-emission machinery on the job site must be taught to contractors. The education and training of construction employees directly affect this driver. It becomes a regular as employees start to feel comfortable using new machines, are aware of how to charge/fuel them, and can handle the equipment securely. The system has to be made aware that there are alternatives to the usual method of building. One of the main motivations that was addressed was the need of knowledge development and sharing.

The creation of new alliances and project stakeholders is another significant factor. Contractors and subcontractors might look for new innovations together when they actively approach one another. Additionally, strategic collaboration between rivals can advance contractors. For instance, innovations may be created more quickly when contractors purchase machinery in bulk and collaborate with other contractors. As a result, manufacturers can ship their machines more quickly. In the relationship with manufacturers and suppliers of zero-emission construction equipment, new collaborations can also be formed.

New business cases may materialize when contractors begin to focus more on value creation than capital investment. For example, value creation may be seen in the improved health of construction workers as a result of lower pollution levels. Total Cost of Ownership of equipment may also be used to find new business cases. The total cost of ownership is the sum of all expenses a client incurs while using an application during its lifetime, including operational, financing, and capital expenses. A construction machine powered by electricity often costs two to three times as much as one powered by fossil fuels. The financial expenses are 20% less when customers consider the total cost of ownership, which includes the purchase price, maintenance fees, repair charges, and gasoline (Bughin et al., 2019). The decreased maintenance costs for electrical equipment might be substantial in a total cost of ownership assessment. The TCO business cases for emission-free equipment are already favorable. Another new company strategy is to switch from owning equipment to providing services.

Renting out equipment from rental businesses is one of the financing options. Contractors can use the equipment that is accessible in this way without having to make a significant investment. Utilizing banks that offer zero-emission equipment leasing is another alternative in this regard. New business cases are clear when client demand is great enough that governments are prepared to pay the entire cost of the high initial investment expenses.

Enhancing individual awareness and knowledge growth in private businesses was also identified as being crucial. Through attitude and behavior on the job, emissions can be reduced. One strategy to cut fuel use, for example, is to alter how drivers and operators of equipment behave. Applying sustainable data management to operations, especially when employing software, might result in another fundamental shift in consciousness. This can improve a company's responsiveness to its environmental effect when coupled with ongoing sustainability data gathering as an operational policy. It enables real-time impact analysis as opposed to retroactive effect analysis. Businesses may utilize software tools to create goals for important climate impacts they want to lessen. Effective monitoring and targeting are believed to further reduce emissions since they encourage behavioral changes (SECR, 2020).

Finally, the personal dedication of employees to their jobs was only cited once as a motivator. Employee intrinsic motivation does not appear to be a major factor at this time.

4.3.3. Technology & Innovation

According to the respondents, a crucial factor driving further emission reduction at construction sites is the rising availability of zero-emission machinery. The equipment is still hard to come by and hence expensive right now. It is anticipated that costs would drop dramatically as more equipment becomes available, which could pave the way for large-scale deployment in the future (translated from ENI, 2020) In addition, respondents noted that a working and accessible fueling and charging infrastructure is a crucial need for the use of zero-emission construction machinery at the sites.

Smaller, lighter construction equipment may already be powered by battery-electric applications today. On construction sites, the use of big batteries has a significant impact on the reduction of CO2 emissions. Particularly for mobile equipment that cannot be plugged into the grid. The battery is evolving quickly and continuously, and new battery-related applications are opening up. Additionally, the function of retrofit in the transition needs to be understood. Retrofitting refers to upgrading outdated construction equipment with more environmentally friendly features like switching out traditional internal combustion engines with electric ones. Due to the dearth of new machines from manufacturers, the majority of the electrical equipment in use today is retrofitted. A particle filter can also be added to modern equipment known as “bouwplaatsfilter”. This tool eliminates nitrogen oxide (NOx) emissions from big machines by 99%. The exhaust from diesel-powered machinery, including drill rigs, construction cranes, and generators, is linked via a pipe to this particle filter. The decomposition of all nitrogen compounds occurs in the particle filter.

In order for sustainable alternatives to be sold on the market, a lot of work is still required in the field of heavy machinery (translated from (White-Paper-Emissieloos-Netwerk-Infra-de-Emissieloze-Bouwplaats, 2020). Future construction equipment that weighs 30 tons or more is anticipated to run in part on hydrogen. Hydrogen is regarded as one of the primary alternatives for electrical equipment, along with hybrid. Applications for hydrogen are growing quickly, however they are still quite small-scale. For instance, a limited number of hydrogen trucks are now being produced, along with others.

Compared to electricity, hydrogen offers a number of important advantages. For instance, mobile machinery's longer driving range. Other drawbacks of hydrogen include a low combustion efficiency, a large storage volume, and the fact that not all hydrogen is environmentally friendly. Future green hydrogen has to be substantially more commercially accessible. The majority of the hydrogen that is now on the market is classified as "grey hydrogen." Since it is made from fossil fuels, this grey hydrogen has no beneficial effects on the environment. The environmentally friendly form, known as "green hydrogen," is created using solar and wind energy. Green hydrogen is currently produced and transported at incredibly expensive costs. To reduce the cost of producing and transporting green hydrogen, economies of scale are required. Years will pass throughout this process, which is connected to several other sustainability concerns in the energy sector.

