Moving towards zero-emission construction sites in the Dutch infrastructure sector

Master Thesis

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TU Delft

Ballast Nedam

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TU Delft Ballast Nedam

Preface

The purpose of this master thesis was to explore how the transition towards zero-emission construction sites could be accelerated. The research was conducted for the study Construction Management and Engineering (CME) at the Delft University of Technology. The research was executed in collaboration with the contractor Ballast Nedam, which provided me with a broad network of practitioners and expert knowledge. As Dutch contractors are slowly moving towards zero-emission construction sites, I hope this research is a contribution to their journey.

S.Y. Aalbers
Delft, February 2022

Acknowledgement

I want to acknowledge everyone who helped contribute to this research. The contributions of all members of the graduation committee are highly appreciated and gratefully acknowledged. A sincere thank you for my daily supervisor from Ballast Nedam, Tom Peppink, for his guidance and support. Our valuable weekly meetings and insights are highly appreciated. Thank you for sharing your expertise and enthusiasm during the entire project. I would like to express my sincere gratitude towards my chair, professor Paul Chan, for our valuable discussions and feedback which continuously opened up my mind. I thank Jan Anne Annema for all his comments and guidance during the process, especially his knowledge on conducting scientific research. I would like to thank Leon Hombergen for his guidance and combined knowledge of practice and science, which helped me to make the connection between both orientations.

I would also like to thank all the interview participants, that took the time to participate in this research. Their willingness to contribute was an essential part of this study.

Sebastiaan Aalbers

Executive summary

To limit the effects of climate change, it is crucial to motivate contractors and the government to reduce emissions at construction sites in the infrastructure sector. Yet, little research has been done on how the transition towards zero-emission construction sites can be accelerated. This research is an exploratory study on which barriers slow down and which drivers accelerate the transition towards zero-emission construction sites in the Dutch infrastructure sector. The results were obtained through case study research, based on semi-structured interviews, desk research and participant observation meeting notes. Thirteen interviews were conducted with representatives from Rijkswaterstaat as client, Ballast Nedam as contractor, a sub-contractor, consultant and a developer. The goal of this study was to gain insight into the transition process from a government and contractor perspective. Also, the role of technology and innovation in the transition process was explored. Eventually, drivers and actions were established to answer the main research question: How can the transition towards zero-emission construction sites be accelerated?

Technologically, the most important barrier was the limited availability of zero-emission construction equipment. This hinders both governmental policy instruments and contractors. Another important technological restraint were limited charging and fuel facilities. The costs of zero-emission alternatives are currently too high to be profitable compared to the existing machines functioning on fossil fuels. The low availability and high investment costs are mainly caused by the fact that the zero-emission construction equipment is still in development and innovations are introduced on the market gradually. Particular barriers of the government, contractor and technology & innovation were found to be interconnected with a cause and effect link. The barrier of a lack of clear vision and clarity towards the market from the government, seems to be connected to the barrier of the wait-and-see attitude of contractors. The results show that interviewees from the government and the contractor generally do not share the same vision. Both actors prioritized different barriers and categories that slow down the transition. This was found to be an inherent barrier in itself.

For motivating contractors, the interviewees indicated the need for incentivizing emission reduction at construction sites by rewarding frontrunners and creating competitive advantage through award criteria in infrastructure projects. The research shows that corporate drivers, e.g. competitive advantage are key internal drivers for contractors. Contractors can accelerate the transition by tendering these emission reduction projects to enhance their competitive advantage. Winning these projects finances new zero-emission equipment and leads to an increased competitive advantage in tendering new zero-emission projects. The respondents also indicated that the government could play a greater stimulating role than it does at present. Interviews argued that two different roles of the government can be distinguished: main client and legislator/policy maker. As main client it is important the government challenges the market to operate in a zero-emission way as much as possible. The respondents indicated that zero-emission could become part of the contract requirements, when enough zero-emission equipment is available on the market. These contractual requirements can become increasingly strict overtime. As legislator/policy maker it is important to create boundary conditions for contractors to enable them to invest and construct zero-emission. For instance, to create new subsidies for the purchase of zero-emission equipment. Clarity and continuity of future policy plays a significant role. Enforcement of emission reduction by law becomes a possibility or option when enough zero-emission equipment is available at construction sites.

Contractors also have their own responsibility to accelerate the transition towards zero-emission construction sites. At the moment, contractors could increase their experience with available small and medium size electric equipment. Construction workers could be educated and trained to become familiar with new equipment and start using it in (both existing and upcoming) projects. Contractors could also pro-actively approach suppliers, manufacturers and sub-contractors to search for new partnerships and project stakeholders to stimulate early equipment development, access and delivery.

When the actions for acceleration are taken, the first step towards an accelerated transition can be made, by slowly changing the underlying problems of how the construction industry is organised. These are mainly changing the competing market dynamics, the enabling policy environment and increasing the attractiveness of alternative technologies. The interviews led to the finding that the government and contractors generally have a different vision about this transition. The government can use policy instruments to incentivize, communicate and cooperate with and enforce the private sector to enhance private emission reduction efforts.

Moreover, contractors could also take social responsibility, and not consider emission reduction at construction sites only as a governmental matter. Contractors could embrace the transition towards new ways of construction which includes emission reduction at the sites. This involves acknowledging the need for emission reduction, seizing and recognizing emission reduction opportunities and receptively positioning themselves towards the governments using policy instruments. The research findings can be used to inform contractors and governments about private actions and use of policy instruments to achieve acceleration. The combination of more intrinsic motivation of contractors and an active use of policy instruments by the government can pave the way for creating more resilient and future-proof ways of construction.

This research has several limitations. Firstly, a embedded single-case design was chosen to conduct the empirical study. More clients or projects could have been chosen as units of analysis. Secondly, the case study projects were only from one country, the Netherlands. When projects from other countries would have been included the results could have been more nurtured. Lastly, this research did not cover all the parties that were involved in the cases. However, a strong point of research is that interview saturation was reached. Still, it would have been fruitfull to explore different perspectives in the research, such as suppliers and machinery manufacturers.

The research contribution of this study is the list of actions for acceleration. This list of combined actions for both the government and contractors was not found before in previous scientific literature as an direct strategy to accelerate the transition towards zero-emission construction sites. Additionally, the list of barriers that slow down and the drivers that accelerate the transition contribute scientifically, as this has not specifically been researched before for the perspectives of the government, contractors and technology and innovation in one combined study within this context.

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List of acronyms

B&U Burgerlijke en Utiliteitsbouw (English: civil and utility construction)

BZK Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (English: Ministry of the Interior and Kingdom Relations)

CSR Corporate Social Responsibility

DGK De Groene Koers

EMVI Economisch Meest Voordelige Inschrijving (English: Most Economically Advantageous Tender)

ENI Emissieloos Netwerk Infra

EU European Union

EZK Ministerie van Economische Zaken en Klimaat (English: Ministry of Economic Affairs and Climate Policy)

GHG Greenhouse Gases

GPP Green Public Procurement

GWW Grond-, weg- en waterbouw (English: civil engineering, road construction and hydraulic engineering)

HbR Havenbedrijf Rotterdam (English: Port of Rotterdam Authority)

HND Het Nieuwe Draaien

HVO Hydrotreated Vegetable Oil

IPCC Intergovernmental Panel on Climate Change

IPO Interprovinciaal Overleg (umbrella organisation)

I&W Ministerie van Infrastructuur en Waterstaat (English: Ministry of Infrastructure and Water Management)

LNG Liquefied Natural Gas

MEAT Most Economically Advantageous Tender

MKI Milieu Kosten Indicator

MLP Multi-Level Perspective

NGO Non-Governmental Organisation

NRMM Non-road mobile machinery

OEM Original equipment manufacturer

RAW Rationalisatie en Automatisering Grond-, Water- en Wegenbouw

RVB Rijksvastgoedbedrijf

RvB Raad van bestuur (English: Board of Directors)

RVO Rijksdienst voor Ondernemend Nederland (funder)

RWS Rijkswaterstaat

SDGs Sustainable Development Goals

SEB Schoon en Emissieloos Bouwen

SMEs Small and medium-sized enterprises

TCO Total Cost of Ownership

TEU Twenty Foot Equivalent Unit

TRL Technology readiness level

UN United Nations

UvW Unie Van Waterschappen (umbrella organisation)

VNG Vereniging van Nederlandse Gemeenten (umbrella organisation)

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Introduction

1.1. Background

Global warming has increasingly gained attention over the last decades. To limit global warming, 195 countries have signed the Paris Agreement (United Nations, 2015). The main goal of this agreement is to keep the global temperature rise below two degrees Celsius. The most important factor to realise this goal is reducing the amount of CO_2 equivalents emitted (Brander & Davis, 2012).

Global construction accounts for 25-40% of the world's CO_2 emissions (World Economic Forum & The Boston Consulting Group, 2016). Approximately 5-10 % of these CO_2 emissions comes directly from activities on construction sites, predominantly due to the combustion of fossil fuels to power equipment, machinery and transportation vehicles (DNV GL, 2019; Bellona, 2019). Therefore, there is a high potential to reduce the amount of CO_2 equivalents emitted at construction sites.

1.2. Context and relevance

There is a growing social and political awareness towards a more sustainable society. This results in governments aiming to reduce CO_2 emissions. Not only governments, but also other actors play an important role in reducing CO_2 emissions. The role of both the public and the private sector were acknowledged in the Paris Agreement. Since then, many cities and companies have committed themselves to reducing CO_2 emissions.

Eventually, such ambitious goals of governments will result in stricter emission requirements for the construction industry. The importance of emission criteria keeps growing, but the exact direction in which requirements are headed is not clear. This makes it difficult for contractors to anticipate on zero-emission trends. On the one hand, contractors know that requirements are becoming stricter yet want to stay competitive. On the other hand, contractors still work traditionally while zero-emission technologies are in a constantly and rapidly developing. This brings a high degree of uncertainty and makes it difficult for contractors in the decision making process to invest in zero-emission technologies that are currently available on the market. Contractors act as intermediaries between the sustainable demands of the government and sustainable solutions offered by the market. This hierarchical position in which contractors are situated is demonstrated in figure 1.1.

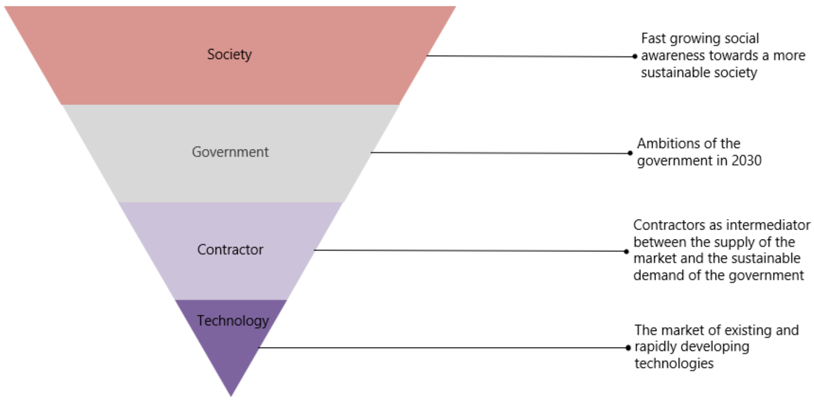


Figure 1.1: Hierarchy in which a contractor is situated

Besides the roles of governments and contractors, the speed and direction in which new technologies develop have an enormous impact on the transition towards zero-emission. This transition starts by introducing more zero-emission construction equipment at construction sites. Several different tools and pathways exist to cut emissions from construction site machinery. This can range from component improvements, process optimisations, and training of machine operators to reduce fuel use, to alternative technological solutions such as electric and/or hydrogen based construction equipment (Bellona, 2019).

The urgency to radically change the construction sector is high (Rotmans, 2021). The world is in a transition period to achieve the climate goals to reduce CO_2 emission.

The Netherlands have committed to the Paris Agreement and the corresponding future goals. The Dutch government is steering contractors towards zero-emission construction sites by 2030 (Ministerie van Infrastructuur en Waterstaat, 2020). However, the current pace of this transition is too slow and the optionality of sustainability is still high (Rotmans, 2021). Accomplishing zero-emission construction sites will be a process of months and years of reshaping the current practice of contractors.

The current practice of contractors is far away from implementing innovative zero-emission technologies on a sector-wide level in the existing industry. This is mainly because many technologies are still in development, limitedly available and currently too costly to be profitable for construction companies (Aragonès & Serafimova, 2018). The construction sector is also considered to be a relatively traditional and conservative industry (Davidson, 2013; Barbosa et al., 2017).

A transition period is ahead, working towards the goal of a zero-emission construction sites. The threats associated with climate change need to be limited with a much faster transition then is seen nowadays. The time for contractors to actively start anticipating and start working to reach this goal is right now. However, the roadmap to speed up this transition has not been filled in yet.

1.3. Problem analysis

There is a threat of fragmentation in the construction sector (Clarke et al., 2017). Many initiatives in the construction sector are focused on content related goals, stimulation of cooperation and making a positive impact. However, the construction industry consists of many different actors: branch organisations, contractors, sub-contractors, suppliers, network operators, investors, knowledge institutes, umbrella organisations and public clients. All these actors have different ambitions. This results in an uneven playing field and many differences in perspectives between parties (Rotmans, 2021).

It is the fragmentation, the division and arbitrariness that causes the construction sector to fail (Simons & Nijhof, 2020). There is no overarching strategy, everyone just does what they think best (Simons & Nijhof, 2019).

This fragmentation, division and arbitrariness hinders the speed of the transition towards zero-emission construction sites and increase the need for acceleration There are three main reasons why the transition of emission reduction is moving too slow and needs to speed up. Firstly, the SDG (Sustainable Development Goals) problems are already substantial. We are confronted with planetary boundaries; what the earth can scientifically withstand in terms of pollution, climate change, nitrogen and acidification. The known planetary boundaries limits have already been exceeded (Simons & Nijhof, 2021). Secondly, problems worsen exponentially (Simons & Nijhof, 2021). Population and economic growth only makes everything go faster. Thirdly, there are no simple solutions (Simons & Nijhof, 2021). Sustainability is a long-term change process. If problems need to be solved in time to prevent worse, people have to start right now (Simons & Nijhof, 2021).

This urgency is not yet reflected in the behaviour of contractors. Contractors do not yet make enough use of existing opportunities (Rotmans, 2021). Contractors are waiting on the market to further develop instead of proactively taking a lead role in starting the transition. Furthermore, the government gives no clarity to contractors about the transition path that they are taking as a client on the short term concerning sustainability requirements in tenders of future infrastructural work. This results in a transition speed for emission reduction at construction sites that is **too slow** (Rotmans, 2021).

1.3.1. Problem statement

The identified problems lead to the following problem statement:

The transition speed of contractors and the government seems slow and we do not know how to speed it up to achieve zero-emission construction sites in the Dutch infrastructure sector in 2030.

1.4. Research gap

To identify the research gap, the existing body of literature was examined. An overview of previous studies that focus on low or zero-emission construction sites is demonstrated in table 2.1.

Table 1.1: Previous studies concerning low or zero-emission construction sites

Literature	Location	Methodology	Main findings
Clarke et al. (2017)	United Kingdom	Interviews to determine what kind of expertise is needed for low energy construction	Obstacles are a decline in the quality and breath of vocational education and training, fragmented employment structure and lack of learning on infrastructural sites. This can be overcome by a radical transition pathway, rather than market-based solutions.
Fufa et al. (2019)	Norway	Case studies to identify main challenges and opportunities from low emission construction sites	Achieving fossil and/or emission free construction sites requires open and thorough collaboration between stakeholders, attention to the early planning phase, clear ambitions, system boundary requirements and quantitative evaluation methods to document emission reduction
Anderson (2019)	California	Case study to research the achievability of zero-waste and zero-emission construction sites	The decarbonisation of commercial construction will eventually shift jobs from the gas industry to the electric power and equipment manufacturing industry. They state that governments have the opportunity to pave the way for healthy, safe, and affordable zero-emission construction.
Andresen et al. (2019)	Norway	Analysis of construction documents to identify main lessons learnt from pilot zero-emission building projects	The importance of an integrated design, process choosing locally sourced materials with low embodied carbon, having clear goals and associated assessment methods
Venås et al. (2020)	Norway	Literature review and qualitative case study with interviews to map current status and future of no or low emission construction logistics	Challenges for low or no emission construction logistics: lack of awareness, specific requirements, regulations and use of traditional methods to avoid risks. Opportunities: improved environmental requirements in public procurement tenders, political ambitions, market ambitions and demand for reductions in emissions and costs.
Karlsson et al. (2020)	Sweden	Literature review and scenario analysis to assess the carbon reduction potential of road construction	There is a need to speed up the implementation of decarbonisation in road construction. Procurement and policy measures should be aligned. Key opportunities: electrification and hybridisation for construction equipment and heavy transport. Main pitfalls: over-reliance on bio fuels, cost optimizations that can not be scaled up.

These studies show that general challenges and opportunities to reach zero-emission construction sites are known (Fufa et al., 2019; Anderson, 2019; Venås et al., 2020). An opportunity is for instance the importance of governments and public procurement in driving societal goals such as carbon reduction (Kadefors et al., 2021). The increasing need to speed up this transition has been acknowledged in the existing body of literature (Clarke et al., 2017; Karlsson et al., 2020)

However, less research has been done on *how* the transition towards zero-emission construction sites can be accelerated.

The understanding of speeding up this transition can still be improved. Additionally, an overview of the main barriers and drivers in the transition towards zero-emission construction is missing in previous studies.

Constructing emission-free is no daily practise in the Dutch construction industry, which hinders contractors to effectively work towards zero-emission construction sites. Currently, it is not clear which strategy contractors should take in the transition towards zero-emission construction sites.

1.5. Research questions

The gap as explained, leads to the following main research question:

How can the transition towards zero-emission construction sites be accelerated?

To answer the main research question, the following sub-questions were established:

Q1 *Which barriers slow down the transition towards zero-emission construction sites?*

To answer the main research question, it is important to first understand which barriers slow down the transition towards zero-emission construction sites. These barriers are mapped, leading to an overview of the most important barriers. The barriers are considered from three different perspectives: the government, contractors and technology & innovation.

Q2 *Which drivers accelerate the transition towards zero-emission construction sites?*

After the barriers are mapped, it is important to understand which drivers stimulate and accelerate the transition towards zero-emission construction sites. Mapping these drivers results in an overview of all the identified opportunities. These drivers are also considered from different perspectives: the government, contractors and technology & innovation.

Q3 *What actions accelerate the transition towards zero-emission construction sites?*

After all the barriers and drivers are mapped, the last step is to develop actions for acceleration. Identifying which barriers need to be overcome and which drivers need to be enhanced leads to actions to accelerate the transition towards zero-emission construction sites.

1.6. Research objective

This research is both theory and practice oriented. Therefore, the following research objective was defined to fit both orientations.

To contribute to the acceleration of zero-emission construction sites in the Dutch infrastructure sector, by providing insight into possible actions for contractors and the government.

This study aims to develop actions for acceleration to advice both contractors and the government how to speed up the transition towards zero-emission construction sites. The tangible result consists of an overview of the main barriers that hinder this transition. Secondly, an overview of the main drivers that stimulate this transition. Lastly, it involves actions to accelerate the transition towards zero-emission construction sites were formulated.

1.7. Research scope

The transition towards zero-emission construction sites was approached from three different perspectives. Firstly, the role of the government both as main client and as legislator/policy maker was considered. Secondly, the perspective of the contractor and how they can contribute to accelerate the transition towards zero-emission construction sites was focused on. Lastly, the role of technology & innovation was taken into account. The transition towards more zero-emission construction sites is an interplay between these three main influential perspectives. These perspectives correspond with the layers that were introduced in figure 1.1.

The study remained on a strategic level of depth. For instance, the study did not consider a particular piece of equipment that needed to be replaced for another specific model from a niche company. There were no specific sub-contractors, suppliers or niche companies taken into account. This would exceed the strategic level of depth of this study.

The focus of this thesis was on road and harbour infrastructure. Within the road infrastructure network, the focus of this thesis was on highways. The scope was limited to the procurement and construction phase of infrastructure projects. This was motivated by the expectation that the procurement process has a large impact on contractors to reduce emissions on construction sites.

The focus in this thesis was on the reduction of carbon dioxide (CO_2) emissions, as decarbonisation has the largest societal impact. Less emphasis was placed on other emissions (nitrogen, particulate matter, noise). These emissions were not fully left out of the scope of this research because zero-emission goes hand in hand with the reduction of the other emissions.

From a technological point of view, this study mainly focused on the construction machinery and logistics. The system boundary of the construction site in terms of emissions is demonstrated in 1.2. This scope in terms of emissions explicitly applies to the technology & innovation perspective. The figure demonstrates that the resources, equipment manufacturing, transport of suppliers and disposal are out of the scope of this research.

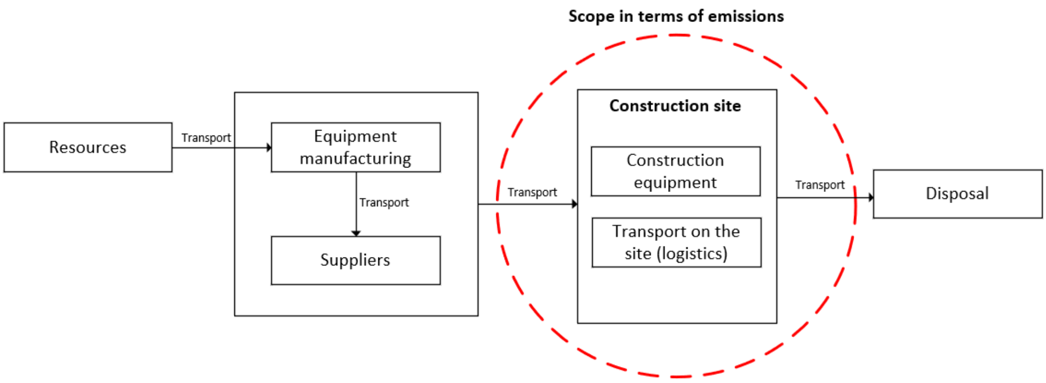


Figure 1.2: Construction site boundary in terms of emissions. Adapted from Hamdan (2018)

The carbon footprint coming from the production of construction materials (concrete, steel and asphalt) were out of the scope of this research. Also the emissions that occur during the operation of a structure after completion were out of the scope of this research.

The topic of energy supply to construction sites has not be explicitly researched in this study. The focus of this study is on emissions from the demand-side and not the electricity production emissions from the supply-side. It is paramount that zero-emission solutions should be simultaneously developed on both the demand and supply side. All the zero-emission definitions did not include the provision of the energy carrier which tend to be hydrogen or electricity. It is also necessary to work on the production of electricity and hydrogen with more renewable energy. An overview of the most important definitions used in this thesis are elaborated on in appendix A.

Summary scope

The scope can be summarised as follows:

- Governmental, contractor and technological perspective: main focus on contractor perspective and the relation with clients
- Procurement and construction phase: focus on the influence of tenders on the execution phase
- Dutch infrastructure: focus on road infrastructure (highways) and harbours
- Zero-emission: focus on reducing CO_2 emissions (decarbonisation)
- Construction site: focus on machinery and logistics

1.8. Structure of the research

This research is structured as follows. Firstly, the theoretical background of the study is elaborated. It introduces two transition theories which are used as a theoretical lens for this research. Secondly, the methodology of the research is explained. This involves, for instance, the specific case study choices. Chapter four and the confidential appendix D are the execution of the case study research. Thereafter the results of the research are demonstrated in chapter five. These results are discussed in chapter six. In chapter seven the main conclusions of the research are set forth and recommendations for further research are given.

The full structure of the study is demonstrated in figure 1.3.

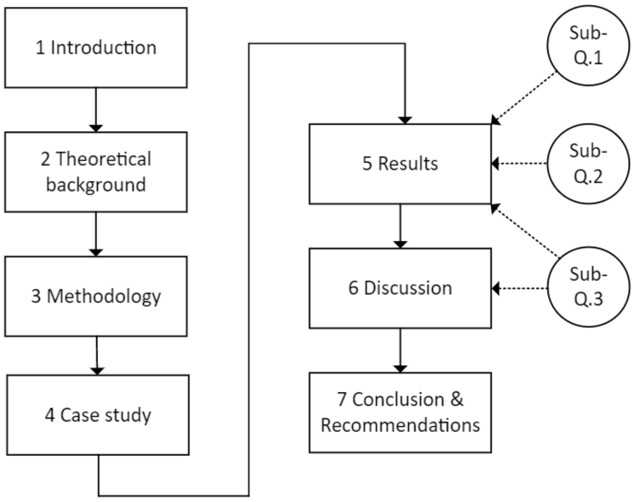


Figure 1.3: Structure of the research

2 Theoretical background

This chapter elaborates on the two concepts of the main research question: *construction sites* and *transitions*. Firstly, the theoretical concept of seeing construction sites as socio-technical systems is explained. Secondly, the multi-level perspective theory is explained for a better understanding of transitions conceptually (Geels, 2002). Thirdly, the Sustainable Market Transformation theory is explained (Simons & Nijhof, 2021). This theory gives a deeper understanding of market transformation, theoretical barriers, drivers and the concept of accelerating transitions. The result of this chapter is a theoretical framework, based on the exploration of transition theory and prior scientific research on transitions. This framework was used as a theoretical lens for designing the next chapter, which is the methodology.

2.1. Socio-technical systems and transitions

This theoretical perspective is chosen because construction sites can be seen as socio-technical systems. This theory contributes to answering the sub-research questions, as it gives a deeper understanding of construction sites. This theory sheds light on tangible and non-tangible elements of construction sites.

Theoretically, a socio-technical system incorporates humans and technology and consists of many elements that are clustered together and deeply locked in (Geels, 2002). There is a need to change existing socio-technical systems to more sustainable ones. Incremental change and business as usual is not enough to solve problems related to climate change (Kemp, 2010).

Socio-technical transitions are multi-dimensional, fundamental, long-term changes of socio-technical systems (Geels, 2002; Smith & Stirling, 2010). Changing socio-technical systems means that a various number of elements in the system need to be changed. Sustainability transitions are socio-technical transitions associated with sustainability targets (Markard et al., 2012). These are a particular kind of socio-technical transitions that are often 'guided' by public policies.

Socio-technical transitions involve looking at three interrelated dimensions (Geels, 2004):

- Socio-technical systems
- Actors
- Rules and institutions

Tangible and measurable elements can be seen as the socio-technical system (artefacts, infrastructure, regulations, public opinion, consumption patterns, market shares) (Geels, 2002). All these elements can be linked to particular actors. Specific kind of actors and roles differ for each socio-technical system. The human actors are interacting and making decisions. These actions and reactions to each other make change happen, but also drive stability. Actions are influenced by the rule system that they are part of. These institutions and rules shape stability and guides the structure that people are working under. This is a continuous and recursive process (Geels, 2004). It is the interaction between the system, the rules and the actors that one needs to study.

2.1.1. Construction sites as socio-technical systems

A construction site consists of many different elements. These are for instance the main infrastructure on the site, temporary roads, storage places of material, construction machinery and the construction shack with offices and facilities for the staff. An overview of contruction activities at the site is demonstrated in figure 2.1.

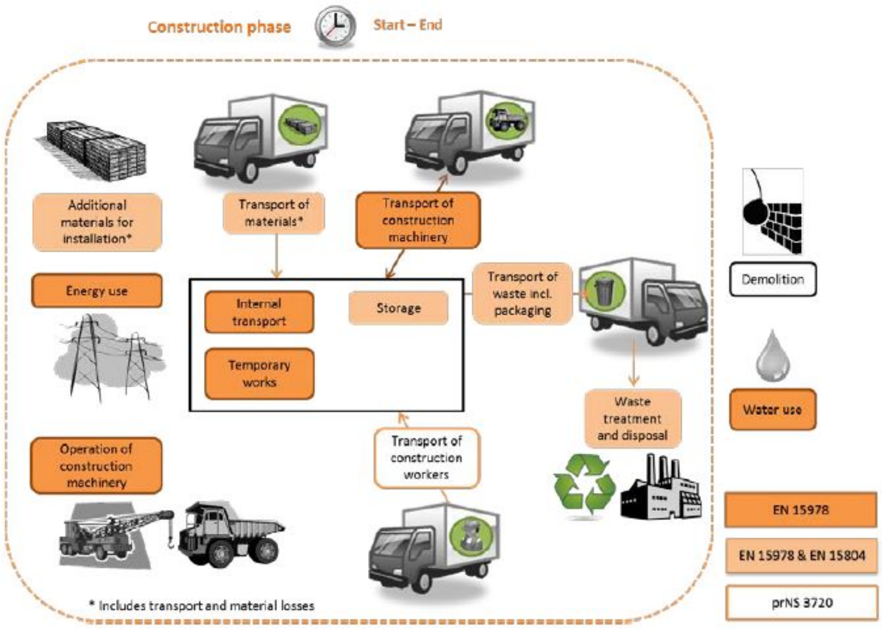


Figure 2.1: Boundary for construction activities at the site (Fufa et al., 2019)

Construction sites can be seen as socio-technical systems because they do not only consist of physical infrastructure, but also of markets, user practices and other intangible elements. A socio-technical system for construction sites is demonstrated in figure 2.2.

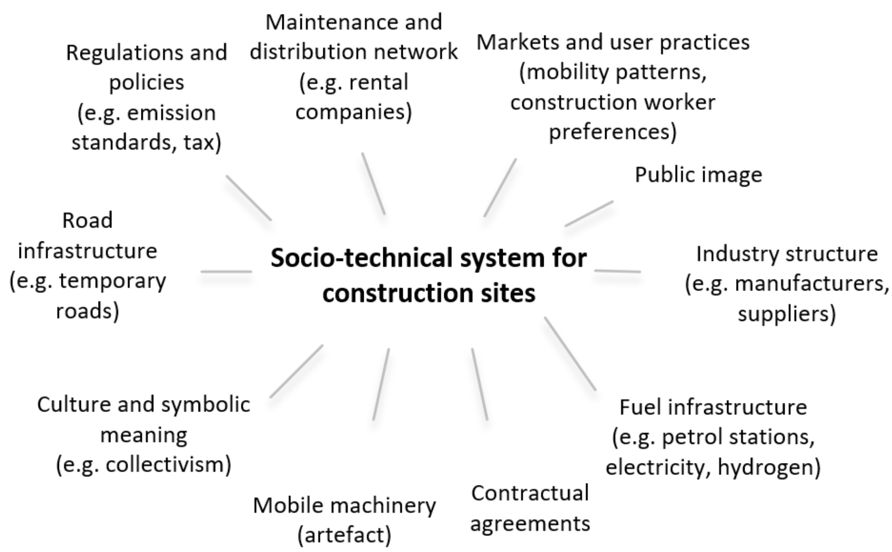


Figure 2.2: Socio-technical system for construction sites (adapted from Geels (2002))

Later in the research, the barriers and drivers that were found also deal with these different elements of construction sites as socio-technical system.

2.2. Multi-level perspective (MLP) framework

The multi-level perspective (MLP) theory is described in detail because it is one of the core frameworks to get a deeper understanding of transitions. The theory is linked to the three perspectives (government, contractor, technology & innovation) of this research. The scope of sub-question one and sub-question two are directly linked to these three different perspectives that form the foundation of this study.

The multi-level perspective is a conceptual transition framework that is used to deal with complexity and resistance to change (Geels, 2004). The MLP is particularly concerned with socio-technical transitions towards sustainability (Geels & Deuten, 2006). One of the strengths of the framework is that it is an relatively open framework. This allows researchers to ask new kinds of questions. The framework is used to understand the struggles that are going on while systems are transforming in various domains. The total framework is based on two fundamental dimensions of transitions: scale and time.

2.2.1. Multi-level concept

Transitions can occur in different levels of scale. The static MLP conceptualization of transitions is demonstrated in figure 2.3.

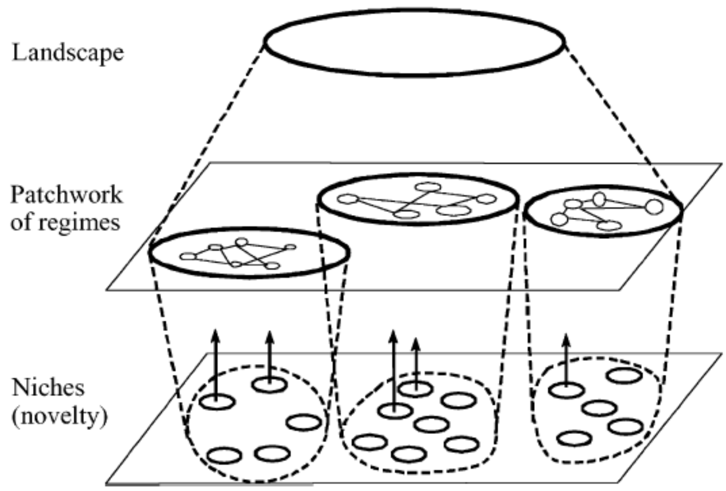


Figure 2.3: Multi-level perspective (Geels, 2002)

In the MLP, three levels of scale are distinguished in which processes align and interact (Geels, 2004):

- Landscape (macro-level): exogenous broad contextual developments
- Regimes (meso-level): current structures and practises characterised by technologies, institutions and dominant rules. Underlying and intangible deep structures (heuristics, routines, visions, policiy paridigms, norms, social expectations, engineering beliefs, rules of thumb, standardized ways of doing things,
- Niches: (micro-level): the development of technical innovations.

This struggle of transition is being played out and influenced by the wider landscape. These are slow-changing secular-trends, such as climate change. This level is considered to be exogenous and can not directly be influenced or changed.

The interest is particularly focused on the regime level. It deals with the question how existing regimes change from one system to another. Transitions are ultimately about stability and change. The problem is that the existing system has been there for a long time and is locked-in, path dependent and resistant to change.

Systems do not change radically, but more incrementally over time. This can be explained by economic, social and political mechanisms that result in stability. Economically, this can be for instance vested interests, sunk investments, scale advantages, and low costs. Also social cognitive routines and political power play an important role.

The micro-level concerns the niche innovations. These niche innovations are radical innovations that are the seed of sustainability transitions. These are innovations are emerging in the periphery. The innovations want to break through, but they are struggling in a system that is deeply locked-in.

2.2.2. Multi-phase concept

Transitions can also be approached from the dimension of time. The diffusion of an innovation means the the rate and the reason why an innovation is picked up by society. Rotmans (2003) distinguished the following transition phases for the diffusion of a technological innovation into society:

- Pre-development: The system is in a dynamic equilibrium, status-quo stays the same.
- Take-off: the start of a social change
- Acceleration: visibility of structural changes
- Stabilization: the system obtains a new dynamic equilibrium

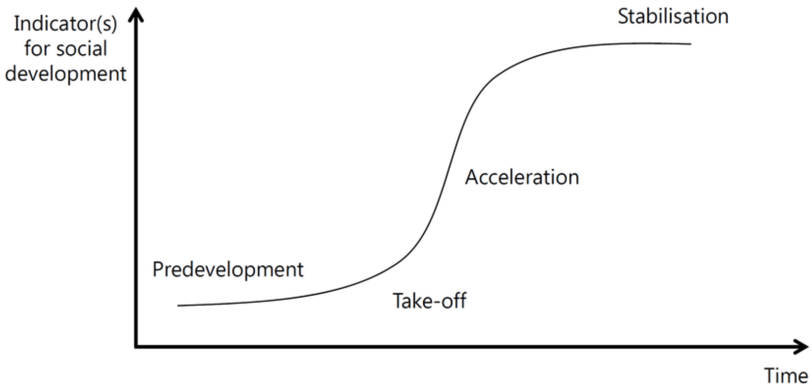


Figure 2.4: Different transition phases (Rotmans, 2003)

The radical innovations are all emerging from somewhere and the development over time can be tracked. Innovations initially emerge in the periphery and can not immediately compete on mainstream markets. At first, price performance characteristics of innovations are much lower compared to exiting technologies. This changes when innovations gain performance and get valued by for instance main clients. How can these helpful niche innovations gain momentum over time to overthrow the existing regime? That is the core puzzle of transition studies.

2.2.3. Dynamic multi-level perspective

The multi-level and multi-phase concept can be put together in a more dynamic sense. Geels (2004) used a similar four-phase approach for the conceptualization of time. This dynamic multi-level perspective is demonstrated in figure 2.5.

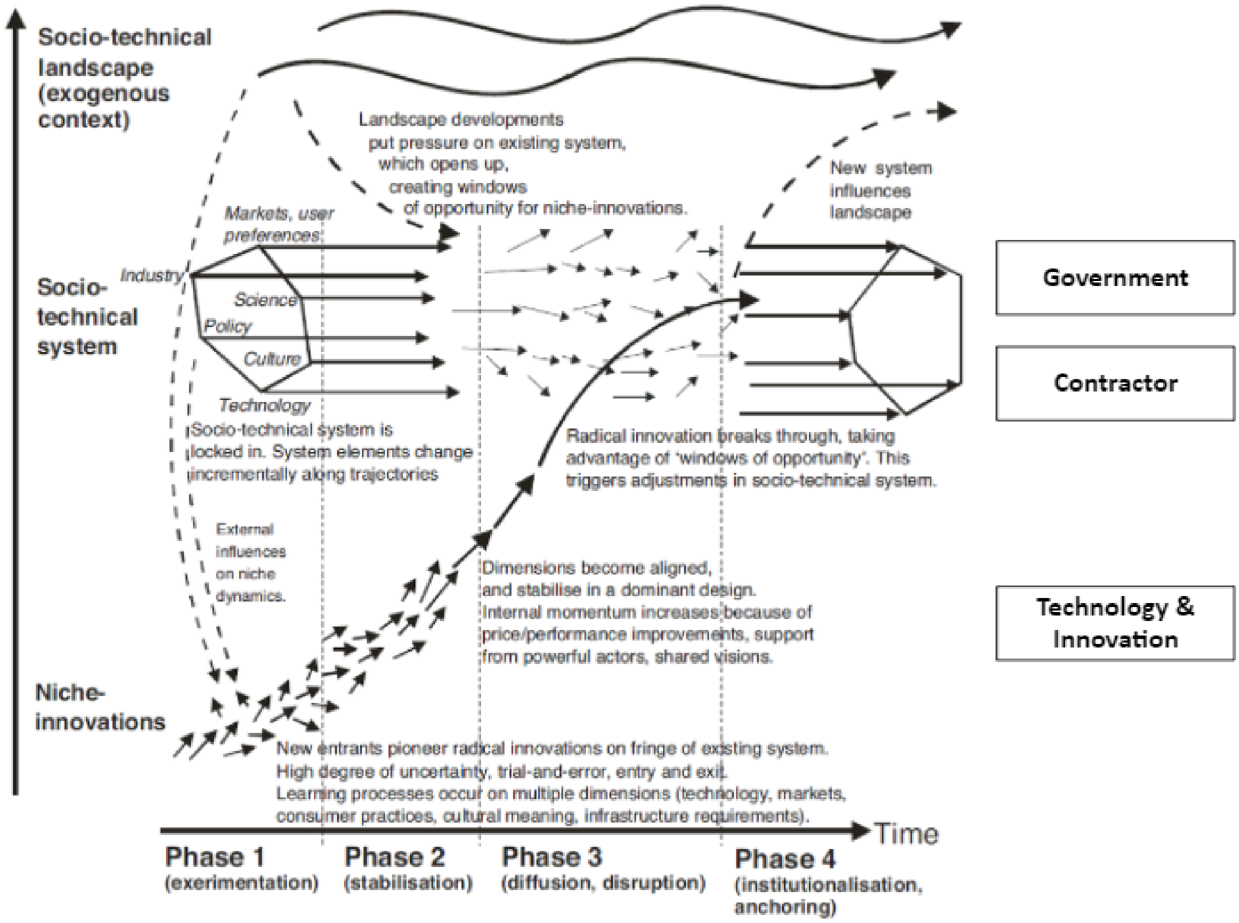


Figure 2.5: Dynamic multi-level perspective on transitions Adapted from Geels 2019

Figure 2.5 graphically demonstrates how the multiple scale-levels are unfolding over time. Radical innovations are emerging and there is a lot of trial and error. There is much variety in the niches and also lots of failure. Niche-innovations are struggling against the existing regime. This regime is not entirely inert, but incrementally developing over time (represented by the straight horizontal lines). The broader landscape level usually tends to evolve much more slowly.

The first phase describes how radical innovations emerge in small niches. There is a prolonged period of experimentation, learning, building of networks and articulation of visions. Then gradually the system stabilizes. There is more agreement on where to go, visions become clearer, prices go down and the performance becomes better.

Then you get the struggle of the second and the third phase. How do the innovations diffuse and get into the existing system? Usually this also involves external pressures on the regime, such as policy instruments. This tends to overcome deep seated lock-ins and path dependencies. These pressures open up the regime and create windows of opportunity for niche innovations to break through more widely and replace the existing regime.

2.2.4. Research application of the MLP

The three perspectives of this study are coupled to the macro, meso and micro levels of the MLP. The increasing feeling of urgency in society about dealing with climate change conceptualizes the landscape. Both the government and the contractors perspective is the meso level and conceptualizes the regime. The government and contractors are the main focus of the study, as the regime changes are the main focus of the MLP. The technology & innovation perspective conceptualizes the niche-innovations from the framework.

2.2.5. Transition paths

Geels & Schot (2007) describe four different transition paths:

- Technological substitution: niche innovations emerge, substitution happens primarily in the technological dimension. The use of one technology goes up, while the use of another technology goes down.
- Transformation pathway: existing actors gradually reorientate their direction. This gradual transformation in a regime over a long period of time leads to a different system without having a substitution.
- Reconfiguration pathway: radical innovations emerge in niches and are being incorporated in existing systems. Partial substitution in the systems leads to knock-on effects and may change the architecture of the system. New and old actors work together in alliances, rather than overthrowing the existing regime.
- De-alignment and re-alignment: Major landscape pressure create a shock on the system. The system begins to destabilize and fall apart. This creates space for niche innovations to emerge which leads to a new re-alignment of the regime.

There transition paths are interesting, because they demonstrate that there are many ways to achieve a transition.

2.2.6. Limitations of the MLP

There are several limitations concerning the theoretical MLP framework. Geels (2011) responded on these limitations and summarised the criticisms.

- Lack of agency - The attention for actors and their role of power and politics in the MLP framework is limited (Smith et al., 2005). Geels (2011) argues that the multi-level alignments and trajectories are enacted with social actors, and thus contain agency. Agency in the MLP is accommodated in the form of interpretive activities and bounded rationality (search activities, trial-and-error learning, routines). However, certain types of agency are underdeveloped such as power struggles, cultural-discursive activities and rational choice (Geels, 2011). The framework could also benefit from insights in strategic management and business studies.
- Operationalization and specification of regimes - Berkhout et al. (2004) find it unclear how to empirically apply these conceptual levels. This has to do with the problem of defining the topic of analysis and drawing boundaries. The frameworks does not prescribe how narrow or broad a certain topic should be delineated. The regime can contain empirical topics of different scope (Geels, 2011). What looks like a regime shift on a particular level, may be an incremental change at another wider lever. Additionally, the framework focuses on the transition process of a single regime. More attention should be paid to other multi-regime interactions.
- Bias towards bottom-up change models - Berkhout et al. (2004) suggest that the framework has a bias towards bottom-up change models. The MLP tends to emphasize a regime change that begins within niches and then work up. This underestimates the effect that the landscape has on the socio-technical regime that operates downwards. Geels & Schot (2007) aimed to overcome this bias by defining the four transition pathways.
- Heuristics, epistemology and explanatory style - Genus & Coles (2008) suggests that the contribution of the framework is limited to providing a heuristic device. The framework is also considered to have a theoretical and explanatory style. However, the MLP is an open framework and lets analysts ask particular questions about mechanisms and patterns (Geels, 2011).
- Methodology - The use of secondary data sources in historical case studies has been criticized (Genus & Coles, 2008). The discussion of the quality of data sources in the framework was underdeveloped. The transition researches were aimed more at exploration and illustration rather than systematic research. However, researching complex phenomena such as transitions always contains elements of creative interpretation (Geels, 2011).

- Socio-technical landscape as residual category - The socio-technical landscape level was criticised for being a residual category. This level needs more theorization and the concept could be made more dynamic (Geels, 2011).

- Flat ontologies versus hierarchical levels - The idea of hierarchical levels was criticised, because society is not always a multilevel image. Shove & Walker (2010) proposed a flatter model with multiple relations between actors, rather than hierarchical levels. However, doing this might result in trade-offs in empirical operationalization, generalization and accuracy of the framework (Geels, 2011).

2.3. Transition theories

The previously described theory of socio-technical systems and the multi-level perspective provide the basis for various transition theories. Four widely used transition theories are: 1) Transition Management 2) Innovation systems 3) Sustainable Market transformation 4) Small wins (Het Groene Brein, 2021). This section aims to argue why the transition theory of sustainable market transformation was chosen to be elaborated in the next section, out of the four widely used theories. Table 2.1 compares the four theories against each other on scale application, actor application, advantage and disadvantage. The two theories that have a particular focus on private firms are the Innovation systems and Sustainable Market Transformation. The other two theories, transition management and Small Wins, were not chosen because they lack this specific focus and were considered to give a more general perspective. The innovations systems (TIS-model) is particularly focused on innovations, while the scope of this study is not only focused on innovations. This leads to the choice of the Sustainable Market Transformation theory. The main advantage of the Sustainable Market Transformation theory is that is focuses on interventions of stakeholders, including private firms. This aligns closely with the objective of this study.