Another commenter brought out the often-overlooked impact of electrifying short-distance transportation at the building site. Trucks are the largest emitters of pollution at construction sites, thus electrifying them for travel to and from the site will have a significant impact. To lower emissions of undesired pollutants, truck manufacturers can also incorporate an after-treatment system into their conventional engines. Construction equipment with an after-treatment system can thus also satisfy the more stringent stage class standards.

The usage of green engine generators is a driving technology to speed up the shift because there isn't any reliable and accessible fueling and charging infrastructure. Future trends toward the use of electric and/or hydrogen construction equipment during the execution stage of sizable infrastructure projects may lead to high energy demand peaks that are beyond the capacity of the conventional electrical grid. Additionally, green energy is produced intermittently by renewable energy sources based on real environmental conditions. The usage of green energy engine generators is increased as a result of the variable availability of green energy and the rising need for electricity.

4.4. Current Actions for Acceleration

This section details the accelerated initiatives that directly resulted from the interviews. The government and contractors are now carrying out these tasks. Chapter 5.1's discussion of implications contains the second part of the solution to this sub-question. The researcher states that the chapter on implications combines the theory and the data from chapter 4 to develop actions for acceleration. Section 5.1.2 presents the list of acceleration-related

activities. This list is based on the outcomes chapter's theory, obstacles, drivers, and current activities.

In order to summarize the findings from the preceding sub-question, figure 16 lists the most important drivers in order of how frequently they appeared in the interviews. The most important internal factors identified by contractors are shown visually, as are the government-created exterior policy tools.

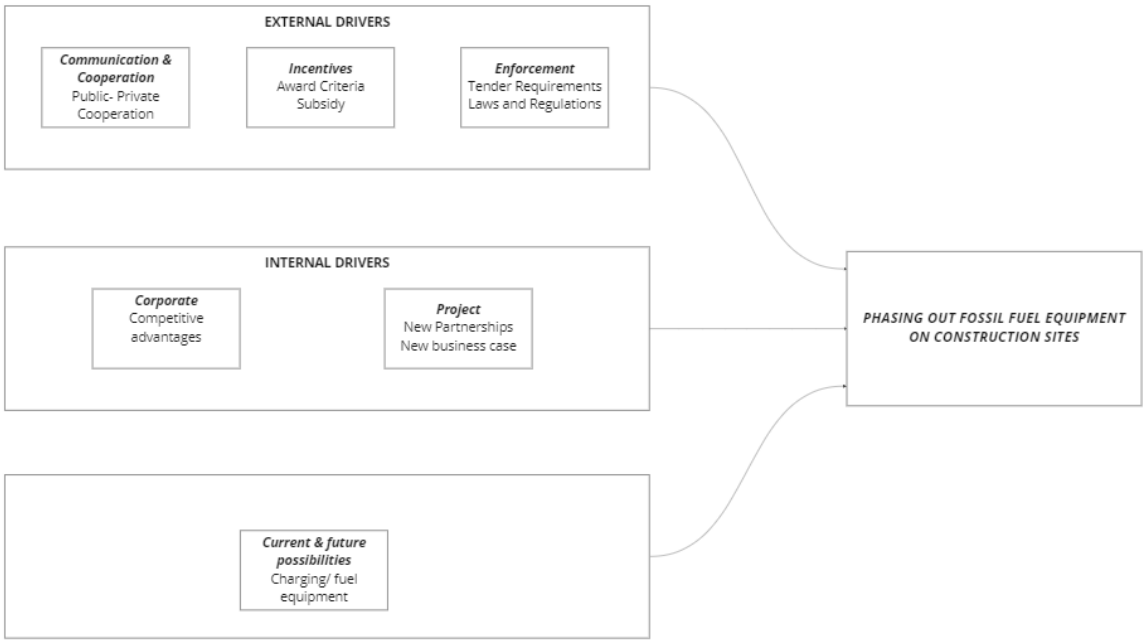

Figure 16 : Drivers that accelerate the transition

4.4.1. Government

With the goal of accelerating the transition to zero-emission building sites, the government, the primary client, has already begun to take action. The government, as the primary client, began to recognize frontrunners with a few cutting-edge initiatives. The government desired a nearly emission-free building location for this project. This was a forward-thinking and creative request from the customer, as many pieces of zero-emission equipment are still in development and won't be ready for purchase for several more years. The government hopes to challenge contractors to come up with novel ideas with this frontrunner strategy. When a contractor wins a major project like this, the business has the opportunity to invest in the emission-free machinery. For contractors, these expenditures typically result in projects.

Another move is that the federal government, as the primary client, already collaborates with some local governments on a limited basis. These clients are discussing their procurement strategy with one another and working to partially harmonize them.

Rijkswaterstaat is not the only client who requests zero-emission equipment when they coordinate their procurement strategy; the other clients do as well. This increases confidence in the public sector and gives contractors incentive to increase their private investment.