Table 2.1: Four transition theories compared (Het Groene Brein, 2021)

Theory	Scale level	Actors	Advantage	Disadvantage
Transition Management	Applicable on any scale	Applicable to any actor	Offers the most broad perspective	Less detailed in the analysis of market movements and innovations
Innovation systems (TIS-model)	Regional, national and international (sub-) sectors	Governments and companies	Provides a deep understanding on the success of innovations	Less focus on other aspects besides innovations
Sustainable Market Transformation	Regional, national and international (sub-) sectors	Governments, companies, NGO's, financial institutions and knowledge institutes	Focus on interventions of stakeholders in (sub-)sectors	Less focus on the broad societal transition process
Small Wins	Applicable on any scale	Applicable to any actor	Focus on small and meaningful steps	Less focus on deeper underlying transition problems

2.4. Sustainable market transformation

The sustainable market transformation theory was chosen to be elaborated because it gives an deeper understanding on how sustainability transitions can be accelerated. The theory has a focus on interventions of stakeholders, which includes the industry and governments. This is directly linked to the third sub-question of this research, which is the development of actions for acceleration. The theory also distinguishes theoretical barriers and drivers for stakeholders to move forward with sustainability issues.

This theory approaches sustainability problems from a system level, but zooms in what individual actors (e.g. private companies) could do to accelerate sustainability transitions (Simons & Nijhof, 2021). Multiple stakeholders are considered, because companies are not the only actors struggling with these large sustainability problems. It is a multi-stakeholder issue and not a single-company problem.

2.4.1. Introduction

The sustainable market theory aims to recognize patterns in behaviour of actors that lead to unsustainable outcomes. Simons & Nijhof (2021) argue that if this behaviour is recognized, transitions can be accelerated. Especially, the incentives for people to maintain this behaviour should be identified. This applies to governments, private parties and all the other actors in the construction industry. Later in this research, this unsustainable behaviour was also identified by looking at the barriers for the transition.

Changing systems is argued to be a long-term (multi-year) process that has to go through phases. Each phase has its own characteristics (Simons & Nijhof, 2021). It is important to understand where the change process is in the theoretical model, to understand what the government, a private party or another actor in the construction industry must do. System change is argued to be an organisational issue between stakeholders in an industry. The key element is to understand which actor should do what, at which moment in time (Simons & Nijhof, 2021). The stakeholders should organise how they interact with each other in a multi-stakeholder environment.

2.4.2. Four-loop model

This section explains the four-loop model, developed by Simons & Nijhof (2021). This model gives a deeper understanding on the slow pace of transitions in the construction industry. The model is theoretically introduced and directly applied to the construction sector, which gives insights of the dominant underlying incentives in the industry.

To get a better understanding of the system of the construction industry, four loops with corresponding questions have been outlined that lead to unsustainable outcomes. These four theoretical loops are demonstrated in Figure 2.6. These questions are answered in the context of the construction industry, the relevant sector where zero-emission construction sites are a part of. The model contains vicious loops that are causing a downward spiral. Understanding these vicious loops for the construction industry gives insights in the slowness of the transition towards zero-emission construction sites.

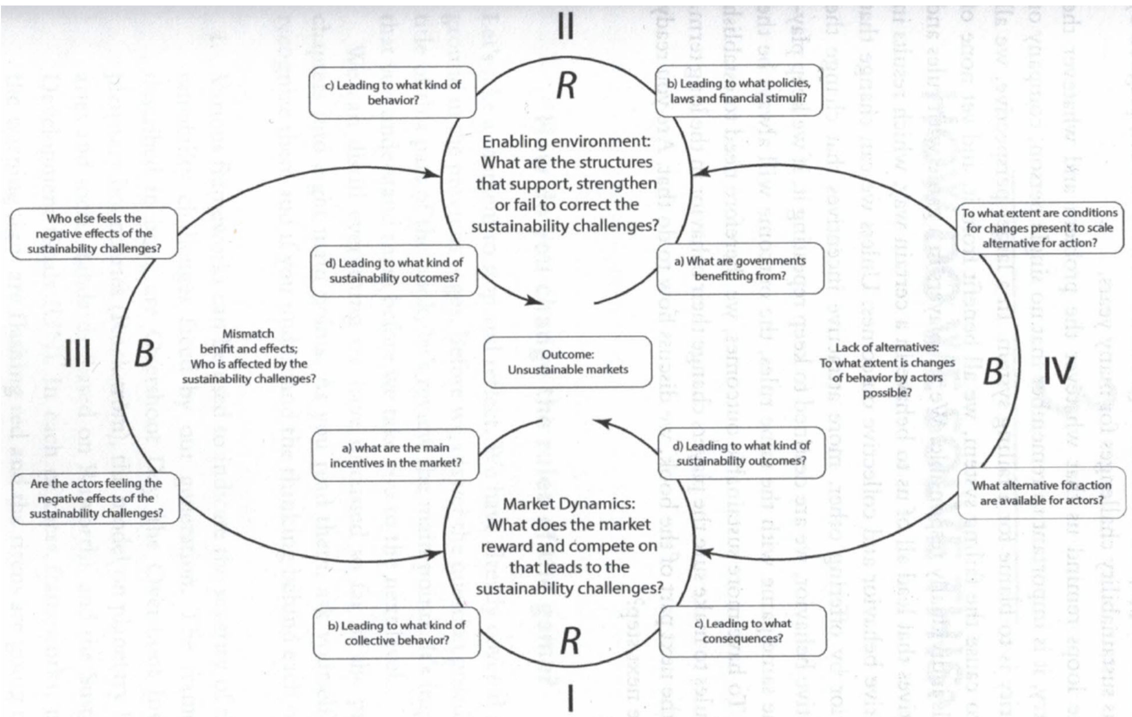


Figure 2.6: Four-loop model (Simons & Nijhof, 2021)

Loop I: market dynamics
What does the market compete on? In the construction industry, there are supplying parties and demanding parties along the entire value chain. The dominant culture in the construction sector is to aim for the lowest price, safety, fastness and as little risks as possible (Simons & Nijhof, 2021). Contractors that behave accordingly, will be successful and win the project contracts. Clients are generally not paying for the most sustainable projects, with the most emission reduction. The whole sector is busy reducing costs, lowering risks or outsourcing to others.

Loop II: enabling environment
What is the policy and the context? The Dutch government has an interest in a construction sector that is efficient. This provides jobs, is cheaper, and leads to investments. This makes the Netherlands competitive and this also applies to the construction market. The policy, financial incentives, legislation and how people are educated are generally aimed at keeping projects cheap, efficient and unsustainable. In this way, a construction sector is created in which the winning contractors are those with the lowest costs, lowest risks, and who have become good at externalising costs.

Loop III: mismatched benefits and effects
Who is affected? Contractors and governments are not personally affected. It is nature and future generations that are directly affected. Contractors are only indirectly affected, when they are not allowed to build anymore because of emissions. This is the case in the current Dutch nitrogen crisis. Generally, parties benefit from continuing with business as usual and thereby maintaining a construction industry with unsustainable sites.

Loop VI: lack of alternatives
What are the alternatives, and how attractive are they? Technically, a lot is already possible, but it is more expensive, riskier or there are not many suppliers. Contractors are not familiar with the alternative practices and new techniques. There are plenty of reasons for stakeholders to argue why the zero-emission alternatives are not yet that attractive.

Figure 2.7 summarizes the vicious loops that are currently dominant in the construction industry. The slowness of transitions in the construction industry can be appointed to maintaining these vicious loops. It is because transitions are being obstructed by these deeper causes and incentives for unsustainable behaviour in the underlying system.

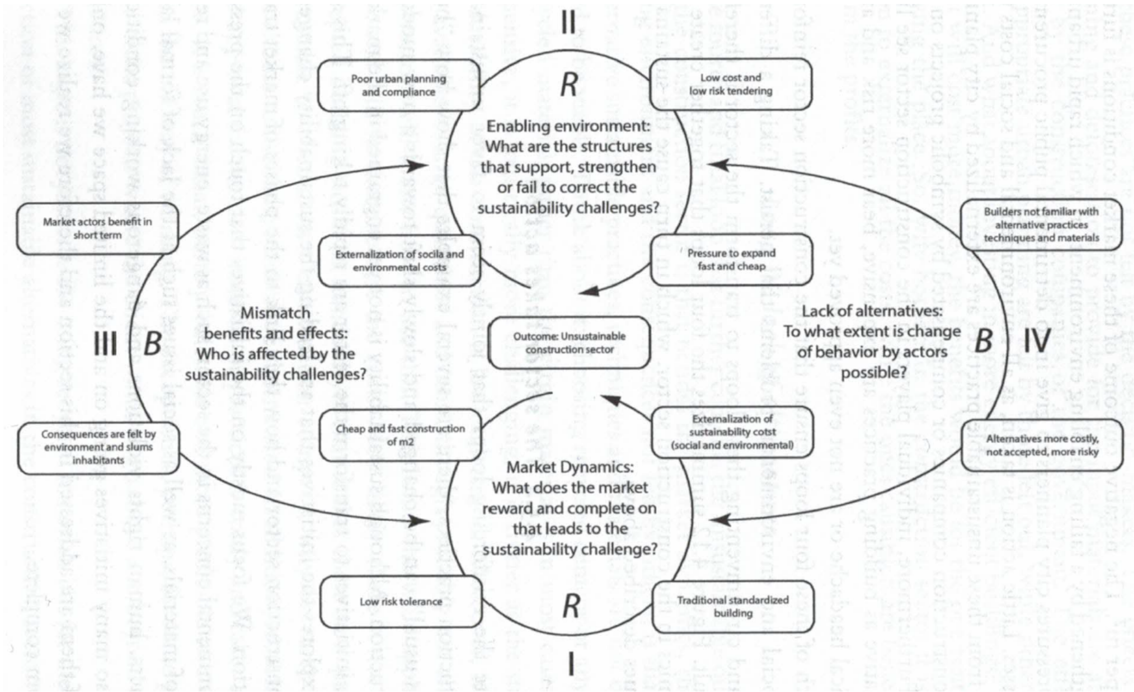


Figure 2.7: Four-loop model applied to the construction sector: systemic loops that lead to unsustainable outcomes (Simons & Nijhof, 2021)

Governments, the private sector, and all other stakeholders in the construction industry have contributed to maintaining these loops (Simons & Nijhof, 2021). The actors understand there is a problem, but argue that others have to act first. Private parties are waiting on the government, while the government waits for the market mechanism to work and incorporate more zero-emission equipment at construction sites. There is no simple solution to break these loops, the change process goes through phases (Simons & Nijhof, 2021). Later in this research, the actions for acceleration are aimed at breaking these loops and creating a trend upwards, instead of downwards.

2.4.3. Strategy: sustainable market transformation

This section aims to explain the four phases of sustainable market transformation. Once known in which phase the transition towards zero-emission construction sites is, the theory steers the researcher into the interventions that are needed to move the construction sector forward.

Figure 2.8 demonstrates the different phases of market transformation. the figure includes the percentage of sector being sustainable. To achieve acceleration, this line might need to be even steeper.

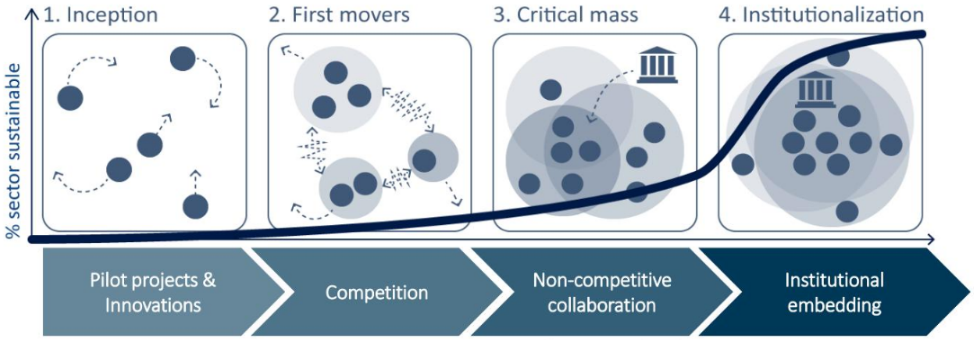


Figure 2.8: Sustainable Transformation Curve (NewForesight, 2018b)

Phase 0: Denial
This phase is not visually shown in figure 2.8, because it appears before any of the phases start. The construction sector works like normal and the vicious loops are maintained. The need for emission reduction has been known for a long a time, but was not yet considered to be a problem. This continued until there was a moment of crisis. Then the sector woke up and urgency was created. Denial is often the first reaction of a sector. In the Netherlands, this urgency was created with the nitrogen crisis in 2019 (Stokstad, 2019).

Phase 1: Inception - increasing urgency and move towards actionable alternatives through projects and pioneering
In phase one the sectors starts with new projects and pilots. The objective here is to learn what requirements solutions should meet. When the sector wants to reduce emissions at construction sites, the aim in this phase is to learn about the technologies that are able to achieve this goal.

Phase 2: Competitive advantage - creating new business models through innovation and competition
Phase two is about the first movers that will apply these new solutions first. Contractors can start applying zero-emission equipment at construction sites. These first movers need to be recognised and acknowledged to get get a competitive advantage. This could be an award, access to better innovations, networks or a better reputation. It is also important to gradually affect those who do not want to join in. Private firms do not want to do exactly the same as their competitors in order to distinguish themselves. In this phase, innovation takes place, new business models emerge and there is more commitment from companies because they want to win from their competitor. The loops are not yet resolved, but the sector has already gone from denial, pilot projects, learning to competition.

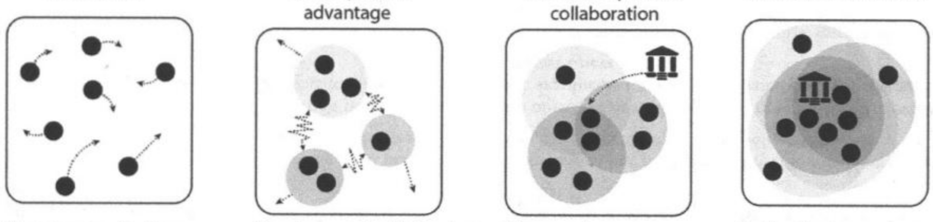
Phase 3: Pre-competitive collaboration - enabling scaling through collaboration between multi stakeholder coalitions and platforms In phase three, the sector needs to enable scaling through collaboration between multi-stakeholder coalitions and platforms. The leaders of the sector start to talk with each other to discuss their vision, the structural role of the government and the role of the business community. The actors start to reach consent on what they want to achieve and a clear vision on what zero-emission construction sites look like in the Netherlands should now be established.

Phase 4: Institutionalization - ensuring a level playing field through legislation and coercive self-regulation
In phase four, the tipping point has been reached. Political leadership is needed to ensure a level playing field through legislation and coercive self-regulation. There has been enough time for everyone to adapt to emission reduction practices. This means that some parties will drop out, but the sector has moved forward. Thereafter, new market transformation waves will start to come. Sustainable market transformation is a constant stream of market transformations and innovations.

2.4.4. Theoretical acceleration

If the key stakeholders know what to do in which phase, everyone can work together to accelerate this transition (Simons & Nijhof, 2021). A cycling metaphor can be used to illustrate how this acceleration works. If everyone is kept in a peloton, it will move, but it will have a certain pace. There is no drive to accelerate, because people stay together. To accelerate, the peloton has to be pulled apart. However, this goes against the perception that everything should be a level playing field and level entry. The most strategic question that can be asked is: under what conditions can boundary behaviour (Dutch: grensgedrag) be recognised and acknowledged? In this way, the peloton is pulled apart. Then the peloton has to be brought back together by scaling up. It is a harmonica movement that must be organised. To create urgency, understand and learn what the solutions are, pull the peloton apart, accelerate, bring back together, scale it up and institutionalise. This movement is the trick of market transformation.

If a market party is at the back of the peloton, this process will force them to get on board quickly or disappear from the market. If a party is leading on its own and is too innovative, that is also a risk. That is why risk-taking frontrunner behaviour should be rewarded to accelerate transitions. This can also be done for instance by entering into smart partnerships with competitors.
To achieve acceleration, it is important which stakeholder does what at which point in time in the various phases (Simons & Nijhof, 2021). An overview of what the main actors should do in which phase is described in the stakeholder matrix. This stakeholder matrix is demonstrated in Figure 6.2. It gives insight of the roles that the industry and the government should ideally take in the various phases.



	1. Inception	2. Competitive advantage	3. Pre-competitive collaboration	4. Institutionalization
Industry	Stop denying the issue	Develop sustainable business models	Communicate a non-competitive agenda	Lobby for the new normal
	Partner with NGOs or other stakeholders	Differentiate by introducing new business models and labels	Form or join platforms	Recognize leading politicians
	Pilots, CSR projects, support or partner with foundations	Engage value chains	Be inclusive when others want to join	Comply with legislation
	Identify solution principles	Participate in rankings and benchmarks	Develop a sector strategy	Take on subsequent issues
Government	Embrace the crisis	Emphasize long-term vision	Develop policy goals and measures	Show political leadership
	Communicate a long-term vision	Challenge market actors on principles	Support platforms and coalitions	Announce legislation
	Make space for experiments and fund projects	Be a launching customer	Influence behavior of consumers	Create the new normal
	Identify solution principles	Recognize market leaders	Change tax incentives	Remove the laggards

Figure 2.9: Stakeholder matrix for the industry and government (Simons & Nijhof, 2020)

2.4.5. Limitations

The main assumptions in relation to market transformations (Simons & Nijhof, 2021):

1. Any sustainability issue can lead to a full market transformation
2. This transformation always includes four phases
3. None of these phases can be skipped, as each phase shapes the market conditions of the next phase
4. Each market actor has its specific roles in each phase
5. Resistance can be predicted; friends in one phase will be enemies in the next
6. The game can only be changed if it is clear who should do what and when

Only part of the assumptions are theoretically addressed. With for instance viable systems theory, evolutionary economics, stakeholder salience theory, deliberative democracy theory and neo-institutional theory.

However, there is a need for more theoretical strengthening of the underlying assumptions.

Per sector the stakeholder matrix and the understanding of specific roles of various market actors can still be strengthened. Depending on the sector of interest, some actors are missing. The theory does not provide insight in how each stakeholder should be motivated to act in the necessary way

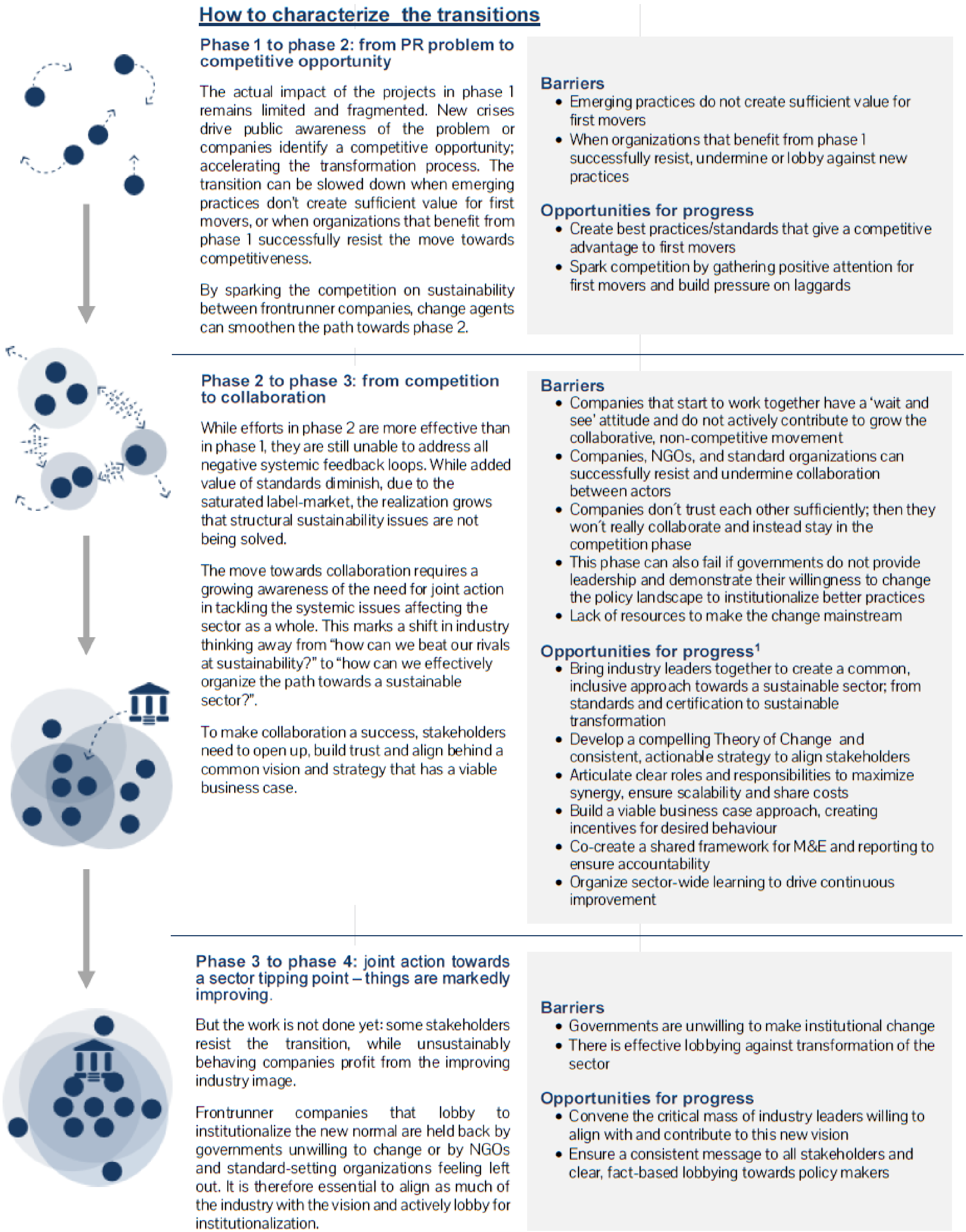
Longitudinal research would be needed to see the impact of market transformations in reality. This is needed to see if the theory really result in effective sustainable development goals solutions.

2.5. Barriers and drivers

2.5.1. Theoretical barriers and drivers

In figure 2.10, a framework to characterize transitions is demonstrated. Each phase contains different barriers and opportunities for progress to move to the next phase. Depending on the phase where particular transition is in, different theoretical barriers and drivers apply. For instance, moving from phase two to phase three is the shift form competition to collaboration. A barrier that hinders this is for instance a 'wait and see' attitude and not actively contribute to grow the collaborative environment. Another barrier is that companies don't trust each other sufficiently. Then companies stay in the competition phase and won't really collaborate. The competition phase may also be hindered if government does not demonstrate their willingness to change or do not provide leadership to change the policy landscape. Opportunities for progress here are for instance to build a viable business case approach, creating incentives for desired behaviour. Moreover, the theory argues to articulate clear roles and responsibilities, ensure scalability and maximize synergy. Stakeholders need to build trust, open up and align begind a strategy and common vision.

To further build on the previous framework, figure 2.11 demonstrates the Market Transformation Matrix which also helps to recognise the four market transformation phases. For each phase, this matrix includes triggers for change, level of awareness, willingness to collaborate, drivers, barriers, main change agents and main opponents to change. For instance, a trigger for change in phase two is the increasing realization that sustainability can be leveraged as a competitive advantage. Main change agents in this phase are first mover companies and standard organisations. Drivers in this phase are considered to be first mover advantages, marketing sustainability and media pressure. Stakeholders can use this matrix as a roadmap to see both pitfalls and priorities in each stage of 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 2.10: How to characterize transitions (NewForesight, 2018a)

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 2.11: Market Transformation Matrix (NewForesight, 2018a)

2.5.2. Barrier and driver categories

To better understand barriers and drivers, it is helpful to categorize them. Based on previous literature on barriers and drivers related to transitions in infrastructure, four categories were distinguished 1) Institutional/regulatory, 2) Social/cultural, 3) Economic/financial/market, 4) Technological (adapted from De Jesus & Mendonça (2018)). "Harder" factors can be considered to be related to the more techno-economic trajectories (De Jesus & Mendonça, 2018). "Softer" factors have more to do with cultural and regulatory issues. The "drivers" are factors that encourage or enable the transition towards zero-emission construction sites. The "barriers" are the bottlenecks that obstruct the transition towards zero-emission construction sites. These four catagouries and their definitions are demonstrated in table 2.2.

Table 2.2: General classification of barriers and drivers (De Jesus & Mendonça, 2018)

Category	**Definition**
Institutional / Regulatory	Associated with legislation, (mis)aligned incentives, standards
Social / Cultural	Connected to awareness, behaviour and business routines
Economic / Financial / Market	Related to supply and demand, high initial cost, uncertain return and profit
Technological	Availability of technologies, (in)appropriate technology

Scientific research on the acceleration of the transition towards zero-emission construction sites is scarce. Because previous research not yet discussed internal driver categories for private emission reduction at construction sites, the researcher looked beyond the scope of this topic. Literature on green building shows similarities with emission reduction at construction sites, and therefore provides a useful context for this research. To better understand what drives private reduction behaviour, internal drivers can be classified according to three additional categories 1) Corporate, 2) Project, 3) Personal (adapted from Darko et al. (2017)). Corporate drivers exceed the scope of individual projects and relate to organisational benefits of emission reduction efforts (Darko et al., 2017). Project drivers are concerned with the benefits during the construction phase. Personal drivers internally drive individuals to enhance emission reduction efforts, based on commitment and personal belief (Darko et al., 2017). The definitions of these internal drivers are demonstrated in table 2.3.

Table 2.3: Internal drivers (Darko et al., 2017)

Category	**Definition**
Corporate	Drivers based on professional value capture and organisational benefits
Personal	Drivers based on personal commitment and beliefs
Project	Drivers based on benefits during construction

Besides the internal drivers, contractors are externally driven by governments. First, the government is in most cases their main public client. Secondly, the government is the legislator and policy maker. To deeper understand these external drivers from the government perspective, an additional categorisation can be applied. Policy instruments can be seen as external drivers by governments (Olubunmi et al., 2016). These policy instruments were categorised according to three different classifications: 1) Communication & Cooperation, 2) Enforcement, 3) Incentives, (adapted from Mees et al. 2014; Huang et al. 2021). These driving mechanism from the policy instruments work top-down on contractors, viewed from the multi-level perspective model. Table 2.4 summarizes the external drivers and their definitions.

Table 2.4: External drivers, policy instruments (Mees et al. 2014 Huang et al. 2021)

Category	**Definition**
Communication & Cooperation	Promoting and cooperating with the private sector to achieve emission reduction
Incentives	The use of (financial) incentives to achieve emission reduction
Enforcement	Use power to enforce emission reduction

2.6. Theoretical framework

To combine the previously described theories from prior studies on transitions, the following theoretical framework was specifically developed for this study. This theoretical framework is demonstrated in figure 2.12.

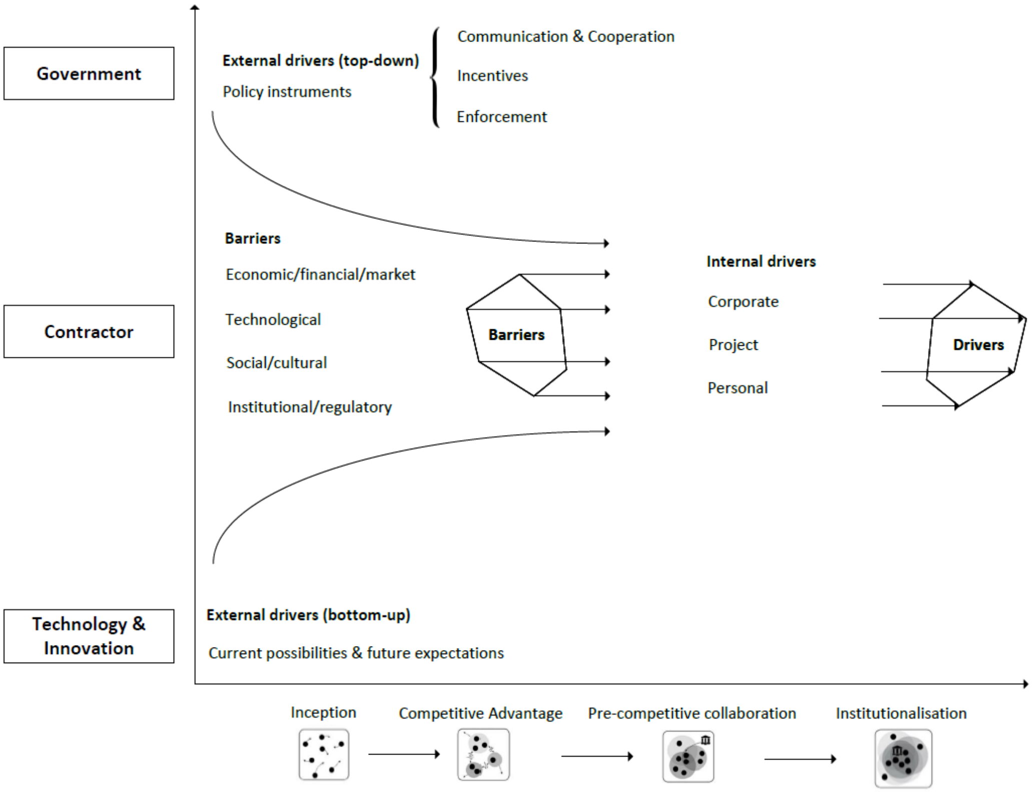


Figure 2.12: Theoretical Framework

The framework starts with identifying empirical barriers and drivers, during the interviews. Barriers and drivers are defined for three different perspectives: government, contractor and technology & innovation. These three perspectives were placed in the multi-level perspective theory (Geels, 2004). Both the government and contractors are part of the regime. Technology & innovation are part of the niche innovations, when this perspective is placed in the multi-level perspective theory. Reasoning from this theory, contractors and construction sites are part of the regime that is currently locked-in. Barriers for all three perspectives were divided into four different categories: 1) Economic 2) Technological 3) Social/Cultural 4) Institutional/Regulatory.

Within the drivers, the framework makes a distinction between internal and external drivers. External drivers coming from the government, are policy instruments. The policy instruments are divided into three categories: 1) Communication and Cooperation 2) Incentives 3) Enforcement. These policy instruments from the government can pressurize the contractor regime. These pressures are acting top-down as external drivers on contractors.

The external drivers for technology & innovation perspective, are the current possibilities and future expectations of technology and innovation. These current possibilities and future expectations externally drive contractors bottom-up. As described in the multi-level perspective theory, niche innovations slowly emerge and radical innovations start to break through.

The internal drivers specifically drive contractors forward. These internal drivers for private firms were divided into three different categories 1) Corporate 2) Project 3) Personal.

Lastly, within the framework, the sustainable market transformation theory by Simons & Nijhof (2021) was included. This is visually demonstrated by presenting the various phases of sustainable market transformation, at the bottom of the framework (inception, competitive advantage, pre-competitive collaboration and institutionalization). Each phase calls for a different set of actions to safeguard momentum and achieve progress. Every phase comes with theoretical barriers and drivers, to move through the phases. Eventually, these theoretical barriers and drivers were compared with the empirical barriers and drivers found in the interviews. With this pattern matching of the empirical and theoretical barriers and drivers, a list of actions for acceleration was developed, according to the researcher.

Later in this research, this framework formed the basis of structuring the results. The theoretical framework was used as a scientific lens to design the interview questions, case study and themes for coding.

3
Methodology

This chapter elaborates on the research methodology. The main method was a qualitative case study research. The research design was based on the theoretical framework established in the previous chapter. This theoretical background was used as a lens to design the research. Data was gathered through semi-structured interviews and secondary data sources. The case study research was chosen because it provided an in-depth understanding within the real-world context of construction sites by analysing specific projects and actors.

3.1. Theoretical background

The theoretical background was used as a scientific lens to design the case study, interview questions and themes for coding. The framework can be directly coupled to sub-questions one and two, as the barriers and drivers were categorized according to the framework. The theoretical background also helped to analyse the case study data and gave a deeper understanding on transitions and market transformation. Empirical data obtained from the semi-structured interviews was compared against the theoretical framework. The theory underlying the theoretical framework was used to answer the third sub-question to develop a strategy for acceleration.

A theoretical framework guides analysts to better think through problems (Porter, 1991). The theoretical framework for this research mainly consisted of two theories: the multi-level perspective and sustainable market transformation theory (Rotmans, 2003; Simons & Nijhof, 2021). The theoretical background provided greater clarity on the tools and processes needed to drive contractors to speed up the transition towards zero-emission construction sites. Unpacking this evolution elucidated activities that are necessary in this transition. The multi-level perspective provided deeper understanding on transitions and formed the conceptual context of the study by formulating the three different perspectives: government, contractor and technology & innovation (Geels, 2002). The sustainable market theory guided the analysts attention to identify the relevant problems and questions. This helped to see interesting mechanisms and patterns.

3.2. Literature research

The research started with a literature review. A narrative review was undertaken to develop a broad background on the existing body of knowledge on the topic (Bryman, 2012). The reason for choosing this approach is because of the interdisciplinary nature of the research. It covers topics of zero-emission, infrastructure projects, public procurement and innovation. A narrative review is less focused and has a more wide-ranging scope compared to systematic reviews and supports the interdisciplinary nature of the research. A systematic review method would be more comprehensive, less biassed and would increase the reliability of the study. However, it is more important to gain knowledge on the topic and allow a snowballing effect to discover new articles that are relevant for the study.

Scientific search engines (Google Scolar, Scopus, Web of Science and ScienceDirect) were filled with the most important keywords. Keyword search is preferred over journal search because no single journal would cover the broad research topic (Bell et al., 2018).

The main keywords are 'contractor', 'zero-emission', 'decarbonisation', 'carbon neutral' , 'fossil-free' , 'CO2 reduction', 'transition', 'construction site', 'construction logistics', 'construction equipment', 'infrastructure',

’innovation in construction’, ’sustainable procurement’ and ‘green public procurement’.

Outcomes of articles were downloaded and named accordingly. Articles were read carefully and irrelevant articles were excluded. The remaining articles were be sorted by author, location, methodology, limitations and intended use. During the literature review the table was updated frequently and new articles were be included, or less relevant ones were be excluded. This process kept going on parallel to case study research. This eventually led to a broad overview of the most relevant body of literature for this study.

The literature list with scientific articles used in this study is demonstrated in Appendix B. The various headings in the literature list are particularly linked to the three different perspectives of the research (government, contractor and technology & innovation) and the main subject of this research (zero-emission construction sites). The literature list starts with a few general articles. Thereafter, articles that form the foundation of literature for zero-emission construction sites are demonstrated. These articles are under put under the heading: ’low or zero-emission construction sites’ and ’emission reduction in construction’. Articles related to the contractor perspective can be found under the heading ’contractor behaviour’. The governmental articles can be found under heading ’procurement by governments’ Furthermore, there are articles that are related to the technology & innovation theme which are named as ’innovation in the construction industry’. Lastly, the articles used to design the research methodology are included in a separate heading.

3.3. Case study research

3.3.1. Selection of research design

Yin (2014) described five different methods to conduct research: archival analysis, history, experiment, survey and case study. Choosing the best method highly depends on the research questions of a study (Yin, 2014). This research has no control over behavioural events and will be focused on contemporary events rather then historical events. Then the only two remaining methods are a survey or case study. This means that the suggested approach would be a case study, survey or both. However, the case study approach has been chosen for several reasons.

Firstly, the case study approach was chosen for this research because this method provides rich qualitative and detailed information. Qualitative research provides in-depth understanding of complex issues and new topics (Bryman, 2012; Hennink et al., 2020). It also allows analysts to work close with data sources (interviews) which enables to help unfold unexpected findings over a period of time. Qualitative research helps to better understand rather than explain. This makes qualitative research the appropriate strategy for this study, which aimed to understand the potential of contractors to accelerate the transition towards zero-emission construction sites.

Secondly, the case study approach provided an in-depth understanding within the real-world context of the practise of emission-reductions at construction sites. This gave insights in the struggles of people in real projects. The case study method is especially useful when the boundaries between the context and phenomenon are not evident (Dubois & Gadde, 2002a). Case studies have an multi-sided approach that could shed light on particular aspects of human behaviour and thinking that would be impractical to study in other ways (McLeod, 2019).

Lastly, the number of available projects with the purpose to reduce emissions at the construction site was limited. It would have been time consuming to find other projects and resources to arrange a survey and could not be achieved within the time span of this project. Since the theme was the potential of contractors to accelerate the reduction of emissions at construction sites, employing a case study with a number of projects was necessary to understand what it takes for contractors to achieve emission reduction measures.

The nature of the case study was a single-case design. A single-case design is justifiable over a multiple-case design under certain conditions (Yin, 2014). The chosen case is claimed to relevant, because contractors that work actively to reduce emissions at construction sites were not available nor common years ago. A multiple-case may have been the preferred option, due to the analytical benefits that are more powerful compared to a single-case design (Yin, 2014). However, multiple cases are recommended when enough resources are available (Yin, 2014). Dubois & Gadde (2002a) claim that increasing the number of cases leads to less depth, but more breath. With the time span and availability of resources (e.g. amount of research participants) in consideration, the single-case desgin was the option that is favoured.

The method of research was a single-case with multiple units of analysis. This is called an embedded single-case design and is demonstrated in figure 4.1.

The choice for Ballast Nedam as main case for this research is important to understand. In the year 2020 Ballast Nedam signed the Paris Proof Commitment in which it promises to actually reduce emissions on construction sites (Ballast Nedam, 2020). Additionally, Ballast Nedam committed to "De Groene Koers" and "Emissieloos Netwerk Infra" in which the construction sector works towards the use and development of more zero-emission construction machinery. This case study provides the opportunity to analyse and observe their methodology in preparation to target emission reduction at construction sites. This makes Ballast Nedam an attractive case for research purposes.

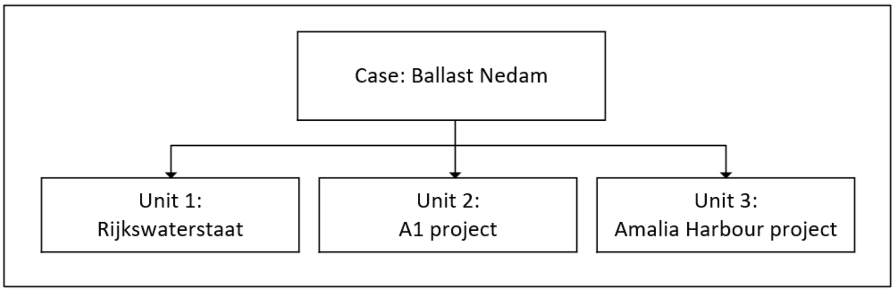


Figure 3.1: Embedded single-case desgin

Within the main case Ballast Nedam as contractor, the study was be based on three units of analysis. These units of analysis are Ballast Nedam's main client and two of Ballast Nedam's infrastructure projects:

- Unit 1: Ballast Nedams's main client: Rijkswaterstaat
- Unit 2: Ballast Nedam's project: Widening the A1 highway Apeldoorn-Azelo phase II: Apeldoorn - Twello
- Unit 3: Ballast Nedam's project: Quay wall construction Amalia Harbour

It is important to understand why these three particular projects were chosen as units of analysis. The first unit of analysis was Ballast Nedam's main client for infrastructural works: Rijkswaterstaat. The projects that Rijkswaterstaat put on the market play a significant role for contractors as Ballast Nedam. To better understand the transition towards zero-emission construction sites it is crucial to know the strategy and behaviour of Rijkswaterstaat concerning this particular subject. Contractors are largely dependant on their client needs and projects, as it is their core business.

The second and third unit of Analysis were Ballast Nedam's projects. The main requirement that both projects had to fulfil was a dominant existence of sustainability requirements in the tenders concerning the execution phase of the projects. These requirement had to concern emission reduction at the construction sites of the projects. The other requirement was that both projects had to be Dutch infrastructure projects. Different features of both units makes them complementary to provide greater insights in the barriers and opportunities that exist in the cases. One of these features is for instance the difference in client, which are Rijkswaterstaat and the Port of Rotterdam Authority. The second unit of analysis is currently in the tender phase. The third unit of analysis is a tender that has already been awarded to Ballast Nedam. Both projects are not yet executed.

The purpose of the case study was to find out how contractors can accelerate the transition and achieve emission reduction at construction sites. The units of analysis helped to determine if current emission reduction opportunities were being exploited and which barriers exist for contractors to lower emissions at construction sites. Additionally, the way that the contractor gave substance to the sustainability requirements and the way that the clients interpreted their projects will be considered. Relevant actors were be interviewed about the way they dealt with the sustainability requirements in the tender, particularly focused on emissions during construction. The choice of respondents was based on the theoretical background. Respondents were chosen from each perspective from the multi-level perspective (government, contractor and technology & innovation). This shed light on the aspects that went wrong and right in this process and resulted in the main barriers and drivers in the projects. They were asked about the lessons that can be learnt from these particular projects.

3.3.2. Selection of interview type

There are three different types of interviews: resume=,

1. Unstructured: This format does not involve structured questions, which leads to an open and free-flowing conversation. The interview is shaped by the spontaneous interaction of the respondents and the researcher (Creswell et al., 2007).
2. Structured: This format involves predetermined and structured questions. All respondents receive the same open-ended questions (Turner III, 2010).
3. Semi-structured: This format also involves predetermined, open-ended questions. Additional questions may arise from the conversation between the interviewer and the respondent (DiCicco-Bloom & Crabtree, 2006).

The semi-structured interview combined the best of both features of the structured and unstructured type of interviews (DiCicco-Bloom & Crabtree, 2006). The semi-structured interview ensured that the main topics of focus are covered while the possibility to steer the interview in other directions still remained present. It also allowed the the responses of the interviewees to be unbiased. The semi-structured interview type was deemed to be the most suitable for this study and was therefore selected.

Choosing the unstructured interview type would have resulted in inconsistent interviews (Wildemuth, 2016). This makes it hard to analyse obtained data and would make an unreliable choice (Creswell et al., 2007). The exploratory nature of this research also makes the structured interview type not suitable for this study because empirical data from the case study not exactly determined and known beforehand (Turner III, 2010).

3.3.3. Selection of interview questions

Two different types of interviews were conducted: strategic-level and project-level interviews. In the strategic-level interviews, questions were more strategically oriented, with a higher level of abstraction. In the project-level interviews, questions were specifically focused on the case study projects. The literature study and theoretical framework formed the basis in the formulation of the interview questions and inspired the researcher to ask certain questions. Questions were be asked about different themes: barriers and drivers, transitions, innovations, legislation, contracts and procurement, cooperation and financial investments. The full interview protocol is demonstrated in Appendix C

McNamara (2009) described five recommendations for effective interview questions. For the interviews, it is important to make sure that: resume=,

1. All wording is open-ended
2. Questions are phrased as neutral as possible
3. Questions are asked only once
4. Questions are worded unambiguously
5. “Why”-questions are asked tentatively

The interview questions followed these recommendations. Respondents answers were not be steered into certain directions. However, when the respondent was not able to provide an answer, they were asked if they recognise proposed opportunities to accelerate the transition towards zero-emission construction sites.

The interviews were transcribed from audio recordings and were conducted in the Dutch language. The time of each interview took approximately one hour. To describe the respondents answers concise and clear some paraphrasing was necessary.

3.3.4. Selection of respondents

The interviewees were categorized in three different response groups. These response groups are based on the different perspectives from the theoretical multi-level perspective. These groups are demonstrated in table 3.1.

Table 3.1: Description of respondent groups

Respondent group	Description
A	Client
B	Contractor
C	Other construction industry stakeholders (sub-contractor, consultant and developer)

Group A consisted of respondents from Rijkswaterstaat that are involved with the topic of zero-emission construction sites from the perspective of the client. Rijkswaterstaat is governmental and represents the marco-level in the theoretical framework. Group B consisted of respondents from Ballast Nedam that were both related and not related to the case study project from a contractor perspective. This group corresponds to the contractor perspective which represents the conceptual regime level. Group C consisted of a sub-contractor, project developer and consultancy firm. The sub-contractor represents the technology & innovation perspective which are the conceptual niche-innovations in the theoretical framework. sub-contractors are directly related to the niche-innovations because they are the second-last actor in the contractor supply chain. Manufacturers are not explicitly considered in this research.

3.3.5. Selection of data processing method

The selected data processing method for this study was Bryman's four stages of qualitative analysis (Bryman & Burgess, 2002). The four stages of this data analysis method were followed:

- Stage 1: Read the whole text and make notes at the end. Look what the data is about and discover the major themes. Search for unusual issues and events.

- Stage 2: Read the data again. Mark the text and make marginal notes. Highlight key words and identify labels for coding. These labels tell what the piece of data is about. Also note suggested analytic ideas.

- Stage 3: Code the text. Systematically mark the data so that every label of a certain theme is now coded. Indicate what the chucks of text are about. Review the codes and eliminate repetition and similar codes. Also think of groupings. Some codes may naturally come together and are examples of different ways of doing something or different places where something appeared.