As a lawmaker and policy maker, the government also began to take some initial steps toward acceleration. They've announced a future subsidy for construction equipment in an effort to lessen the financial demands on contractors. The SSEB (Subsidieregeling Schoon en Emissieloos Bouwmaterieel) is a subsidy that aids in filling the financial gap left by equipment that is still currently unprofitable for contractors.

Additionally, the Dutch government initiated contact with other European countries. These governments met several times to address the issue of reducing emissions at the building site. This hasn't yet resulted in any real partnerships to encourage massive, globally focused-manufacturing or generate general demand. The first step in doing so, though, is these meetings.

4.4.2. Contractors

New chances for contacts with manufacturers and suppliers of emission-free equipment emerged when the government started mentioning the usage of electric equipment in the construction sites.

Contractors have also started to contribute to platform techniques as a means of accelerating progress. Many construction firms signed up for the ENI (Emissieloos Netwerk Infra) platform. This is a platform that links customers, vendors, manufacturers, and suppliers of equipment. The ENI is a forum for exchanging information where members may all share their experiences with emission reduction. People benefit from one another's experiences and are kept informed of the most recent advancements in the field of zero-emission equipment. In addition, the contractors utilize these platforms to make bulk purchases of equipment with other. This collective demand from several contractors might entice major equipment producers to expand their capacity for zero-emission production and promote the early delivery and development of equipment.

Along with the tools, construction logistics are crucial. Contractors work to optimize their construction logistics as a means of accelerating projects. Contractors perform this in a variety of ways. For instance, spreading out labor activities in an efficient manner and transferring via water instead of land can all help to cut down on emissions.

Additionally, contractors are considering novel business cases. For instance, BAM employees are examining TCO business cases to see whether purchasing zero-emission equipment is already a wise financial decision and stepping in with Green Road Equipment in buying tandem rollers for their projects. Whereas Heijmans, is majorly focusing on retrofitting their fossil-fuel equipment and converting them into an electric one.

Within private companies, contractors are starting to gradually develop their own corporate and social responsibilities. For instance, in private businesses, the Board of Directors' knowledge of and responsibility for the subject of the zero-emission building is growing. Contractors have also started organizing workshops in a routine basis to educate their employees and operators about the operations and maintenance of the electric equipment.

This section discussed current government and contractor initiatives that are directly derived from desk research, and interviews. The remainder of sub-question three on acceleration actions was addressed in the next chapter. Based on the obstacles, motivators, and actions from the findings chapter, the researcher may more freely interpret what the actors can do to advance in the discussion of the implications part.

4.5. Summary

This chapter discussed about the barriers, drivers and actions taken that are currently subjected in this transition. Capital investment and technological availability were analyzed as the main barrier. The lack of availability of electrical equipment in the market was one of the major hinderance for the contractors. Whereas, international cooperation was determined to be the most biggest obstacle for the government’s standpoint. Clear marketing strategy was also missing which doesn’t guide the stakeholders at the right direction. Including sustainability and award criteria in the tenders increase the pace of the transition. Adding to this, the competitiveness between the contractors, pushes them to be the first in the market by using electric equipment in the construction site. Stakeholders have leaned towards the creation of social and environmental value more than monetary value.

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5. Discussion

The study findings are discussed in this chapter. First, the consequences of the findings are explored. The formulation of activities for acceleration is prompted by these implications. Second, the outcomes were contrasted with earlier scientific studies. Thirdly, the topic of results generalization was covered. Finally, the research's shortcomings were stated.

5.1. Discussion on Implications

The third sub-question, “What measures can speed up this transition in electrifying the equipment on the construction site?” is addressed in this section. The theory is integrated with the findings from the preceding results chapter in this part. According to the researcher, the theory, barriers, drivers, and current activities from the previous chapter result in enumerating the actions for acceleration.

5.1.1. Results and Theory Combined

Sub-questions were categorized according to Chapter 2 description of the stages of sustainable market transformation. The figure 17 illustrates this. Depending on the stage of a transition, certain drivers seem to be more important. For instance, hydrogen uses and electrifying heavy equipment are still in the early stages (phase one). Pilot projects are required to further develop these advances because these technologies are not yet mature. Another force that seems to be more prominent in the competitive advantage phase is the creation of new business cases. In the pre-competitive collaboration phase, public-private cooperation is a crucial motivator, and rules and regulations are particularly important in the institutionalization phase. In order to create actions for acceleration, theoretical actor interventions defined in the stakeholder matrix from Chapter 2 were contrasted with empirical drivers discovered in the interviews. In figure 18 , the stakeholder matrix is shown. The stakeholder matrix's heading industry includes a representation of the contractors' involvement.

Governments establish the rules of the game in the construction industry since they are typically the main client for contractors (Lucas Simons & Andre Nijhof, 2021). The subject of carbon neutral equipment is often located in the second phase of the S-Curve.