- Stage 4: Relate general theoretical ideas to the text. Doing the coding is only part the the analysis. After the coding, add your interpretation. Start asking questions about relationships and key ideas that come out. Identify the significant codes of all the coded data. Look for interconnections between codes. The last step is to relate the codes to the research question and research literature.

3.3.6. Participant Observation

The method of Participant Observation (PO) was used within the case study context. In this research method, the researcher becomes an active part of the object of study: 'fly on the wall'. The researcher listens, observes, and conducts informal conversations (Spradley, 2016). The level of involvement stayed limited to passive participation, where the researcher is only in a bystander role.

3.3.7. Focus Group

To validate the results of the research, a focus group was organised. A group of five industry practitioners was selected to discuss the validity of the results. An overview of the focus group participants is demonstrated in Appendix D, Table D.2. Only one of the participants was interviewed before. During the focus group, a recap of the study was given, followed by a presentation of the main results. Some bold statements were made, with the aim to initiate discussion between the focus group participants. The findings were mostly agreed with and well-received by the industry practitioners. Only a couple of refinements and additions were mentioned, which led to only small adjustments to the research results.

3.3.8. Case study limitations

While there were many benefits of doing a case study research, there are some limitations to this research approach (Yin Robert, 1994; McLeod, 2019).

- Lacking scientific rigour and results give little basis for generalization to the wider target population - Conclusions that are drawn from particular cases may not be applicable to other settings. Case studies deal with only a selective amount of persons events or groups. Analysts can never be sure if the particular investigation is representative to wider instances.
- Unmanageable level of effort and time consuming - The volume of data and the time restrictions in place will impact the depth of analysis that is possible within the available resources.
- Difficult to replicate - The replication of case studies is extremely difficult because the data in the original study will never perfectly match in follow up studies.
- Researchers' subjective feeling could influence the case study (researcher bias) - Case studies are based on qualitative data. The analysis of descriptive data could depend on the researchers interpretation of the acquired information.

With the choice to limit the research to a strategic level of depth, these limitations are considered to be acceptable.

4
Case study

4.1. Introduction

The execution of the case study research is elaborated in this chapter. The case study is demonstrated in figure 4.1

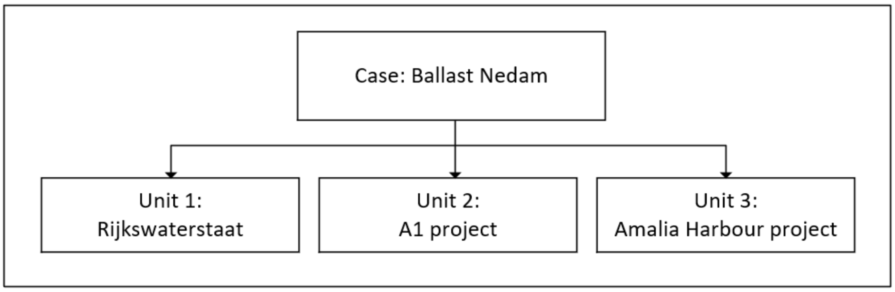


Figure 4.1: Embedded single-case desgin

The case study about the contractor Ballast Nedam consisted of three main unit's of analysis:

- Case study unit 1: Ballast Nedam's main client: Rijkswaterstaat
- Case study unit 2: Ballast Nedam's A1 Highway project
- Case Study unit 3: Ballast Nedam's Amalia Harbour project

The case study starts by describing Ballast Nedam's general view on sustainability by introducing their policy on zero-emission construction sites and logistics. Thereafter, the view of Ballast Nedam's main client - Rijkswaterstaat - is elaborated. Their approach to reach zero-emission construction sites was described.

The case study research was continued in confidential appendix **??**, since the projects are still in development and in the tender phase. In this appendix the A1 highway project and Amalia Harbour project were described. Appendix **??** ends with an analysis of the case study results. In this analysis the two projects were compared against the theoretical framework, and compared against each other. Some of the results of this research are elaborated in the next chapter.

4.1.1. Data

The case study data was obtained through a combination of desk research, meeting notes and semi-structured interviews. All the secondary data was obtained from literature.

4.2. Ballast Nedam

4.2.1. Actor introduction

Ballast Nedam is a Dutch contractor. The company resulted from a merger between Turkish construction company Renaissance Construction. As a construction and development company, Ballast Nedam works on a future-proof living environment. Main projects are buildings, roads, tunnels, bridges, hospitals, airports and harbours. This varies from small-scale projects to large infrastructure projects.

4.2.2. Ballast Nedam's policy

Corporate Social Responsibility (CSR)

The CSR policy aligns the core values of Ballast Nedam with the Sustainable Development Goals (SDGs) of the United Nations (UN). These SDGs include 17 world goals that strive to make the earth a fair, healthy and safe working and living space for everyone in 2030. One of these themes is 'Environment and Sustainability'.

Ballast Nedam follows several covenants, codes of conduct, guidelines and certificates. Examples of these are the CO2 Aware certification and the IFC Performance Standards on Environmental and Social Sustainability.

Energy, Air Quality and CO2

The goal of Ballast Nedam's energy policy is to achieve more energy-efficient and sustainable operations over the next few years. For its long-term objective for 2030, Ballast Nedam set 2019 as a reference year.

This target involves their CO2 emissions (scope 1 and 2) from energy use at the office (heating, cooling and electricity), at their production and construction sites (gas, electricity and diesel) and for mobility (diesel, CNG and petrol).

The target for scope 1 (natural gas, diesel and other fuels) is a 100% CO2 reduction compared to 2019. For scope 2 (electricity, district heating and air traffic), Ballast Nedam is also aiming to become completely CO2 neutral (i.e. 100% CO2 reduction). Scope 3 includes purchase and sale of products and services. In line with this, Ballast Nedam has set a target for the CO2 emissions that are generated by all their activities. They use a lifecycle analysis (LCA) to determine the environmental impact of products and services. One of their reduction targets for 2020, was to perform LCAs together with their suppliers/subcontractors for at least three products. Collaboration with the chains in which they are active is required to achieve concrete ways in which consumption can be reduced.

Ballast Nedam wants to improve their energy performance by:

- Acquiring projects which strongly focus on sustainability and reduction of CO2 emissions as an award criterion, as well as projects which have a LEED, BREEAM or CO2 Aware certification;
- 100% green electricity for all Ballast Nedam connections as of 2021;
- Realising a CO2 neutral construction site by 2023 and fully CO2 neutral construction sites by 2030;
- All electric vehicle fleet by 2030;
- CO2 neutral company vans by 2030
- Using as much CO2 emission-free machinery as possible;
- Compensating for the CO2 emissions from flights

Where it is not possible to be completely CO2 neutral by 2030, e.g. for heavy machinery, there will be compensation. For Ballast Nedam, the main opportunities are the reduction of CO2 emissions of its fleet and the implementation of sustainability measures on construction sites.

Construction sites

Ballast Nedam focuses on sustainability measures on the construction site itself to reduce their footprint. Their goal is to achieve carbon neutral construction sites in 2030. This will be achieved by investing in sustainable construction chains and making their machinery more sustainable. In order to make their machinery more sustainable, Ballast Nedam will draw up a roadmap that focuses on the electrification of their machinery, or the use of HVO fuels for machinery for which electrification is not yet possible. Together with De Groene Koers and the ENI (Emissieloos Netwerk Infrastructuur), Ballast Nedam works on initiatives to make heavier machinery more sustainable as well. For the construction chain, Ballast Nedam invests in more sustainable units with high insulation, double glazing, light sensors, LED fixtures and a sustainable heat pump for cooling and heating. Of all units, 15%-20% have been disposed of and replaced by these more sustainable units.

At the moment, these targets are comparable to those of other companies in the sector. Ballast Nedam views itself as an average player when it comes to reducing CO2 emissions. Their aim, however, is to belong to the top of the Netherlands' most sustainable companies.

Steps that contractors can take towards CO2 neutrality are visually demonstrated in figure 4.2.

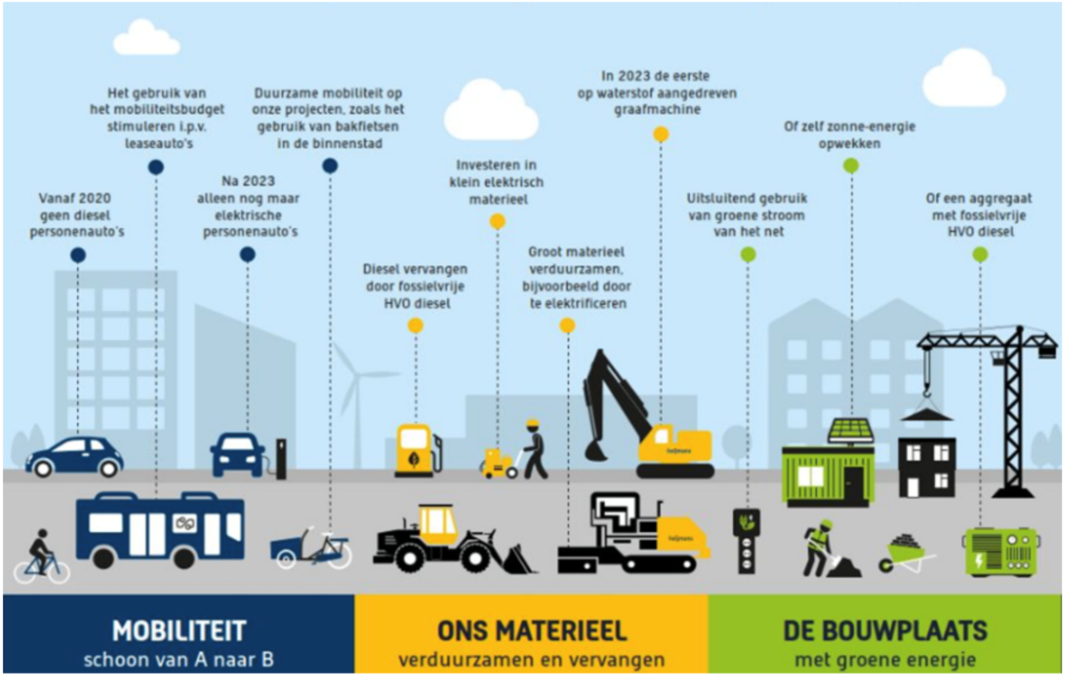


Figure 4.2: Disclaimer: this figure is not Ballast Nedam's property. It visually demonstrates steps that all contractors can take towards CO2 neutrality (Heijmans, 2021).

Mobility
In 2021, Ballast Nedam is facing a major challenge to replace their vehicle fleet. The choice for an all-electric option will be included per lease category. In regard to this, the charging facilities will be reviewed, which demands an expansion of charging facilities at both the offices and the constructions sites.

Innovation
Ballast Nedam sees itself as an average player when it comes to reducing energy consumption. But when it comes to the development and engineering of affordable sustainable energy systems, Ballast Nedam regards itself to be a leader in the field. Ballast Nedam has always been one of the innovators in the market regarding the adaption and development of ‘new’ fuels. In particular, Ballast Nedam was one of the pioneers in the development and construction of CNG, LNG and hydrogen stations in the Netherlands. Currently, Ballast Nedam is working on three hydrogen stations across the Netherlands and Belgium, and thus contributes to the acceleration of the energy transition.

Summary policy
Ballast Nedam’s ambitions are 100% reduction in CO2 emissions by 2030. In 2023, Ballast Nedam wants to carry out the first work with a fully CO2 neutral construction site. This does not only apply to energy consumption, but also to working with recycled materials and raw materials and as much electrical (heavy) machinery as possible. In 2022, Ballast Nedam will be working entirely with Dutch green energy. The goal of having at least 4% of its leased vehicles running on electric power has already been achieved. Ultimately, Ballast Nedam’s vehicle fleet will be completely electric

4.3. Rijkswaterstaat

4.3.1. Actor introduction

Rijkswaterstaat is the largest client providing tenders for infrastructural work for contractors such as Ballast Nedam. Rijkswaterstaat operates as the executive organisation of the Dutch Ministry of Infrastructure and Watermanagement. Rijkswaterstaat is the main client for 25% of the GWW sector, which makes them a major player in the Dutch construction sector. Each year, Rijkswaterstaat spends 4 billion euro on Dutch infrastructure. With this responsibility they have an enormous opportunity to reduce climate impact through their procurement strategy.

4.3.2. Strategy KCI

The KCI strategy (Dutch: naar klimaatneutrale en circulaire rijksinfraprojecten) is an initiative of the Ministry of Infrastructure and Water Management in which Rijkswaterstaat and ProRail are involved. The KCI roadmap will be exactly the same as that of the SEB (Schoon en Emissieloos Bouwen) initiative. For the construction site and construction logistics, these initiatives are working together to develop a joint roadmap

Figure 4.3 gives an impression of the transition path for construction sites and construction logistics developed by the Dutch government.

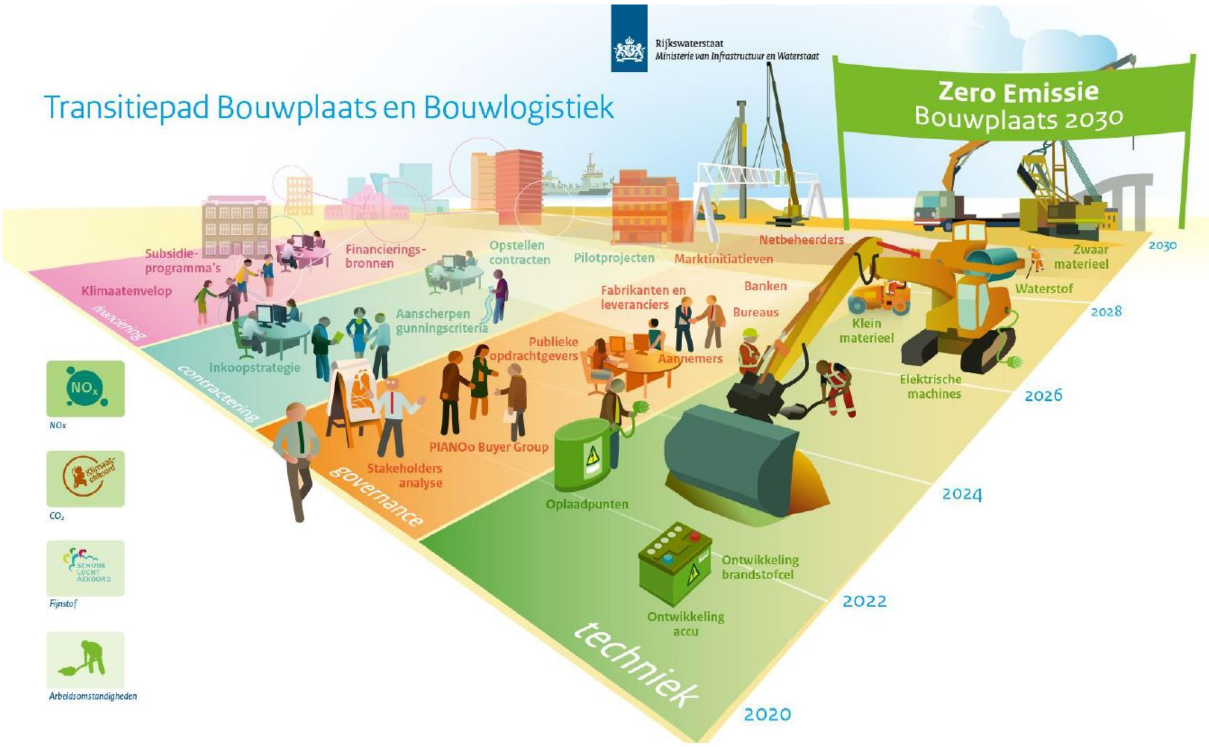


Figure 4.3: Transition path zero-emission construction sites and construction logistics (Ministerie van Infrastructuur en Waterstaat, 2021)

As the figure shows, the playing field is complex. The ultimate goal is to accomplish zero-emission construction sites by 2030. The government aims to achieve this through the four tracks of governance, financing, contracting and technology. This transition path contributes to several policy areas; the nitrogen problem, climate targets, Schone Lucht Akkoord, and the goals of the Inspectorate SZW which is working to eliminate carcinogenic substances from construction sites. A DME (diesel engine emissions) directive has already been issued and will be enforced. With this transition Path, Rijkswaterstaat will have to deal with all kinds of technology, various stakeholders and market initiatives.

Figure 4.4 demonstrates a more detailed vision of the transition path elements in time.

This main elements for the construction site and construction logistics are:

- Construction machinery (shovels, cranes, pile drivers, aggregates etc.)
- Transport (on the construction site and the road)
- Optimisation of soil and material flows

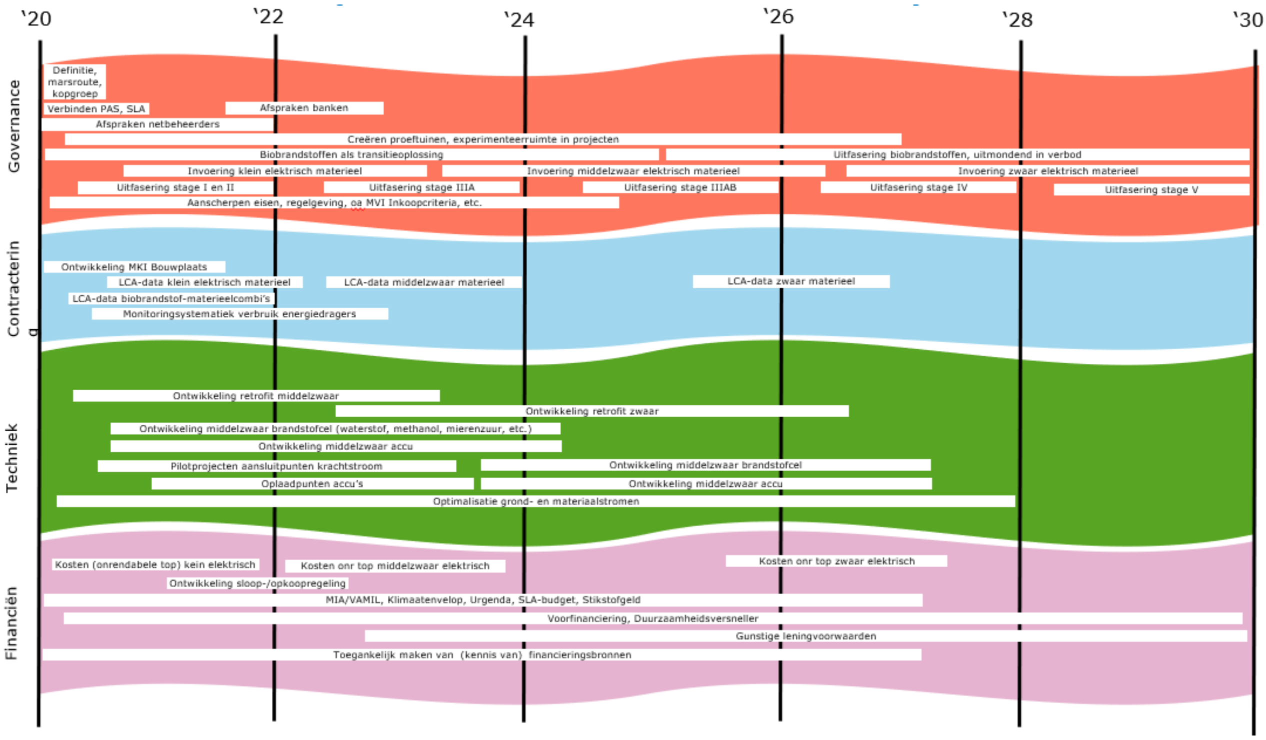


Figure 4.4: Transition path to zero-emission construction sites in 2030 formulated by Rijkswaterstaat (Rijkswaterstaat, 2020)

The main elements of transition paths consist of:

- Bio-fuels as a temporary transition solution
- Step-by-step introduction of small, medium and heavy electric machinery
- Development of retrofit in medium heavy and heavy machinery
- Development of fuel-cells

The targets agreed between the government and the construction sector are enormous. The goals is 0.4 Mton CO2 reduction (compared to 2019). Currently, 0.7 Megaton CO2 emissions occur in the infrastructure projects of the Ministry of Infrastructure and Water Management. For the Schone Lucht Akkoord the goal is to achieve 75% health gain for mobile machinery. The aim of the Aanpak Stikstof is a 60% reduction in nitrogen emissions. The ambition of the KCI strategy is to be fully climate neutral and circular by 2030.

Currently, there are 150,000 mobile machines in the Netherlands. If these all have to be de-fossilised by 2030, this is a huge challenge. At the moment, the biggest challenges are:

- The technology is still under development
- High investment costs for market parties who want to replace their equipment now. Ultimately, this has to become part of the market's own earnings model. The market will have to incorporate this into their own business cases.
- The production capacity of zero-emission equipment is still limited. For now, this is a major limitation, which must be overcome.
- There are still too few charging facilities at the construction sites. It is an important prerequisite that enough power is made available there for electrical equipment.
- International cooperation is needed to make this a robust and sustainable transition. The Dutch market is actually very small for international manufacturers.

Despite these challenges, the government says: we have to work emission-free by 2030. The government sets the bar high and hopes that everyone is willing to contribute.

The government can contribute positively to the transition path in various ways:

- Contract requirements and award criteria
- Pilot projects
- Subsidies
- Legislation and regulations

The governments' contributions take shape in the four different tracks: governance, technology, contracting & procurement and financing.

Governance

The government is in the process of aligning the transition path with the policy areas. The governance track ensures that all stakeholders are properly involved in this transition. There are many stakeholders involved in this transition. An overview of the supply chain is shown in figure 4.5.

Figure 4.5: Stakeholders in the construction sector (SEB, 2021)

The main actors in the supply chain are:

- Mobile machinery and construction logistics chain: equipment manufacturers/suppliers, leasing/rental companies, contractors and clients GWW (and B&U).
- Facilitating parties: funders, charging and fuelling infrastructure companies and network operators.
- Knowledge, policy and interest groups: branch organisations for construction and equipment, knowledge partners, umbrella organisations and the government.

There are also less obvious players among them, such as grid operators. Banks and leasing and rental companies can also play a major role here. For SMEs, the route via the rental companies will become a very attractive option. In this way, SMEs do not have to make high investment costs, but can benefit from the equipment that is already available.

Another important element is the investment in knowledge and innovation development. Innovation is necessary, because the current solutions will only suffice for half of the goals that are set. This is the reason why Rijkswaterstaat invests in knowledge development and research, together with the technical universities. They also increasingly work with companies on innovation development, using instruments such as the

Innovatiepartnerschap (Innovation Partnership) and the Small Business Innovation Request (SBIR). In this context, Rijkswaterstaat acts as launching customer. This means they are the first to buy an innovation.

The government must invest even more in getting knowledge organisations on board. International co-operation is also part of the governance track. The Dutch government is already affiliated with a number of international activities. So this is already beginning to take shape.

“Ultimately, it is up to contractors to decide how they want to arrange emission-free machines and energy supplies. We are happy to think along and to help with the preparation and to make the right preconditions available. For example, by checking whether it is possible to arrange permits in advance. Or by making agreements with grid operators" (Rijkswaterstaat, 2019).

Technology

The government has to deal with technology that is still highly in development. In practice, it will come down to the government making use of a combination of a number of measures:

- Electrification of mobile machinery and transport. This will be an important part of the transition.
- A charging infrastructure is required to power mobile machinery on site. This charging infrastructure is a prerequisite.
- A great deal of CO2 reduction can already be achieved with the use of biofuels. This is a short-term solution, with a number of drawbacks. Combustion engines continue to work and emissions cannot be reduced to 100%. This Is why biofuels are an intermediate solution. The government would like to discuss with the market how this can best be done and how they can make optimal use of it.
- Hybrid solutions are applied
- Optimising construction logistics (soil and material flows). By reducing transport movements and the handling of material, energy can be saved. The less machinery is needed, the fewer emissions there will be.

Contracting & Procurement

For the implementation of the track contracting and procurement, the government will consider a number of scenarios.

- Scenario 1: Autonomous development. This is part of the current strategy as it stands.
- Scenario 2: Growth path. This is the more realistic scenario. This scenario makes use of the financial resources that are currently being promised by the Ministry. It considers the various policy interventions. Here, it is also necessary to make agreement with other authorities to ask for the same ambition.
- Scenario 3: Maximum feasible variant; this requires a system shift. This is the other extreme. If the construction site is to become 100% emission-free, a system shift must be made. This scenario explores what that would look like.

The government has developed a system dynamic model. This can be used to calculate the different scenarios and asses the results. This will result in an assessment of the most effective interventions. This model will play an important role in the continuation of the drafting of the roadmap.

The procurement strategy consists of three parts.

- The inclusion of emission/free work in the contract requirements. The relevant questions here are: what can the market already do? What can be asked from them? This is an ongoing process and not a static concept. Consideration is being given to how the government can tighten this up over the years. This will result in emission-free work being a logical fact for all parties and part of the standard working.
- Calling for tenders via award criteria. The work will be carried out partly via the requirements and partly via the award criteria. The MKI will play an important role in this. The government is busy giving emission-free equipment a good place in this. The national environmental database, which forms the basis of MKI calculations, will be expanded and supplemented with data on emission-free equipment.

> "It is also important that a good procurement strategy is developed in consultation with other authorities. We follow developments closely, so that we know what is technically feasible and what equipment is available. In tenders, this allows us to set firm but feasible requirements that do no not frustrate the market."

- In a number of projects it is the aim to adopt a frontrunner approach. In these projects, the market will be challenged as much as possible. For example, these are projects (or parts of projects) that the government puts on the market 100% emission-free. The market is being told: only tender if your project is carried out 100% emission-free. In projects, Rijkswaterstaat offers competitive advantage if it is possible to achieve a lower MKI value. If that proves feasible, such a value is made a requirement for other projects. In addition, they award leaders in the field of sustainability. It is important that parties are given equal chances, but it must also be worthwhile for market parties to really invest in new solutions. That is why Rijkswaterstaat applies a pioneer approach that rewards companies that are really able to offer more sustainable projects. Time will tell how the government will interpret this further in the future.

The government has also already started the *PIANOo Buyer Group Zero Emissie Bouwplateriaal* in which the government works with a number of public clients to implement this procurement strategy. In this process, the experiences of commissioning parties are being bundled. This has already been tried out in various tenders to see what works and what does not. In the Buyer Group, a focus group has been set up in which a number of market parties also participate. In this focus group, the Buyer Group discusses with the sector how it views the developments of the procurement strategy. Municipalities, provinces and water boards are also part of the Buyer Group.

Financing
The transition path will have to be paid for. The government will need to know what the actual costs are. Because the technology is still being developed, in many cases the government does not know exactly what the costs will be. However, TNO has carried out an update of the cost curves for the construction site and construction logistics. This research has brought forth interesting and remarkable results and gives more grip on the question what the costs will be. This results in the smartest packages of measures to achieve a certain objective. This is what TNO has been calculating and they have come up with very specific data.

The other question is: how will the government cover all these costs? Money will be made available by the Ministry. In 2021, a start has already been made on financing the additional costs of deploying emission-free equipment in a number of project. The Ministry of Infrastructure and Water Management has made 42.5 million euros available for this purpose. This money has been put aside in a number of projects by Rijkswaterstaat, of which 7.5 million euros were for projects by Prorail. "We also help by communicating that government budgets for nitrogen policy will become available for the construction sector. And by talking to investors, to stimulate them to come up with lease constructions for the expensive electrical equipment, for example." This is going to be an amount of two times 500 million euros. The way in which this will be channelled to the market is still under discussion. This will be partly via a subsidy scheme, which can be accessed directly by the contracting industry via the RVO. Partly, it will be made available by the contracting authorities; the Central Government Real Estate Agency, ProRail and Rijkswaterstaat. In this way, the remaining additional costs can be recovered through the projects as contracting party.

Money is also used for the means of innovation and knowledge development. The question is whether this is sufficient. However, there are also other forms of financing. These could be EU subsidies, for example. In the government's view, it is important for the rental market to step in, and that there is cooperation in the purchase of emission-free equipment. A number of banks have also already set up a leasing branch where concrete initiatives are taken with regard to the purchase and leasing of emission-free equipment.

4.3.3. Roadmap
The roadmap will be created by the Dutch Ministry of Infrastructure and Water Management, Rijkswaterstaat and Prorail. The purpose of the roadmap is:

- To describe conditions that are needed to achieve the ultimate goal, such as knowledge and innovation.
- For governments, the roadmaps provide insight into the measures and policy options needed to realise their ambitions.

- For the market, the roadmaps wil indicate the pace and direction of the transition.

The roadmaps set out intermediate goals, which are put into practice in, for example, award criteria and contract requirements. The tenders of Rijkswaterstaat are integrally geared towards sustainability, by applying the Milieu Kosten Indicator (MKI). The MKI consists of 13 different components that provide information on the environmental impact of a project.
The main points of the four tracks (governance, technology, contracting & procurmenent and financing) form the basis of the roadmap. The government will work to make these points concrete in the coming years. It is important to make sufficient progress and to do things in the right order. If there is sufficient cohesion between the main points, the desired goal will be reached in 2030. Until then, the government will also enter into discussion with market parties. At the end of 2021, the decision-making process will start. It will then be reviewed whether it can all be realised and whether the plans can be signed. After that, further optimisation will still be an ongoing process. So far, the policy of Rijkswaterstaat.

4.4. Ballast Nedam's Projects

The case study research about Ballast Nedam's A1 highway project and Amalia Harbour project are described in confidential appendix **??**.

5

Results

5.1. Introduction

This chapter presents the results of this research. These results were obtained through the case study research in the previous chapter. The case study research was founded on semi-structured interviews, desk research and participant observation meeting notes. Thirteen interviews were conducted with representatives from Rijkswaterstaat as client, Ballast Nedam as contractor, a sub-contractor, consultant and developer. The full list of respondents is demonstrated in Appendix D.

This chapter starts by answering the first sub-question, which aims to identify barriers that slow down the transition towards zero-emission construction sites. Thereafter, the second sub-question was answered which aimed to identify drivers that accelerate the transition towards zero-emission construction sites. Lastly, the third research question is answered where - based on the previous two sub-questions and the theoretical framework - a actions for acceleration were developed. By answering these sub-questions, an answer on the main research question was obtained. The results provide insight into what internally drives contractors and what governments can do to externally facilitate, stimulate or enforce private emission reduction behaviour.

Figure 5.1 demonstrates the data saturation that was reached during the interviews. In this figure, the number of new codes is plotted against the number of conducted interviews. The figure demonstrates that interview saturation was reached after doing eleven interviews. Thereafter, the next interviews did not lead to any more new codes. It is important to note that the interview questions did not change over time. Wile doing the research, the researcher could have gone into more depth while improving the knowledge on the topic during the interviews. This could have led to asking different kinds of questions, with the consequence that the saturation might have changed. However, with these specific and interview questions and type of interviewees, it seems that saturation was reached.

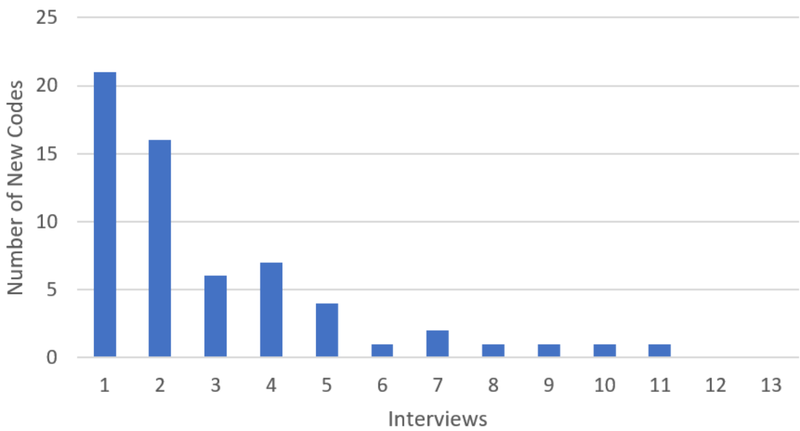


Figure 5.1: Data saturation

5.2. Barriers

This section aims to answer the first sub-question:

Which barriers slow down the transition towards zero-emission construction sites?

Firstly, section 5.2.1 describes the barriers that were found from a government perspective. Secondly, section 5.2.2 describes the barriers from the contractor perspective. Lastly, the technology & innovation perspective was covered in section 5.2.3.

5.2.1. Government

Interviews were analysed to investigate which barriers slow down the transition towards zero-emission construction sites from a government perspective. Table 5.1 shows an overview of the main barriers that slow down the transition from the government perspective.

Table 5.1: Main barriers that slow down the transition from the government perspective, sorted by occurrence in interviews (n=13)

No.	Barrier	Category	Interview reference(s)
1.	Lack of international collaboration	Institutional/regulatory	A1, A3, A4, B4, C3 (38%)
2.	Absence of clear vision	Social/cultural	A4, B1, B2, C2 (31%)
3.	Not enough priority in tenders	Institutional/regulatory	B1, B2, B3, B4 (31%)
4.	Procurement limited by technology	Technological	A1, A2, A3, A4 (31%)
5.	No short term clarity towards the market	Economic/financial/market	B3, C1, C3 (23%)
6.	Ensuring a level-playing field	Economic/financial/market	A2, B3, C1 (23%)
7.	Limited budget	Economic/financial/market	A3, A4, C1 (23%)
8.	Prescriptive contracts, limited design freedom	Institutional/regulatory	A4, B5, C1 (23%)
9.	Political dependence, trustworthiness	Institutional/regulatory	A2, A3, A4 (23%)
10.	Decentralized government differences	Institutional/regulatory	A3, B1, B2 (23%)
11.	Risk-averse attitude	Social/cultural	B2, B3 (15%)
12.	Absence of a clear financing strategy	Economic/financial/market	A4 (8%)

The results show that the lack of international collaboration is the barrier that was most often mentioned from a government perspective. International collaboration between European countries does take place, but on a too small a scale. "The Dutch market is relatively small. When the Netherlands increase their demand for zero-emission machinery, prices of large European manufacturers may not drop" (Respondent C2, personal communication, May 4, 2021). When the Dutch demand for zero-emission machines increases, it does not necessarily have to lead to an increased supply by worldwide orientated manufacturers.

Respondents also indicated there is an absence of a clear vision on zero-emission construction sites. "Within the government there is quite a lot of diversity in how they think about this transition" (Respondent B2, personal communication, April 23, 2021). Subsequently, this leads to the lack of a short term clarity towards the market. "Companies need clarity to make major investments" (Gehrels, 2021, as cited in Stooker, 2021). Currently, there is no short term clarity coming from the government, which slows down corporate investments due to uncertainties.

Also, respondents stated that sustainability has still not enough priority in Dutch public infrastructural tenders. Currently, only in 35% of the Dutch infrastructural tenders is sustainability a decisive factor (Rotmans, 2021). Despite the fact that sustainability requirements are becoming more important, many tenders are still focused on the criterion of the lowest price (Rotmans, 2021). It is notable that only contractor respondents perceived this as being a barrier, while respondents from the government did not share this perspective.

Furthermore, the procurement strategy of the government is hindered by technological constraints, such as the availability of zero-emission equipment and a technology that is still in development (Respondent A1, personal communication, 30 June 2021). This barrier was mentioned by all the government respondents and is considered to be of significant importance.

Another barrier mentioned by respondents was the preservation of a level-playing field. A government that starts rewarding frontrunners hinders the perception that there needs to be a level-playing field within the construction industry (Simons & Nijhof, 2021). Only contractors considered this as being a barrier coming from the government.

The government is also hindered by a limited budget and the absence of a clear financing strategy (Respondent A4, personal communication, 7 July 2021). There is no consensus which stakeholders need to contribute to which part of the necessary investments. Contractors are pointing towards the government to pay for the necessity investments in the transition. While the government expects initiative and financing from the private sector.

Prescriptive contracts with a limited design freedom were also considered to slow down the implementation of zero-emission innovations into projects. The case study harbour project revealed that contracts that are dictatorial in their design and way of building, offer less room to implement zero-emission innovations.

Another factor mentioned by respondents is the uncertainty caused by political dependency of public clients, like Rijkswaterstaat, that depend on political decisions on a national level. Respondents indicated that inconsistent policies lead to a decreased trustworthiness of public clients.

An additional barrier is the difference in sustainability ambition of the national government and decentralized governments. A respondent mentioned that larger clients, like Rijkswaterstaat, are often less progressive compared to smaller decentralized governments (Respondent B1, personal communication, June 16 2021). This makes it it unclear for contractors what to expect from clients on different governmental levels.

Lastly, the case study highway project revealed that the government acted with a risk-averse attitude, while tendering an innovative project, starting September 2022. (Respondent B2 & B3, personal communication, April 23 & 4 June 2021). They were not yet willing to take risks concerning the implementation of innovations that were not fully developed yet. This risk-averse attitude in the tender valuation contradicted with their progressive project ambition which slowed down the transition process.

5.2.2. Contractors

In this section the interview results are presented to investigate which barriers slow down the transition towards zero-emission construction sites from a contractor perspective. Table 5.2 shows an overview of these barriers resulting from the interview analysis.

Table 5.2: Main barriers that slow down the transition from the contractor perspective, sorted by occurrence in interviews (n=13)

No.	Barrier	Category	Interview reference(s)
1.	No positive business cases	Economic/financial/market	A1, A2, B2, B3, C1, C2, C3 (54%)
2.	Lack of (long-term) investment	Economic/financial/market	B1, B3, B4, B5, C1 (38%)
3.	Wait-and-see attitude	Social/cultural	A4, B1, C1, C3 (31%)
4.	Culture differences	Social/cultural	B1, B2, B5, B6 (31%)
5.	Overoptimism	Social/cultural	B1, B2, B5 (23%)
6.	Recoup investments on single project	Economic/financial/market	A4, B3 (15%)
7.	Lack of knowledge	Social/cultural	A4, C2 (15%)
8.	Contractor - client understanding	Social/cultural	B2, B3 (15%)
9.	Lack of awareness	Social/cultural	B2 (8%)
10.	Traditional client-contractor relation	Institutional/regulatory	A4 (8%)
11.	Internal resistance to change	Social/cultural	A4 (8%)

The results show that for contractors the absence of positive business cases is the barrier that was mentioned most often. Desk research also confirms that the market has not yet found suitable sustainable business models, while the transition to the next phase is already being made (Nijhof, 2021, as cited in P+: People Planet Profit, 2021). The majority of respondents indicated that they are trying to find a balance between the high costs of zero-emission equipment, which often seems unbalanced compared to the uncertain future benefits. Because of this, contractors do not make full use of the existing opportunities.

Subsequently, respondents indicated that there is a lack of long-term investment. Contractors are more focused on short term profits than on long-term investments. It was mentioned that unclarity about the policy implementations of the government and the rapid development of new technologies are factors causing a restraining investment attitude of contractors. Due to the high uncertainty in the developments of new technologies contractors often wait to make necessary investments. This leads to a wait-and-see attitude in which companies are waiting on the market to further develop instead of taking a lead role in starting the transition. This uncertainty also plays a role in the recoupment of investments (Respondent A4, personal communication, 6 April 2021). It was mentioned that investments in zero-emission equipment are difficult to recoup on a single project.

Respondents also indicated that the Netherlands is relatively progressive on the subject of emission reduction in construction, compared to other European countries. This hinders companies that are internationally oriented or have an international board with less progressive visions. "Companies experience culture differences in making investment decisions for emission reduction at construction sites" (Respondent B1, personal communication, 16 June 2021).

Another barrier that was mentioned was overoptimism. When implementing small changes, people in the work field often tend to think they are already doing a good job, while their actual impact is relatively small (Participant observation, February 17 2021). In that sense, overoptimism actually contributes to a slower pace of transition (Rotmans, 2021).

It was also indicated that contractors suffer from a lack of knowledge on the subject of zero-emission construction sites (Respondent A4 & C2, personal communication, July 7 & 28 June 2021). Desk research also confirmed that there is a structural lack of knowledge on sustainability of people working in the construction sector (Rotmans, 2021). Not only the actual knowledge, but also the awareness was a factor that was mentioned. "The management and board had little or no awareness of the fact that zero-emission construction sites and logistics would become so important in tenders" (Respondent B2, personal communication, 23 June 2021).

Also differences between contractor-client understanding play a role in slowing down the transition. "There is a large mismatch between the contractor and client in the expectations and vision in this transition" (Respondent B2, personal communication, 23 June 2021).

Another inhibiting factor seems to be the traditional division between the client and the contractor roles. That role is often still non-cooperative. While more cooperation initiatives are slowly emerging, in most infrastructural projects this traditional division between the client and contractor is still the same (Participant Observation, February 17 2021). The traditional division of roles between the client and the contractor, which is often non-cooperative, slows down the transition towards zero-emission construction sites (Respondent A4, personal communication, 7 July 2021).

Only one respondent mentioned that contractors experience an internal resistance to change. It was stated that there is a desire to stick to current ways of working and that contractors are not intrinsically motivated to incorporate zero-emission technologies into their standard business model. It is striking that this factor was only mentioned once, from a respondent that did not work for a contractor.

Particular barriers of the government, contractor and technology & innovation were found to be interconnected with a cause and effect link. The lack of clear vision and clarity towards the market from the government, is connected to the wait-and-see attitude of contractors. The results show that interviewees from the government and the contractor generally do not share the same vision. Both orientations prioritized different barriers that slow down the transition. This was found to be an inherent barrier in itself.

5.2.3. Technology & innovation

In the same way as the government and contractor perspective in the previous sections, interviews were analysed to investigate which barriers slow down the transition towards zero-emission construction sites from a technology & innovation perspective. Table 5.3 shows an overview of these barriers resulting from interview analysis.

Table 5.3: Main barriers that slow down the transition from the technology & innovation perspective, sorted by occurrence in interviews (n=13)

No.	Barrier	Category	Interview reference(s)
1.	Low availability	Technological	A1, A2, A3, A4, B1, B2, B6, C1, C2 (69%)
2.	Limited charging/fuel facilities	Technological	A1, A2, A3, B2, B3, B6, C3 (54%)
3.	High investment costs	Economic/financial/market	A1, A2, A3, B6, C1, C2, C3 (54%)
4.	Technology still in development	Technological	A1, A2, A3, B4, B6 (46%)
5.	Depreciation existing equipment	Economic/financial/market	A1, B2, B6, C3 (31%)
6.	Reaching economies of scale	Technological	B1, B3, C3 (23%)
7.	Retrofit is time consuming	Technological	B1 (8%)
8.	Technology choice	Technological	A4 (8%)

The barrier that was mentioned the most often is the low availability of zero-emission equipment. Desk research also confirmed that the industry needs to deal with the fact that there will only be a limited amount of zero-emission construction equipment available in the upcoming years (Emissieloos Netwerk Infra, 2020). This barrier was mentioned by many respondents and is considered to be of significant importance. Not only the availability of equipment, but also the limited charging/fuel facilities for electrical/hydrogen construction applications slows down the transition. It is a prerequisite that enough power is available to charge electrical equipment.

Besides the availability of equipment and charging facilities, also the costs of zero-emission alternatives are currently too high to be profitable compared to the existing machines functioning on fossil fuels (Aragonès & Serafimova, 2018). Many respondents considered this to be a significant barrier. The low availability and high investment costs are mainly caused by the fact that the zero-emission construction equipment is still in development and innovations are slowly introduced on the market.

Another barrier that was mentioned is the depreciation of existing equipment. Construction companies need to deal with the fact that their current machines still have a long period of depreciation. Usually, part of the regular construction machinery gets replaced after a period of six to eight years (or 10.000 working hours) (Emissieloos Netwerk Infra, 2020). "Normally contractors invest in one or two new pieces of equipment a year. Now contractors are forced to replace their entire machinery park in a couple of years" (Respondent B2, personal communication, 23 April 2021).

It was also mentioned that reaching economies of scale was an barrier in this transition. "There are many positive sustainable contributions on project-level, but no real progress is made on sector-level" (Rotmans, 2021). It is hard for small innovative sustainable initiatives to reach large economies of scale. Initiatives tend to stay at a niche or project level of application and not radically dominate the construction industry sector-wide (Rotmans, 2021).

Furthermore, most of the electric equipment is retrofit, because new equipment is not yet available (Respondent B1, 16 June 2021). Retrofitting an old piece of equipment is a time consuming process which contributes to the the slowness of transition.

Lastly, there is no clear direction or one obvious technical solution where a zero-emission construction site should be heading. Both electrification and the development of hydrogen have a potential of dominating the construction site in the future. This choice of technology causes uncertainty was mentioned as another restraint to start investing.

In contrast to the governmental and contractor barriers in the previous sections, the respondents generally agreed on most technological barriers. It is remarkable that there is consensus on this subject, while there is no agreement on role of the government and the contractor in the transition.

5.3. Drivers

This section aims to answer the second sub-question:

Which drivers accelerate the transition towards zero-emission construction sites?

Firstly, section 5.3.1 describes the drivers that were found from a government perspective. Secondly, section 5.3.2 describes the barriers from the contractor perspective. Lastly, the technology & innovation perspective was covered in section 5.3.3.

5.3.1. Government

The drivers from a government perspective are demonstrated in table 5.4.