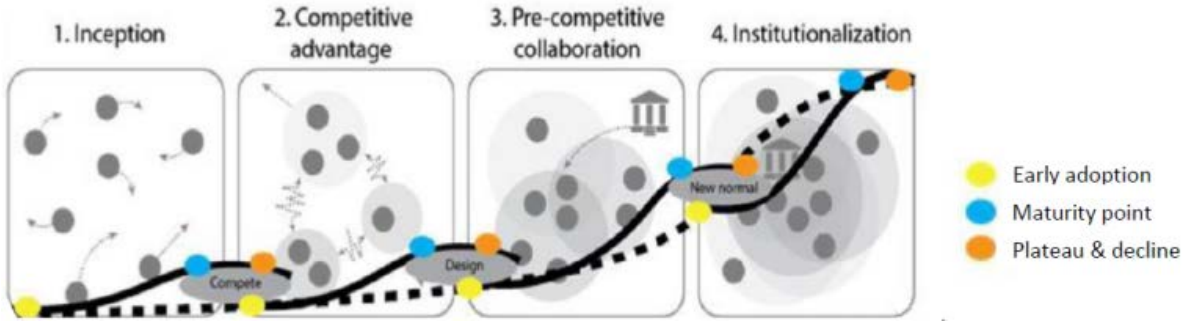

Figure 17 : Transition Curve

Government – Pre-Competitive Collaboration

In phase two, the government might theoretically: based on the stakeholder matrix.

- Focus on a long-term goal and confront market players

- Act as a launching client

- Identify industry leaders

The conclusions of the study can be connected to these hypothetical government measures. According to the study's description, the transition pathways were created with a long-term outlook in mind. In a statement, Rijkswaterstaat stated that they plan to have zero-emission building sites by 2030. Rijkswaterstaat continues to take the lead by challenging businesses to complete cutting-edge projects. Additionally beginning to serve as a launching customer is Rijkswaterstaat. They began to give out more grants for programs that reduce emissions. Additionally, they disclosed that incentives for machinery with minimal emissions are being created. Market players are becoming more and more acknowledged through award criteria. As a result, all of the government's theoretical phase two interventions were discovered empirically. But procurement procedures are still lagging, and the government has to adopt new sustainable criteria right away (Lucas Simons & Andre Nijhof, 2021).

Government – Institutionalization

The federal government has already taken a few initiatives that potentially fall under phase three. Phase three theoretical actions include the following:

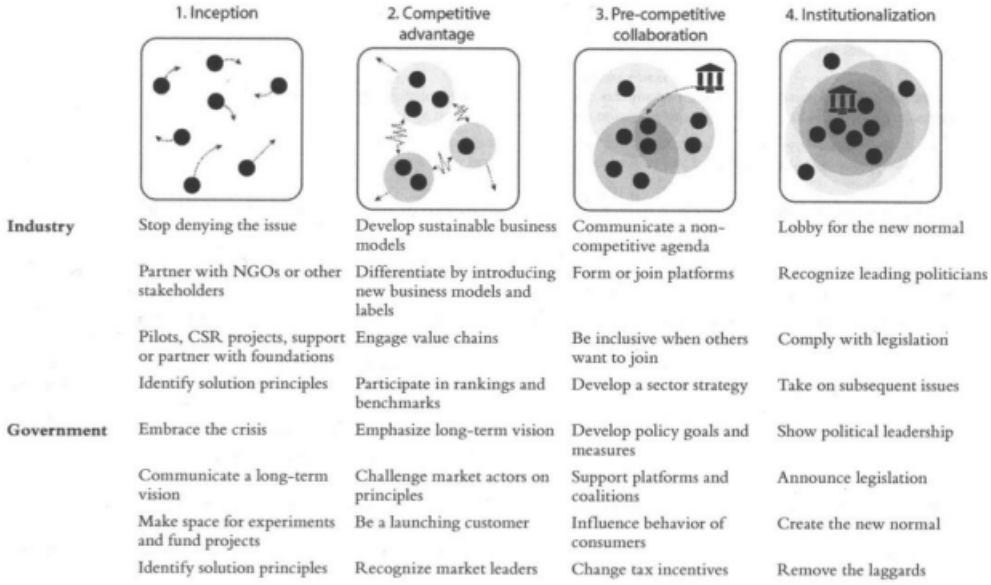

Figure 18 : Stakeholder Matrix(Simons & Nijhof, 2020

Stakeholder matrices for business and government are shown in Figure 18.

- Create policy objectives and benchmarks
- Support alliances and platforms
- Influence customer behavior;
- alter tax incentives

Rijkswaterstaat is actively adjusting its policies to reflect its goals for sustainability by 2030. The focus of pre-competitive collaboration is collaboration, which was identified as an accelerator of increased public-private cooperation. The conduct of contractors is being influenced by the awarding of additional emission reduction projects. However, the use of contract criteria to really alter contractor behavior is still insufficient. One responder highlighted financial incentives as a motivator, although the Dutch government is not (yet) aggressively using tax incentives, such as carbon price, to direct market participants.