Table 5.4: Main drivers that accelerate the transition from the government perspective, sorted by occurrence in interviews (n=13)

No.	Driver	Category	Interview reference(s)
1.	Award criteria	Incentives	A1, A2, A3, A4, B1, B2, B3, B4, B5, C1 (77%)
2.	Contract requirements	Enforcement	A1, A2, A3, A4, B1, B2, B3, B4 (62%)
3.	Subsidies	Incentives	A1, A2, A3, A4, B4, B6, C3 (54%)
4.	Reward frontrunners	Incentives	A1, A2, A3, A4, B1, B2 (46%)
5.	Public-private cooperation	Communication & Cooperation	A2, A4, B1, B4, C2 (38%)
6.	Supervision, monitoring	Enforcement	A1, A2, A3, B4, B5 (38%)
7.	International connections	Communication & Cooperation	A1, A2, A3, A4, C2 (38%)
8.	Programmatic procurement	Communication & Cooperation	A3, B2, B5, C1 (31%)
9.	Policy alignment	Communication & Cooperation	A1, A2, A4, B5 (31%)
10.	Tighten up laws and regulations	Enforcement	A1, A3, A4, B2 (31%)
11.	Align decentralized governments	Communication & Cooperation	A1, A2, A3 (23%)
12.	Offer perspective to the market	Communication & Cooperation	A1, A4 (15%)

The results show that award criteria for winning projects has the highest occurrence in the complete research dataset as an important driver. "To really speed up this transition, the client should make emission reduction at construction sites part of every tender" (Respondent B2, personal communication, 23 April 2021). Especially, attention needs to be on distinctive tender awarding on zero-emission, lesser on lowest price or the speed of project completion. In practice, this is not always easy to accomplish. One of the respondents suggested: "It is important to reward the amount of emission reduction, not the way how this reduction is achieved" (Respondent B2, personal communication, 23 April 2021). It is important to develop an unambiguous tender assessment.

Including zero-emission in contract requirements was another driver that respondents often mentioned. This can be expressed in for instance the requirement of a particular emission reduction percentage for the full project or particular parts of projects.

Besides award criteria and contract requirements, respondents often referred to subsidies as a driver. This can be either Dutch subsidies or financial support coming from the European Union. Subsidies especially help to close the financial gap of investments that are currently still unprofitable (Dutch: onrendabele top). Another development in the area of financing is the emergence of investors that that stimulate the transition towards zero-emission construction sites. Additionally, some banks started offering loans and leases for the financing of zero-emission equipment.

Another driver was the frontrunner approach where the government rewards sustainable leaders. When the government challenges the market by procuring projects with a significant degree of innovation, it can have a stimulating effect. These projects push the limits of possibilities on the topic of zero-emission construction and contractors are able to invest more in zero-emission equipment when winning these projects. This creates an increased competitive advantage, stimulates innovation and moves contractors forward.

More intensive public-private cooperation was also mentioned as a driver. Cooperation can be stimulated by more cooperative and long-term contracts. Different cooperative contracts are for instance innovation partnership contracts, performance contracts with learning space (Dutch: leerruimte) and two-phase contracts (Dutch: twee-phase contracten, bouwteams). These alternatives offer more space to implement innovations in projects compared to traditional contracts.

Supervision and monitoring of project emissions by the government was mentioned to be a driving factor. Active monitoring also helps to prevent opportunistic behaviour by contractors that promised a particular amount of emission reduction.

Another driver was found in connection with international activities. When international governments create aggregate demand, international manufacturers and suppliers will be more likely to move forward with their production lines and scaling up their capacity. Secondly, when governments and contractors connect directly with large international manufacturers and suppliers, this might drive them to incorporate more zero-emission production lines in their organisations.

Also, programmatic procurement was found to be a driver. It helps when zero-emission projects are communicated in advance. The aspect of continuity in future tenders was mentioned by respondents to be a driving factor. A program approach also helps to recoup investments on multiple projects. When a client issues a stimulating and realistic long-term procurement strategy, it offers more financial perspective for contractors to make necessary investments.

The governmental transition paths also need be aligned with the existing policies. It is essential that policies are consistent to increase the trustworthiness of the government. Is is also important that the government sets the right priorities. Not every area can simultaneously go through the transition. According to a ENI report (2021) nature areas and urban areas should be the first to make the transition.

Tightening laws and regulations can enforce contractors to reduce emissions at construction sites. Currently, emission reduction is only stimulated by governmental incentives, but not yet enforced by law. For example, the accelerated phase-out of old diesel equipment was mentioned to be a driver for zero-emission equipment. “Make sure there is clarity and communicate clearly: old diesel equipment is banned by 2025". This will lead to contractors phasing-out the old diesel equipment. Also the introduction of a carbon tax by law, where the government puts a price on carbon emissions was mentioned as an option to enforce emission reduction.

Furthermore, it is important that the ambitions of decentralized governments (provinces, municipalities and regional water authorities) are aligned. When the ambitions of decentralized governments are uniform, it increases the trustworthiness of the national government. This also prevents that emissions get shifted to public clients with less ambition on the subject of emission reduction. Uniform calculation tools are currently in development. Zero-emission machinery is being incorporated in the general Dutch MKI database. These tools can contribute in the future to the development of more uniform government policy at all levels.

Lastly, when clients offer a long-term perspective, it is more likely that construction companies are willing to make investments. "Communicate how zero-emission will grow in the organisation in the coming 5-10 years" (ENI, 2021).

5.3.2. Contractors

The drivers that were found from a contractor perspective are demonstrated in table 5.5.

Table 5.5: Main drivers that accelerate the transition from the contractor perspective, sorted by occurrence in interviews (n=13)

No.	Driver	Category	Interview reference(s)
1.	Competitive advantage	Corporate	A1, A3, B1, B2, B3, B4, B5 (54%)
2.	Experience with zero-emission equipment	Corporate	A1, A2, A3, B1, B6 (38%)
3.	New partnerships and project stakeholders	Project	A4, B1, B3, B6, C3 (38%)
4.	New business cases (value creation, TCO, client demand)	Project	A1, A2, B2, B5 (31%)
5.	Corporate Social Responsibility	Corporate	B1, B4, B6 (23%)
6	Meeting contract requirements	Project	A1, C1, C2 (23%)
7.	Education and training of construction workers	Project	A2, B2, B3 (23%)
8.	Awareness and knowledge development	Personal	A2, C2 (15%)
9.	Marketing benefits, corporate image enhancement	Corporate	A4 (8%)
10.	Personal commitment	Personal	B1 (8%)

The table demonstrates that competitive advantage was mentioned to the be the main driver for contractors. This competitive advantages is achieved by winning the tender for innovative emission reduction projects, allowing for financing of zero-emission equipment. Respondents indicated that the investments for the transition must go through projects. "Contractors won’t buy the equipment without acquiring projects" (Respondent B5, personal communication, 26 May 2021). Contractors are pre-eminently profit oriented and money focused. This explains the focus on monetary corporate drivers. It appears that contractors usually only capture the value of emission reduction efforts indirectly, through client appraisal.

Respondents mentioned that familiarity and experience with zero-emission equipment is an important driver. Contractors need to learn how to handle zero-emission equipment on the site. This driver is closely related to the education and training of construction workers. Once workers start to gain confidence with new machines, know how to charge/fuel them and safely handle the equipment, it becomes part of the routine. It is important to introduce knowledge into the system that there are other ways of construction besides the traditional way. The knowledge sharing and development here are crucial and was one of the other drivers that was mentioned.

Another important driver is the emergence of new partnerships and new project stakeholders. When contractors actively approach sub-contractors, they can jointly search for new developments. Also strategic cooperation between competitors can help contractors forward. For instance, when contractors order machines in large quantities, together with other contractors, innovations can be developed quicker. Manufacturers are then able to deliver their machines faster. New partnerships can also be found in the connection with (large) manufacturers and suppliers of zero-emission construction equipment.

It was mentioned by respondents that the trend towards zero-emission brings about new business cases. When contractors start to think more in value creation, instead of capital expenditure, new (profitable) business cases can arise. For instance, value creation can be found in increased health of construction workers due to reduced pollutants. New business cases can also be found in Total Cost of Ownership of machines. The total cost of ownership is defined as the total incurred costs by a customer over the lifetime of using an application, including operating, financing and capital costs. On average, an electric construction machine costs about two to three times as much as the comparable fossil-based version. However, when customers look at the total cost of ownership - purchase price, maintenance costs, repairs and fuel - the financial costs are 20% lower (McKinsey & Company, 2019). In an total cost of ownership calculation the reduced maintenance cost for electrical equipment can be significant. There are already positive TCO business cases for zero-emission equipment. Another new business model is to shift from equipment in own possession towards a service. One of the financing opportunities can be to rent available equipment from rental companies. This way contractors can make use of the available equipment without the high investment costs. Another opportunity in this respect is to make use of banks offering zero-emission equipment leases. Obviously, when the client demand is high enough that governments are willing to pay the full price for the high initial investment costs, new business cases are evident.

Corporate Social Responsibility (CSR) was found to be an internal driver for contractors. The growing responsibility of companies to work more sustainable and to achieve environmental targets plays an increasing role within private firms. Not only the CSR department, but increasingly shareholders and board of directors are aware of the importance of environmental targets. This enhances the intrinsic motivation of contractors in the work field. A respondent suggested that environmental awareness can be achieved by making a CFO is not only responsible for finances, but also for value creation (respondent B1, personal communication, 16 June 2021). An active participation and early tender involvement of the CSR department and equipment department was found to stimulate contractors to enhance emission reduction efforts (Respondent B6, personal communication, 29 June 2021).

Meeting contract requirements of clients was mentioned to be a driver in the transition. The more clients include zero-emission requirements in tenders, the more contractors are enforced and driven to meet these requirements.

Increasing awareness and knowledge development of individuals in private firms was also mentioned to be important (Respondent A2 & C2, personal communication, 25 May and 28 June 2021). Emission reduction can be influenced through attitude and behaviour in the workfield. For instance, changing the behaviour of drivers/operators of equipment is one of the ways that fuel consumption can be reduced. Another fundamental awareness change can be brought about by applying sustainability data management to operations, especially by using software. This, in combination with continued collection of sustainability data as an operational policy, can increase the reactivity of companies to their environmental impact as well. It allows for the analysis of impact in real time, rather than in retrospective. Companies can also use software solutions to set targets for key climate impacts they would like to reduce. As it promotes behavioural changes, the combination of effective monitoring and targeting is estimated enhance further emission reduction (SECR, 2020).

Companies can enhance their corporate image by marketing their activities and policies in the area of sustainability. A private firm's reputation is of significant importance and social relevance. A respondent mentioned that a sustainable reputation is related to employees willingness to work for a company (Participant Observation, February 17 2021). But, a good reputation will also become increasingly important for winning new contracts in the future.

Lastly, personal commitment of emp loyees in the work field was mentioned only once as a driver. It seems that the intrinsic motivation of employees does not play a significant role yet.

5.3.3. Technology & innovation

The main technologies, mentioned during the interviews, that drive the transition towards zero-emission construction sites are demonstrated in table 5.6.

Table 5.6: Main drivers that accelerate the transition from the technology & innovation, sorted by occurrence in interviews. *Future expectations, not yet possible and/or available (n=13)

No.	Driver	Interview reference(s)
1.	Small equipment electrification (hybrid, retrofit and new)	A1, A2, A3, A4, B2, B4, B5, B6, C1, C2, C3 (77%)
2.	Heavy equipment electrification/hydrogen applications*	A1, A2, A4, B1, B6, C1, C3 (54%)
3.	Functional and available fuelling and charging infrastructure*	A1, A2, A3, B2, B3, B6, C3 (54%)
4.	Hydrogen equipment* (only prototypes, not yet commercial)	A1, A4, B4, B6, C1, C2 (46%)
5.	Bio-fuels (e.g. HVO)	A1, A4, B4, B6, C1 (38%)
6.	Optimise construction logistics (soil and material flows)	A1, B5, B6, C1, C2 (38%)
7.	Electrification of short distance transport (trucks)	A1, A2, B2 (23%)
8.	(Hydrogen, solar, wind, formic acid) engine-generators	A2, C3 (15%)
	**Future expectations, not yet possible and/or available*	

Respondents indicated that an increased availability of zero-emission equipment is a significant driver for more emission reduction at construction sites. Currently, the equipment is still scarce and therefore expensive. The expectation is that as more equipment becomes available, the costs will reduce significantly and hopefully this will lead to large scale deployment in the future (Emissieloos Netwerk Infra, 2020). Moreover, respondents mentioned that functional and available fuelling and charging infrastructure is an important boundary condition for the deployment of zero-emission construction equipment at the sites.

Nowadays, it is already possible to run smaller lightweight construction equipment with battery-electric applications. The deployment of large batteries play a large role in the reduction of CO_2 emissions on the construction sites. Especially for mobile machinery that can not be connected to the grid. The battery is in constant and rapid development and the battery-application opportunities keep increasing. Also the role of retrofit needs to be discovered in the transition. Retrofitting means the replacement of conventional combustion engines for electric motors or adding more environmental friendly solutions to the existing construction machinery that is not ready for replacement. Currently, most of the available electrical equipment is retrofitted, due to the lack of availability of new machines from manufacturers. Also, current machines can be provided with a particulate filter (Dutch: bouwplaatsfilter). This is a device that reduces 99% of nitrogen oxide (NOx) emissions from large machinery. This particulate filter is connected by a hose to the exhaust of diesel equipment, such as generators, drilling rigs and construction cranes. In the particulate filter all nitrogen compounds are decomposed.

In heavy machinery there is still a lot of development needed for sustainable alternatives to become available on the market (Emissieloos Netwerk Infra, 2020). It is expected that in the future, part of the heavier construction machinery (30+ tons) will run on hydrogen (Emissieloos Netwerk Infra, 2020).

Besides electricity, hydrogen is seen as one of the main solutions for zero-emission construction sites. Hydrogen applications are rapidly developing, but these applications still remain on a small scale yet. For instance, hydrogen trucks are already limitedly available and larger amounts are currently in production.

Hydrogen has some significant benefits over electricity. For instance, the increased driving range for mobile machinery. However, hydrogen has other downsides, such as a low combustion efficiency, it takes up a lot of space to store, and not all the hydrogen is green. The commercial availability of green hydrogen needs to significantly increase in the future. The hydrogen that is currently available usually falls under the category of 'grey hydrogen'. This grey hydrogen is produced from fossil fuels and does not positively contribute to the environment. 'Green hydrogen' is the sustainable variant which is produced from renewable energy sources such as wind and solar. Currently, the costs of production and transportation of green hydrogen is extremely high. Economies of scale are needed to lower the cost of production and transportation of green hydrogen. This is a process that will take years and is related to many other sustainability issues in the energy industry.

At the moment, bio-fuels play a role in the transition. But, this should not be a long-term solution and there should be no over-reliance on the use of them. Bio-fuels are viewed as temporary transition solution during the period that the availability of alternatives is still limited. Hydrotreated Vegetable Oil (HVO) is currently the purest biodiesel available. HVO100 provides 90% CO2 reduction compared to diesel. HVO also produces lower emissions of nitrogen, sulphur and particulate matter. Not all manufacturers agree to the pure 100% biodiesel (HVO100); some only agree to a blend of fossil fuels biodiesel. This HVO50 blend provides 45% CO2 reduction. Not all machines can run on the 100% biodiesel, but blends will work in most of the construction machinery.

Furthermore, emission reduction efforts in construction logistics have often even more impact than construction equipment (Respondent B3, personal communication, 4 June 2021). Soil and material flows can be optimised through many different smart activities. For instance, this can be done by the spreading of work activities of the zero-emission equipment. Also, material transportation over water instead of transportation over land is an option. Additionally, reducing the amount of transport movements and distances reduces the carbon dioxide emissions.

Further logistics optimisation is possible through the concept of construction hubs. A construction hub is an area on the outskirts of a city, in which all necessary building materials are centralized. The entire logistical process of the construction chain (from supplier to construction site) is monitored and coordinated from the construction hub. Supplies can be unloaded within a reasonable timeframe, deliveries are consolidated into daily packages and transported to the inner cities in the most efficient way. Goods can also prefabricated at the construction hub. Apart from that, the construction hub serves as a parking lot from which construction site workers are taken to the construction site. Workers can directly start their work, since everything is already in place at their working site. On their way back, the transport vehicles can carry waste from the construction site to the construction hub. The circular 'BouwHub' is a new concept in where all the relevant actors from construction companies to suppliers can make use of the logistical facilities.

Another respondent mentioned that the electrification of short distance transport at the construction site has an impact that is often overlooked (Respondent A1, personal communication, 30 June 2021). The electrification of trucks from and to the construction site has an large impact, as trucks are the most pollutant sources in terms of emissions at construction sites. Truck manufacturers can also integrate an aftertreatment system into their traditional engines to reduce emissions of unwanted pollutants. As a result, construction machinery with an aftertreatment system can also meet the stricter stage class requirements.

Due to the lack of functional and available fuelling and charging infrastructure, the use of green engine generators is a driving technology to speed up the transition. The trend towards using electric and/or hydrogen construction equipment in the future during the execution phase of large infrastructure projects could result in extreme energy demand peaks that the regular electricity grid is not designed for. Additionally, renewable energy sources (wind, solar) produce green energy at irregular moments in time, depending on the actual climate conditions. Due to the inconsistent availability of green energy and the increasing demand for electricity the use green (hydrogen, solar, wind, formic acid) engine-generators (Dutch: aggregaten) is enhanced.

5.3.4. Barriers and drivers category interpretation

Barriers compared to drivers

Barriers and drivers found in interviews were categorised amongst four different categories: 1) Institutional/regulatory, 2) Social/cultural, 3) Economic/financial/market, 4) Technological (see section 2.5.2). The result of this categorisation for both the barriers and drivers is demonstrated in figure 5.2.

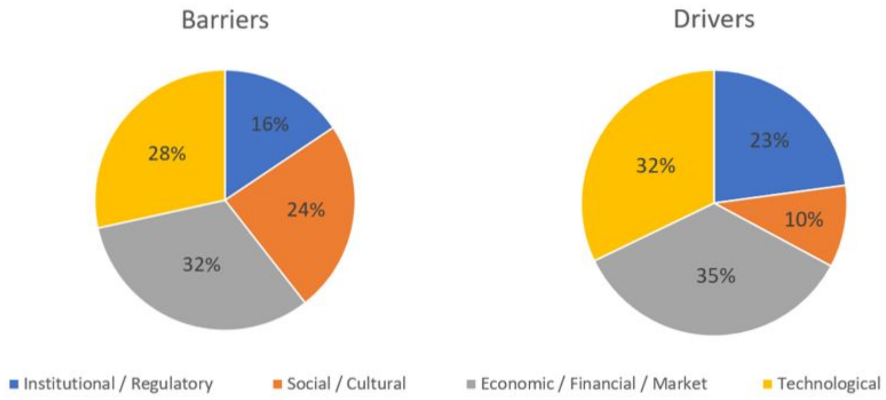


Figure 5.2: Most mentioned barriers and drivers, sorted by category and occurrence in interviews

These categories were used to compare the barriers against the drivers. The figure reveals that most barriers and drivers were found to be "hard" factors (technological and economic). Respondents mentioned economic and technological factors both as main barriers and drivers in this transition. For these factors, the proportions do not significantly differ when the barriers are compared against the drivers. Interestingly, the opposite result was found when barriers and drivers were compared against the "softer" factors (cultural and regulatory). Less evidence was found for regulatory barriers slowing down the transition, while cultural issues were mentioned more often. In contrast, more regulatory drivers were mentioned, while less drivers were mentioned that are culturally related.

Internal and external drivers

To distinguish the drivers between internal and external drivers, an additional categorisation was used. Internal drivers concern the motivation for contractors, while the external drivers are related to policy instruments by governments. The result of the the distribution of both the external and internal drivers from the interviews amongst the various categories is demonstrated in figure 5.3.

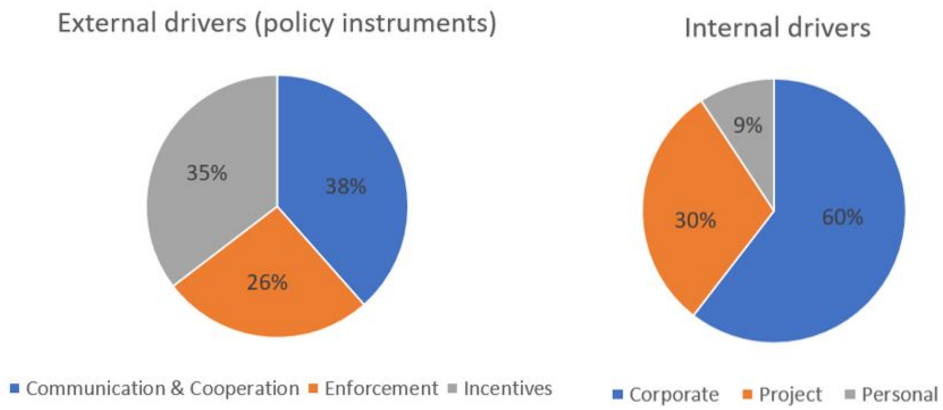


Figure 5.3: Most mentioned drivers, sorted by category and occurrence in interviews. Left figure: external drivers (government), policy instruments. Right figure: Internal drivers (contractor)

As shown in the figure, the policy instruments are in fact a mix between incentives, enforcement and communication & cooperation. There is no dominant policy instrument that stands out and are all considered to be important external drivers.

The results for the internal drivers show that corporate and project drivers prevail. Limited evidence was found for the existence of personal drivers. Only one respondent indicated the existence of personal drivers influencing emission reduction efforts. Nevertheless, none of the respondents mentioned personal drivers to have an decisive or influential role in motivating emission reduction for private firms.

5.4. Current actions for acceleration

This section aims to elaborate the first part of the answer to the third research question:

What actions accelerate the transition towards zero-emission construction sites?

This section reports on actions for acceleration that came directly from the interviews. These are actions that the government and contractors are currently taking. The second part of the answer on this sub-question is answered in chapter 6.1, the discussion on implications. In this implications chapter the results from chapter 5 are combined with the theory, to formulate actions for acceleration, according to the researcher. The list of actions for acceleration is presented in section 6.1.2. This list is based on theory, barriers, drivers, and current actions from the results chapter.

To recap the results from the previous sub-question, figure 5.4 demonstrates the most significant drivers, according to the occurrence in the interviews. It visualizes the findings of the most significant internal drivers by contractors and external policy instruments by governments.