Contractors – Pre-Competitive Collaboration

According to (Lucas Simons & Andre Nijhof, 2021), in order to accelerate, the peloton of Dutch contractors has to be broken up. The peloton then has to be reassembled by scaling up. The stakeholder matrix states that contractors should, in second phase:

- Create business structures that are more sustainable

- Establish new business ideas and labels to set yourself apart.

- Participate in value chains

- Take part in benchmarks and rankings market leaders

The drivers mentioned in sub-question two were connected to these speculative activities. New business models are already being tested by contractors. The TCO business cases were one of the new business models that were discovered. Rather than focusing just on the financial aspects, other business cases were discovered giving prior importance to value creation. As an empirical motivator, engaging value chains was also discovered. Smart sector relationships were cited by respondents as aggressively engaging subcontractors and establishing contacts with suppliers and manufacturers. Although not yet widely used, being proactive in the market and looking for the finest technical solutions combined was seen to be a key motivator.

Contractors – Institutionalization

Theoretically, contractors in phase three's pre-competitive collaboration stage should:

Share a non-competitive agenda

- Create or join platforms

- Welcome new members with open arms

- Develop a sector strategy

Some of these therapies have previously been discovered empirically. Contractors are beginning to sign up for platforms where they can collaborate and share information. Take the ENI platform as an example, where contractors can buy equipment together and save money. On a small scale, contractors that worked strategically with rival companies demonstrated inclusiveness. There weren't many additional indications of inclusion, though. Theoretically, the collaborative phase needs to develop more before phase three is introduced.

Actions for acceleration were developed for the government and contractors by fusing theoretical interventions in the various phases with empirical drives. It's vital to remember that some acts may be more important in one phase than others, depending on the phase. It becomes obvious that the government has to provide more stimulation than it provides at the moment.

The government may be divided into two broad categories: client and Lawmaker. It is crucial that they push the market to function as emission-free as possible because they are the major client. Through the integration of theoretical interventions in the various phases with empirical drives, actions for acceleration were created for the government and contractors. It's critical to keep in mind, depending on the phase, some actions could be more crucial than others. It becomes clear that the government needs to stimulate the economy more than it now does. The principal client and legislator/policy maker are two basic groups into which the government may be split. Since they are the main key, it is imperative they urge the market to provide more possibilities and opportunities for the provision of electric equipment.

5.1.2. Actions for Acceleration

The key-points of the most common behaviors was created by the researcher based on the barriers, drivers, and current actions from the interviews.

Governments should focus on the following:

- Work with motivating incentives. By establishing competitive advantage through award criteria in infrastructure projects, place an emphasis on rewarding leaders. Reward, for instance, a specified reduction in emissions.

- When there is enough electric equipment on the market, zero-emission equipment should be a condition in contracts. Start with a certain reduction in percentage for the entire project or a specific portion of the project. These contractual conditions could get stricter over time.

- Obtain enough funding for initiatives with procuring electric equipment. Programmatic procurement should be used to continuously increase the number of zero-emission projects. Customers may create a project calendar, for instance, to alert the market to upcoming zero-emission developments. By letting the market know, you may give private investments a long-term perspective and foster confidence.

- The public procurement strategies of Rijkswaterstaat and decentralized governments such as municipalities, provinces, and water boards should be coordinated. As a result, confidence is increased and the market has greater certainty for potential investors.

- Strengthen public-private collaboration by selecting long-term, cooperative contracts like innovation partnership agreements, performance agreements with learning spaces, and two-phase agreements (Dutch: twee-phase contracten).

Legislator/ Policy Maker:

Provide contractors with financial support through subsidies, such as the creation of the SSEB (Subsidieregeling Schoon en Emissieloos Bouwmaterieel (SSEB-regeling)).

- Take a more aggressive starting customer stance. Join forces with other national governments to generate a collective demand that will motivate and inspire major global firms to expand their zero-emission manufacturing capacity.

- When there is sufficient zero-emission machinery available, start enforcing the private sector. Old diesel equipment should be phased out, and rules and regulations should protect zero-emission technology. Start keeping an eye on and managing emission reduction efforts. Set a deadline for when all projects must be zero-emission.

- Provision of electric supply to the building projects before the completion of the construction work, would stimulate the use of electric equipment on sites. A trust should be built with the insurance companies and the electric suppliers by the government by making a contractual policy with them. Also when the goal is achieved the other factors such as electric supply infrastructure might become a problem, so these kind of problems needs to be anticipated from now.

The aforementioned measures might result in an expedited transition by creating an upward trend. Contractors will have much more clarity with these boundary criteria, and there will be a rise in the number of investments in zero-emission projects. Of course, contractors also have a social obligation to develop a long-lasting industry.

Contractors should focus on :

- Gain a competitive edge by bidding on projects where the government uses award criteria that encourages zero-emission . Winning these contracts provides funding for new zero-emission machinery and gives the Netherlands a competitive edge when bidding on future zero-emission projects. It is also possible to take use of this competitive advantage internationally. Although the Netherlands is still a very progressive nation, it is anticipated that other European nations will place more and more emphasis on zero-emission in the next years. To be aware of these trends is smart business.

- Increase your familiarity with the small and medium electric devices accessible. Prepare and instruct personnel in the construction industry to use new machinery in both existing and new projects.

- Actively seek out new collaborations and project stakeholders by approaching suppliers, manufacturers, and subcontractors. This will encourage the development, availability, and delivery of early equipment.

- Utilize existing subsidies and a long-term outlook to free up money for the purchase of emission-free machinery. Subsidieregeling Schoon en Emissieloos Bouwmaterieel (SSEB-regeling), a new subsidy program for emission-free equipment, is being developed by the Ministry of Infrastructure and Water Management. This new incentive will assist in covering a large portion of the expenses associated with purchasing new, zero-emission equipment and upgrading existing equipment.

- If the money is there, it can be thought of purchasing zero-emission equipment despite the fact that it is still hard to come by. The desire to make sustainable investments improves the company's reputation, which can have positive marketing effects. Consider renting out the zero-emission equipment to other contractors to recoup some of the expenditures if the circumstance occurs where it cannot be deployed.

- It could be thought about purchasing zero-emission equipment even if the funds aren't accessible because it's still hard to find. Enhancing the business image by investing responsibly can have positive marketing effects. Consider renting out the equipment to other contractors to recoup some of the expenditures if a circumstance develops when zero-emission equipment cannot be used.

- Build cooperation with other construction firms. Sharing information is an essential part of this transition. When the information and knowledge is kept close to the heart, obviously you might win the competition. But it should be realized that it’s not about who goes first, but how could we go longer.

- Contractors also need to get prepared for the future, they need to get anticipated for the troubles they might be facing when their construction site is completely electrified.

The list of the most common acts was constructed based on the barriers, drivers, and existing behaviors. It's crucial to remember that this is not a comprehensive list. However, the researcher states that it was decided to include the most important acts within the parameters of this study.

5.2. Comparing findings to Literature

The findings directly affect contractors by advising them of the steps they may take to hasten the transition to electric equipment on construction sites. As a result, the influence on policymakers is to educate them of the instruments of policy that encourage contractors to speed up the changeover.

This study showed that project drivers and corporate drivers have a significant impact on encouraging emission reduction at construction sites. The importance of personal drivers was determined to be lower. (Darko et al., 2017) found scant evidence of personal drives serving as incentive for more sustainable activities, which is consistent with our findings.

The findings indicated that the primary obstacles were discovered to be contractors' financial obligations, the government's requirement for international cooperation, and the equipment's restricted availability. It appears that contractors are driven by money and are mostly constrained by expensive equipment initial investment costs. (Naz et al., 2022) made the case for a requirement for construction equipment cost reduction. In addition, the research (Naz et al., 2022) identified a lack of knowledge, specific needs, inconsistent government policy, legislation, and usage of traditional approaches to prevent dangers as barriers. These outcomes closely match the constraints we identified for both contractors and the government. Other academic studies have identified challenges such as fragmented job structures and a lack of education on infrastructure projects (Clarke et al., 2017b). These elements don't seem to be present in our findings.

This study discovered compelling evidence that the public sector may act as an external force to improve emission reduction at building sites. This assertion is supported by (Kadefors et al., 2021), who note the significance of public procurement in advancing carbon reduction objectives. Additionally, (Karlsson et al., 2020) contend that policy and procurement must be coordinated in the framework of zero-emission. In our research, this coordination of policy and procurement was also identified as a governmental driver. Improved environmental requirements in public procurement bids are one of the main chances for zero-emission building, according to previous academic study (Naz et al., 2022). This is consistent with our research's conclusions, which show that contract conditions and award criteria in public procurement competitions are important external drivers to accomplish emission reduction at construction sites. Governments have the chance to open the door for wholesome, secure, and reasonably priced zero-emission building, according to(Anderson, 2019), who adduces this assertion.

The findings suggested that collaboration and communication were critical tools for governance. According to (Mamo Fufa, Wiik, et al., 2019), reducing emissions at construction sites requires open and extensive collaboration amongst stakeholders. Our research's findings, which emphasize the value of more intense public-private partnership, also corroborate this conclusion.

The primary technological dangers, according to (Karlsson et al., 2020), are an over-reliance on biofuels and cost optimizations that cannot be scaled up. Many new technologies have moved past the experimental stage but have not yet been adopted on a bigger scale. In our study, respondents expressed skepticism over the usage of biofuels and underlined the necessity for economies of scale. Contrary to other studies, our findings indicated that the scarcity of equipment was more significant.

Construction equipment that is electric, hydrogen-powered, or hybrid represents the majority of technological options. This closely reflects the conclusions of earlier study, which found that electrification and hybridization of heavy machinery and construction equipment represent significant prospects (Karlsson et al., 2020)

Conclusion: Despite the fact that this study did not uncover all of the obstacles and factors mentioned in the scientific literature, its conclusions are usually consistent with those of earlier scholarly investigations. There is compelling evidence that external factors may affect contractors and improve emission reduction at building sites.

The findings highlight how important it is for contractors to use both internal and external motivations to encourage private emission reduction at building sites. The relevance of the interaction between external and internal forces was also supported by earlier studies.

5.3. Limitations of The Research

There are various restrictions to this study. First, the research would have been more longitudinal if case studies had been chosen over a longer time span. In order to monitor several contractors and gather a wider variety of data, a multiple-case approach may have been adopted. Other findings and analytical advantages, such as a wider range of outcomes, may have resulted from this. But given the short time frame and small number of research participants, the survey approach was the preferred choice.

Second, just one nation—the Netherlands—was represented in the case study programs. The outcomes may have been more cultivated if projects from other nations had been included. It would have enabled the researcher to contrast methods used in various nations in the context of construction equipment with zero emissions. In support of the European accords, each nation has its own environmental goals.

Finally, the viewpoint of the equipment makers and suppliers was not included in this study. The public sector served as the client in this study, and the contractors provided the services. The equipment suppliers and manufacturers are the service provider in the construction industry's value chain, and the clients are the contractors. However, this study's weakness was that it did not specifically include the viewpoint of the equipment makers and suppliers. It would have been beneficial to examine several study angles, such as those of suppliers and machinery makers. It would have taken a lot of effort to approach these organizations and the individuals involved, which was impossible given the time constraints and the language barrier issues. Also, other factors such as the availability of electric infrastructure, optimizing the batteries and the number of carbon emissions are not discussed in this research.

6. Conclusion and Recommendations

This chapter presents the conclusions and recommendations of the research.

6.1. Introduction and Context

This study was an exploratory investigation into the factors that slow down and speed up the shift to electric machinery on construction sites in the Dutch infrastructure industry. These findings came from survey research built on semi-structured interviews, and desk research. This study's objective was to learn more information on the transition process from the viewpoints of the government and the contractors. The function of the transition process's use of innovation and technology was investigated. Drivers were eventually described. A plan of action was developed to address the major research issue, which was how to hasten the transition to the use of electric equipment on construction sites.

6.2. Answers to Research Questions

Q-1)

The main obstacles were determined to be monetary and technical. It might be challenging for contractors in particular to understand the obvious financial benefits of electric equipment. The most often cited impediment for contractors is the absence of compelling business justifications. The most significant technological impediment is the restricted supply of zero-emission construction equipment, which is problematic for both contractors and government policymakers. The absence of international cooperation was determined to be the biggest obstacle from a government standpoint. It was discovered that certain hurdles relating to the government, contractors, and technology and innovation were related through a cause-and-effect connection. The obstacle of contractor’s wait-and-see attitude appears to be linked to the barrier of the government's lack of a clear market strategy and clarity. The findings indicate that, in general, interviewees from the contractor and the government do not have the same perspective. Different obstacles and categories that delay the shift were ranked differently by each actor. This was discovered to constitute a barrier in and of itself.

Q-2)

The competitive market dynamics, the supportive governmental environment, and the allure of alternative technologies were the key theoretical contexts in which drivers were discovered. The findings indicate that the primary motivator for contractors is their competitive advantage. This is evident in tendering initiatives that enable for the funding of zero-emission machinery by requiring a large percentage of emission reduction in their award criteria. By including sustainability into this process, this affects the market dynamics by fundamentally altering the factors on which the market competes. The

findings indicate that, from the viewpoint of the government, policy tools may be a blend of incentives, communication, and collaboration. The most significant external motivation for contractors was found to include emission reduction in award criteria for public procurement. This alters both the supportive policy environment and the market dynamics. From a technological standpoint, additional emission reduction at construction sites is being driven by an increase in the supply of zero-emission machinery. It is anticipated that when equipment becomes more widely available, prices will drop dramatically, enabling large-scale deployment in the future. This enhances the appeal of alternatives with no emissions.

Q-3)

The researcher's list of acceleration-related actions was created to define initiatives for both the contractor and the government. By gradually addressing the fundamental issues of how the construction industry is organized, these steps may be taken to take the first step toward a quicker transition. The interventions intended to disrupt some of these underlying viscous loops that account for the transition's sluggishness and are fueling an unstoppable downward spiral. The primary client, the government, might focus on working with more encouraging incentives, enforcement, communication, and collaboration. By fostering competitive advantage through award criteria in infrastructure projects, they might put more of an emphasis on rewarding leaders. When there is sufficient zero-emission equipment on the market, zero-emission might potentially be a condition of the contract. To lessen the financial demands on contractors, the government as a lawmaker and policy maker might pay attention. Additionally, they might guarantee zero-emission equipment in laws and regulations while gradually phasing out outdated diesel equipment. Contractors should be aware of how to get a competitive edge by submitting bids for projects where the government encourages zero-emission in the selection process. Construction employees might receive instruction and training so they are comfortable using the new machinery. Contractors could actively participate in platform techniques as well. If the items on the list are done, an upward trend toward a quicker transition can be established.

Main Research Question

To hasten the shift, the fundamental issues in the building sector must be resolved by dismantling the feedback loops that produce unsustainable behavior. The researcher's efforts for acceleration were designed to disrupt some of these underlying loops that are continuously decreasing. The respondents mentioned the necessity for encouraging emission reduction at construction sites by recognizing leaders and fostering competitive advantage through award criteria in infrastructure projects to hasten the changeover. By submitting bids for these emission reduction projects, contractors may hasten the shift and improve their competitiveness. The interviews also revealed that the government might stimulate society more than it now does. They must push the market to function as emission-free as possible because they are the major client. Lawmakers and policy for contractors so they may invest in and build zero-emission equipment. It is crucial that future policy be clear and consistent. When adequate zero-emission machinery is available on building sites, enforcing emission reduction by legislation becomes a possibility or an

alternative. Accelerating the shift to complete use of electric equipment is also the duty of contractors. Right now, contractors might actively bid on zero-emission projects and get more expertise with the small and medium sized electric equipment that is accessible.

To sum up, the government may leverage policy tools to encourage, coordinate, and enforce the private sector's carbon reduction activities. Instead of viewing emission reduction at building sites primarily as a state issue, contractors might also exercise social responsibility. Contractors might welcome the shift to new building methods, which involve reducing emissions at the job sites. This entails accepting the necessity of emission reduction, identifying and grabbing hold of emission reduction opportunities, and adopting a receptive stance toward the governments through utilizing policy tools. Eventually, a quicker shift might result from a combination of contractors' increased intrinsic drive and the government's active use of policy instruments.

6.3. Recommendations for Further Research

The following suggestions for more study were made:

- Future studies can concentrate on measuring how drivers' actions and decisions affect the reduction of emissions in the setting of infrastructure. Investigating the advantages can help make a stronger business case and motivate individuals to make private emission reduction initiatives. Additionally, this may open up new prospects and boost other contractors' willingness to promote emission reduction at building sites.

- From a government perspective, policy tools were investigated to externally drive emission reduction. Before applying policy measures like incentives or laws, further study is necessary. Future research might concentrate on the effectiveness and execution of policy initiatives to improve emission reduction at building sites.

- The decrease of emissions in The Netherlands was the subject of this study. Future research can examine how drivers might reduce emissions in various global settings.

- Examine how contractors interact with different regimes. It is also advised to use a less hierarchical model that takes numerous relations between more players into account.

- Then, for suppliers, manufacturers, subcontractors, banks, and network operators, barriers, drivers, and actions for acceleration may be developed. It is essential to look at how network operators fit into this study since without a supply-side requirement, demand-side innovation is useless.

- In addition to Rijkswaterstaat, it is advisable to consider smaller clients. The largest customer also implies they are never moving at the fastest rate. Compared to the greatest client, other smaller clients are frequently quicker and more creative.

- It is advised to make an effort to scientifically document the processes that lead to virtuous loops' acceleration. The basic theoretical foundation was built on viscous loops that result in a downward spiral.

- It is advised to look at a shift toward a construction industry that is more process-oriented. The issue of shifting the industry away from projects and toward one that is process-oriented was not addressed in this study. Projects and processes are constantly tension in the construction business because if they were to be separated, there wouldn't be a construction industry at all. The research implicitly anticipated that the project-oriented nature of the construction sector would not change.

- The traditional idea of building sites, where everything is put together on-site, was the major focus of this investigation. The relationship between businesses and transportation may change if the construction process evolves in the future to include largely prefabricated components that are assembled off-site. The current supply chain is altered by this; as a result, new companies may enter the market and the relevance of existing supply chains may change. It is recommended that this entire construction process be further studied scientifically.

- Also, more importance needs to be given to optimize and bring regulations in the working procedure of a project rather than the focusing on the electric equipment. The amount of carbon emission for producing electric batteries and machines is not considered, so the first and major focus should be on the working methods. For example, optimizing the asphalt mix into low temp so that there is a reduce in carbon emission.

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Appendix A

Interview Protocol

The interview will be a semi-structured one, a few questions are predetermined, but other questions aren't planned which will be developed during the conversation.

1. Introduction

The interview session will start with introducing myself, communicating the goal and also the duration of the interview, request for permission to record the interview and the transcription of the interviews will be shared with the stakeholders.

2. Questions

2.1. Introduction questions

- What is your role in the organization that you work for?
- What are your impressions on phasing out fossil fuel equipment and enhancing electric equipment?

2.2. Barriers and Drivers

- To your knowledge and understanding of the current state of this transition in Dutch Infrastructure sector?
- What are the barriers that were faced during this transition in terms and how were they solved?
- Can you think of factors that hinders the transition in Dutch Construction Industry in relation to : (a) Government Perspective (b) Contractors Perspective (c) Technological Perspective (Manufacturers/ Research Institution)
- What are the factors that accelerate the transition to phase out fossil fuel equipment completely in Dutch Construction Industry in terms of : Contractor perspective, Government perspective, technological perspective (Suppliers, manufacturers and researches)?

3. Conclusion

The respondents will be thanked for his/her time.

Appendix B

INTERVIEW TRANSCRIPTS

Confidential

Appendix C

This section contains the list of respondents who showed interest and shared their valuable time to help the researcher with this research.

Confidential