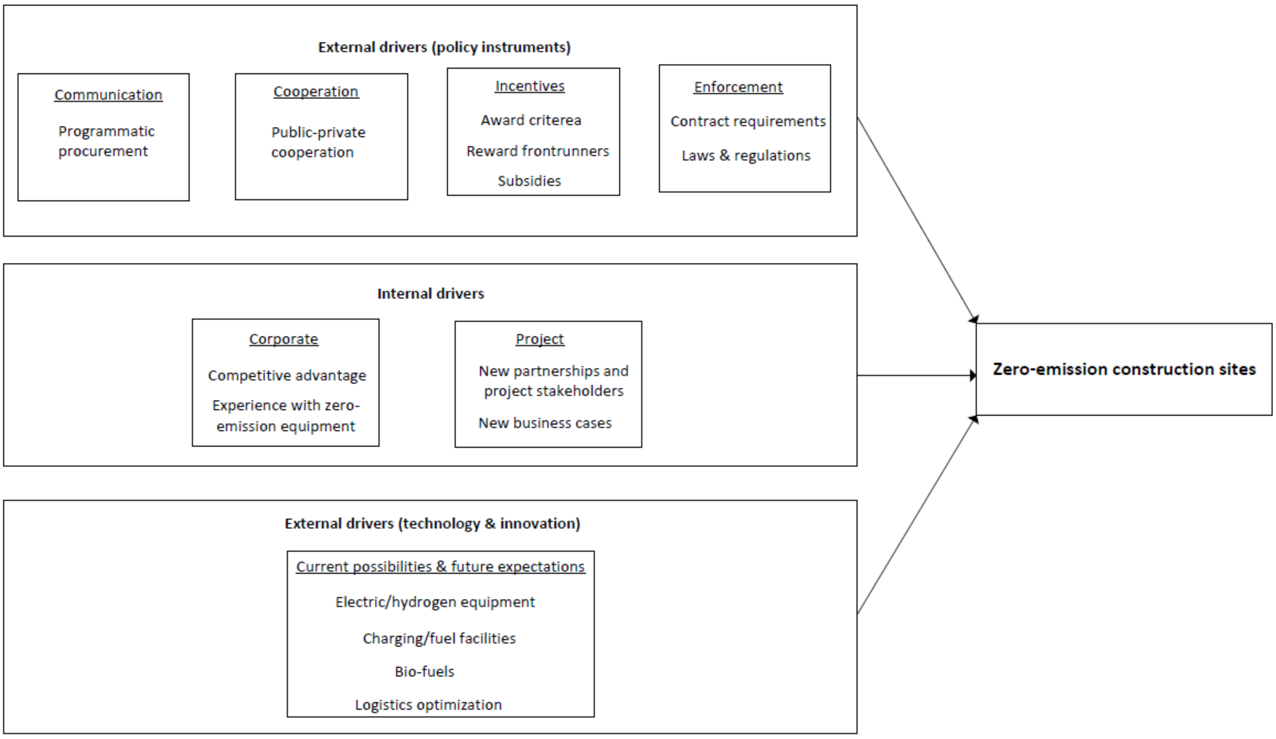


Figure 5.4: External and internal drivers that motivate contractors to accelerate the transition towards zero-emission construction sites

5.4.1. Government

The government as main client has already started taking actions with the aim to accelerate the transition towards zero-emission construction sites. The government as main client started to award frontrunners with a few innovative projects (Respondent A3, personal communication, 26 May 2021). The A1 highway project, as described in the case study, is one of those projects. The government wanted the construction site of this project to be almost zero-emission. This was a progressive and innovative demand coming from the client, because many zero-emission equipment is not yet available and expected on the market in a couple of years. With this frontrunner approach the government aims to challenge contractors to come up with innovative solutions. When a contractor wins such a frontrunner project, the firm gets the change to invest into the zero-emission equipment. These investments for contractors usually go through projects (Respondent B2, personal communication, April 23, 2021).

Another action is that the government as main client is already partly working together with some decentralized governments (provinces, municipalities and water boards) (Respondent A1, personal communication, 30 June 2021). These clients are communicating with each other about their procurement strategies, and trying to partly align them. When they align their procurement strategy, Rijkswaterstaat is not the only client that is asking for zero-emission, but the other clients as well. This builds trust towards the public sector and offers perspective for contractors to make more private investments.

The government as legislator/policy maker also started to take some first actions for acceleration. They are trying to alleviate financial burdens for contractors by announcing an upcoming subsidy for construction equipment (Respondent A2, personal communication, 25 May 2021). This subsidy is called the SSEB (Subsidieregeling Schoon en Emissieloos Bouwmaterieel), which helps to close the financial gap of equipment that is currently still unprofitable for contractors.

The Dutch government also took the first steps of reaching out to other European governments (Respondent A1, personal communication, 30 June 2021). These governments came together a few times to talk and discuss about the subject of emission reduction at the construction site. This has not lead yet to any concrete collaborations to stimulate large worldwide oriented manufactures or create an aggregate demand. However, these meetings are the first step in doing so.

5.4.2. Contractors

Besides the government, contractors have also been taking the first actions towards an accelerated transition. Contractors started to tender projects that are procured and awarded on the topic of zero-emission (Respondent B2, personal communication, April 23, 2021). Ballast Nedam, for instance, started to tender the A1 highway project, while it was not initially one of their projects of interest. They decided to tender this project because this project came with an opportunity to increase their competitive advantage and invest into new zero-emission equipment, when they would have won the project.

During this A1 highway tender, also new opportunities arose for connections with zero-emission equipment suppliers and manufacturers. Ballast Nedam connected to these companies during the tender phase, to search for new partnerships and project stakeholders (Respondent B3, personal communication, 4 June 2021).

Another action for acceleration that contractors are taking is that they started to contribute to platform approaches (Respondent B1, personal communication, June 16 2021). For instance, Ballast Nedam joined the ENI (Emissieloos Netwerk Infra) platform. This is a platform that connects clients, contractors, equipment manufacturers and suppliers. The ENI is an information platform where emission reduction experiences are shared by all the members of the platform. People learn from each others experiences and are kept up to date about the latest developments on the topic of zero-emission construction. Additionally, these platforms are used by the contractors to buy equipment in bulk with other contractors (Respondent B1, personal communication, June 16 2021). This aggregate demand by multiple contractors might encourage large equipment manufacturers to scale up their zero-emission production capacity and stimulate early equipment delivery and development.

Next to the equipment, also the construction logistics play an important role (Respondent B3, personal communication, 4 June 2021). As an action for acceleration, contractors also try to optimise their construction logistics in projects. This is done by contractors in many different ways. For instance, transporting over water instead of over land, reducing the amount of transport movements and the spreading of work activities in smart ways to reduce emissions.

Contractors are also thinking about at new kinds of business cases (Respondent B2, personal communication, April 23, 2021). For instance, within Ballast Nedam, people are looking at TCO business cases, to find out if buying the zero-emission equipment is already a profitable investment.

Lastly, contractors are staring to slowly increase their own corporate and social responsibility within private firms (Respondent B1, personal communication, June 16 2021). For instance, the Board of Directors' awareness and responsibility on the topic of zero-emission construction is increasing within private firms.

This section reported on actions that the government and contractors are already doing, following directly from the interviews, case study and desk research. In the next chapter, the rest of sub-question three on actions for acceleration was answered. The discussion on implications section gives the researcher a more free interpretation of what the actors can do to accelerate, based on the barriers, drivers and actions from the results chapter.

6 Discussion

This chapter discusses the research findings. Firstly, the research implications are discussed. These implications lead to the formulation of actions for acceleration. Secondly, the results were compared to prior scientific research. Thirdly, the generalization of results was discussed. Forthly, a specific focus group discussion was elaborated, Fifthly, the methodology was evaluated. Lastly, some limitations of the research were given.

6.1. Discussion on implications

This section aims to further elaborate the answer to the third sub-question: "What actions accelerate the transition towards zero-emission construction sites?". The first part was answered in section 5.4. In this section, the results from the previous results chapter are combined with the theory. The theory, barriers, drivers, and current actions from the previous chapter, eventually lead to a list of actions for acceleration, according to the researcher.

6.1.1. Results and theory combined

The drivers that were found in the previous sub-question, were placed in the phases of sustainable market transformation, as explained in Chapter 2. This is demonstrated in figure 6.1.
Different drivers appear to be more significant, dependant on the phase a transition is currently in. For instance, the heavy equipment electrification and hydrogen applications are still in the inception phase (phase one). These technologies are not matured and pilots are needed to further develop these innovations. Another driver, the development of new business cases, seems to be more significant in the competitive advantage phase (phase two). Public-private cooperation is a significant driver in the pre-competitive collaboration phase (phase three) and laws and regulations are the most dominant in the institutionalization phase (phase four).

To develop actions for acceleration, empirical drivers found in the interviews were compared to the theoretical actor interventions, described in the stakeholder matrix from Chapter 2. The stakeholder matrix is demonstrated in figure 6.2. The role of the contractors is represented under the header industry in the stakeholder matrix.
In the construction sector, governments set the playing field, as they are in most cases the main client for contractors (Simons & Nijhof, 2021). Respondents mentioned that the topic of zero-emission construction sites is generally situated in phase two of the sustainable market transformation model (Respondent A1 & B1 personal communication, 30 June 2021 & June 16 2021).

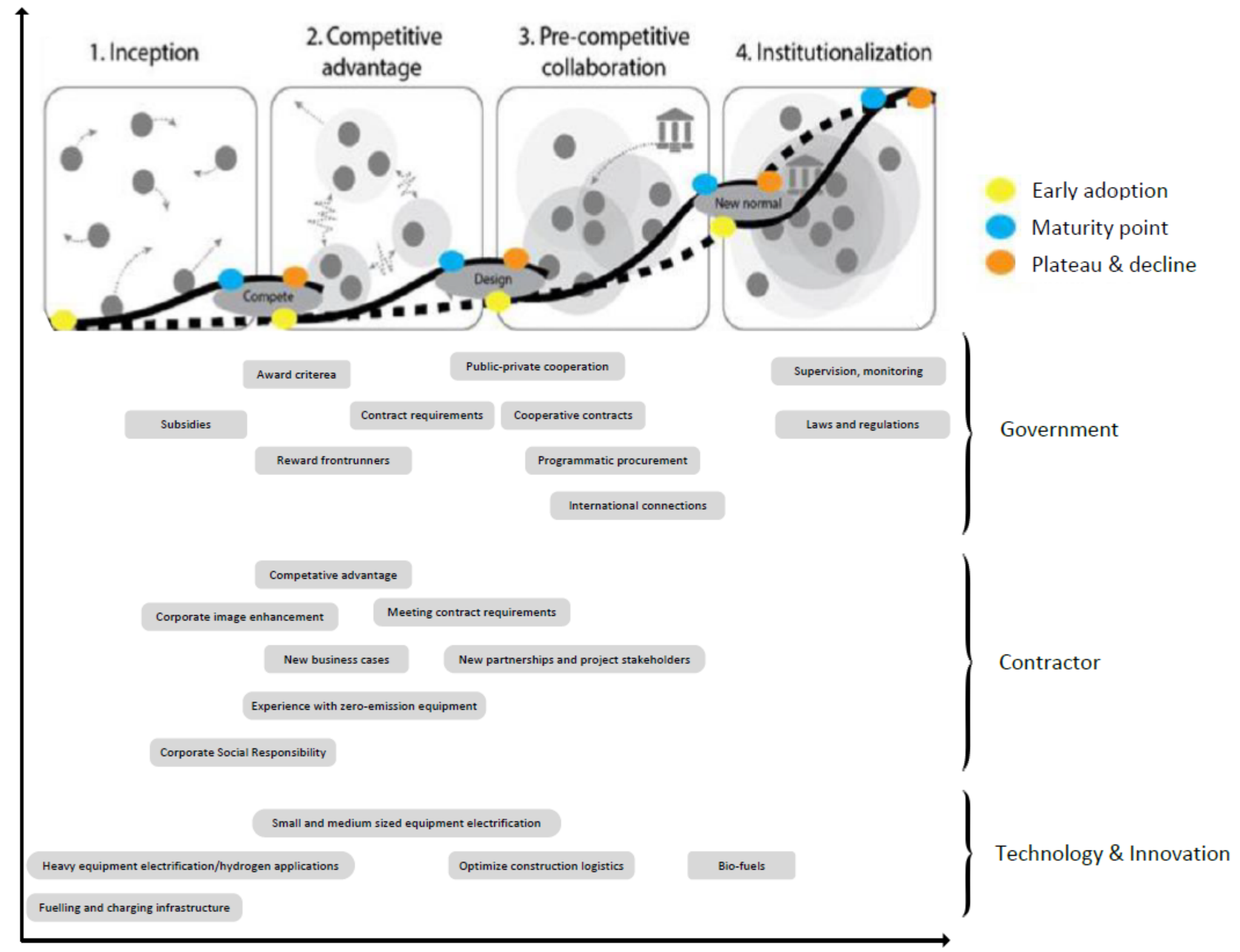


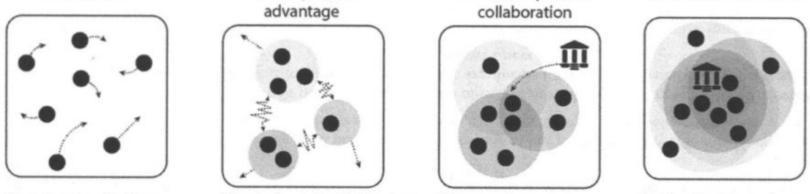
Figure 6.1: Drivers placed in the phases of sustainable market transformation

Government - phase 2
Following from the stakeholder matrix, the government could theoretically in phase two:

- Emphasize a long-term vision
- Challenge market actors
- Be a launching customer
- Recognize market leaders

These theoretical actions for the government can be linked to the empirical case study findings. As described in the case study (section 4.3.2), transition paths were formulated with a long-term vision. Rijkswaterstaat communicated that they are aiming for zero-emission construction sites in 2030. Rijkswaterstaat also maintains a frontrunner approach in which it challenges companies with innovative projects. Rijkswaterstaat is also starting to act as a launching customer. They started to award more projects on emission reduction. They also announced that subsidies for zero-emission equipment are in development. Market actors are increasingly recognized by award criteria. Thus, all the theoretical interventions of phase two for the government were empirically found. However, procurement practices still lag behind and government should urgently set new sustainable standards (Simons & Nijhof, 2021).

Government - phase 3
The government is already showing some actions that theoretically belong in phase three. These theoretical actions theoretically in phase three are:



	1. Inception	2. Competitive advantage	3. Pre-competitive collaboration	4. Institutionalization
Industry	Stop denying the issue	Develop sustainable business models	Communicate a non-competitive agenda	Lobby for the new normal
	Partner with NGOs or other stakeholders	Differentiate by introducing new business models and labels	Form or join platforms	Recognize leading politicians
	Pilots, CSR projects, support or partner with foundations	Engage value chains	Be inclusive when others want to join	Comply with legislation
	Identify solution principles	Participate in rankings and benchmarks	Develop a sector strategy	Take on subsequent issues
Government	Embrace the crisis	Emphasize long-term vision	Develop policy goals and measures	Show political leadership
	Communicate a long-term vision	Challenge market actors on principles	Support platforms and coalitions	Announce legislation
	Make space for experiments and fund projects	Be a launching customer	Influence behavior of consumers	Create the new normal
	Identify solution principles	Recognize market leaders	Change tax incentives	Remove the laggards

Figure 6.2: Stakeholder matrix for the industry and government (Simons & Nijhof, 2020)

- Develop policy goals and measures
- Support platforms and coalitions
- Influence behavior of consumers
- Change tax incentives

Rijkswaterstaat currently is aligning its policy with their sustainability ambitions for the year 2030. Phase three is about collaboration, which was empirically found in the driver of more public-private collaboration. Awarding more projects on emission reduction is influencing the behavior of contractors. However, really influencing contractor behaviour by contract requirements is not yet adequately applied. Tax incentives was mentioned by a respondent as a driver, but the Dutch government is not (yet) actively steering market actors with tax incentives, like carbon tax.

Contractors - phase 2
Simons & Nijhof (2021) argue that to achieve acceleration, the peloton (Dutch contractors) need to be pulled apart (section 2.4.4). Thereafter the peloton needs to brought back together by scaling up. According to the stakeholder matrix, contractors should theoretically in phase two:

- Develop sustainable business models
- Differentiate by introducing new business models and labels
- Engage value chains
- Participate in rankings and benchmarks

These theoretical actions were coupled to the drivers found in sub-question two. Contractors are already experimenting with new business models. One of the new business models that was empirically found were the TCO business cases. Other new business cases were found in value creation instead of looking at financial aspects only. Engaging value chains was also found as a empirical driver. Respondents mentioned smart sector connections as actively engaging sub-contractors and connecting with suppliers/manufacturers. Proactively approaching the market and searching together for the best technological solutions was considered to be an important driver, but is also not yet applied on a wide scale.

Contractors - phase 3
In the pre-competitive collaboration phase (phase three), contractors should theoretically:

- Communicate a non-competitive agenda
- Form or join platforms
- Be inclusive when others want to join
- Develop a sector strategy

Some of these interventions were already empirically found. Contractors have started to join platforms in which they are sharing knowledge and acting jointly. For instance, the ENI platform, where contractors jointly order equipment to achieve economies of scale. Being inclusive was found on a small scale where contractors engaged in strategic cooperations with competitors. However, not many other signs of inclusiveness were found. Theoretically, phase two may need to be more mature before moving to phase three.

By combining theoretical interventions in the various phases with empirical drivers, actions for acceleration were formulated for both the government and contractors. Is important to note that some actions are more relevant in one phase, while other actions might be more significant in another phase. What becomes clear is that the government must play a greater stimulating role than it does at present.

We can distinguish two different roles of the government: as main client and as legislator/policy maker. As main client it is important that they challenge the market to operate in a zero-emission way as much as possible. As legislator/policy maker it is important to create boundary conditions for contractors to enable them to invest and construct more zero-emission. If the goal is to reach zero-emission construction sites in 2030, the following actions must take place at a much faster pace.

6.1.2. Actions for acceleration

Based on the barriers, drivers and current actions from the interviews, the following list of most prevalent actions was developed by the researcher.

What governments could pay attention to

- **As main client:**
- Work with positive incentives. Focus on rewarding frontrunners by creating competitive advantage through award criteria in infrastructure projects. For instance, reward a certain amount of emissions reduced.
- Zero-emission should become part of the contract requirements, when enough zero-emission equipment is available on the market. Start with a particular percentage of reduction for the whole project or part of the project. These contractual requirements can become increasingly strict over time.
- Secure sufficient budget for zero-emission projects. Let the number of zero-emission projects grow steadily through programmatic procurement. For instance, clients can make a project calendar to let the market know in advance which zero-emission projects are coming up. Communicating this to the market offers a long-term perspective for private investments and builds trust.
- Rijkswaterstaat and decentralized governments (municipalities, provinces and water boards) should align their public procurement strategy. This helps to build trust and offers the market more clarity for future investments.
- Enhance public-private cooperation by choosing for more cooperative and long-term contracts, such as innovation partnership contracts, performance contracts with learning space (Dutch: leerruimte) and two-phase contracts (Dutch: twee-phase contracten).
- **As legislator/policy maker:**
- Alleviate financial burdens for contractors with subsidies, such as the development of the SSEB (Subsidieregeling Schoon en Emissieloos Bouwmaterieel (SSEB-regeling)).

- Act more proactively as a launching customer. Connect with other national governments to create aggregate demand to stimulate and encourage large international manufacturers to scale up their zero-emission production capacity.
- Start enforcing the private sector when enough zero-emission equipment is available. Phase-out old diesel equipment and secure zero-emission equipment in laws and regulations. Start to monitor and supervise projects on emission reduction. Publish an end date when zero-emission becomes required in every project.

If the preceding actions are taken, a trend upwards can be created towards an accelerated transition. With these boundary conditions, contractors will get much more clarity and an increased willingness for making zero-emission investments will occur. Naturally, contractors also have their own social responsibility to to create a sustainable sector in the future.

What contractors could pay attention to

- Benefit from competitive advantage by tendering projects where the government rewards zero-emission with award criteria. Winning these project finances new zero-emission equipment and leads to a competitive advantage in tendering new zero-emission projects in the Netherlands. This competitive advantage can also be exploited in the international context. While the Netherlands is yet relatively progressive, it is expected that zero-emission in other European countries will become increasingly important in the future. It is good business sense to anticipate these developments.
- Increase experience with available small and medium size electric equipment. Educate and train construction workers to become familiar with new equipment and start using it in (both existing and new) projects.
- Pro-actively approach suppliers, manufacturers and sub-contractors to search for new partnerships and project stakeholders to stimulate early equipment development, access and delivery.
- Use available subsidies together with a long-term vision to free up budget to buy zero-emission equipment. The Ministry of Infrastructure and Water Management is working on a new subsidy scheme for zero-emission equipment (Subsidieregeling Schoon en Emissieloos Bouwmaterieel (SSEB-regeling)). This new subsidy will help to cover a (large) part of the purchase costs of new zero-emission equipment and retrofitting old equipment.
- Smart zero-emission construction logistics can have an enormous impact. Soil and material flows can be optimised through many different smart activities. For instance, this can be done by the spreading of work activities of the zero-emission equipment. Additionally, reducing the amount of transport movements and distances reduces the carbon dioxide emissions.
- Because equipment is still scarce, it may be considered to buy zero-emission equipment anyway if the funds are available. The willingness to invest sustainably enhances the corporate image, which also can lead to marketing benefits. If the situation arises, that zero-emission equipment can not be deployed, consider the option to of renting it out to other contractors to recover part of the costs.
- Increased client demand for zero-emission construction in the future, will evidently lead to new business cases. Build upon this increased demand with new viable long-term business case approaches. Consider total cost of ownership calculations (e.g. reduced maintenance and fuel costs of electric equipment) and long-term value creation (e.g. less emissions lead to cleaner construction sites and increased health).
- Contribute to platform approaches by sharing experiences with other contractors which will enhance own knowledge development.
- Buy equipment in bulk with other contractors to share risks and costs and create an aggregate demand for large international manufacturers.
- Articulate clear roles and responsibilities by actively involving the CSR and equipment department in tender teams in an early stage.

- From a Corporate Social Responsibility perspective, make the Board of Directors, especially the CFO, responsible for not only financial reporting, but also reporting on sustainability, zero-emission and other environmental aspects.

Based on the barriers, drivers and current actions, the previously described list of most prevalent actions was developed. It is important to note that this list is not exhaustive. But, within the scope of this research a choice was made to include the most significant actions, according to the researcher.

6.2. Comparing findings to literature

The direct impact of the findings for contractors is to inform them which actions they can take to accelerate the transition towards zero-emission construction sites. Subsequently, the impact for policy makers is to inform them which policy instruments motivate contractors to accelerate the transition.

This research demonstrated that corporate drivers and project drivers are great influence for motivating emission reduction at construction sites. Personal drivers were found to be less significant. The research results from Darko et al. (2017) aligns with these findings and also found limited existence of personal drivers underlying motivation for more sustainable practices.

The results showed that main barriers were found in financial burdens for contractors, limited availability of equipment of the governmental need for international collaboration. It appears that contractors are financially driven and mainly hindered by high initial investment costs of equipment. Venås et al. (2020) also argued for a demand in cost reduction of construction equipment. Furthermore, a lack of awareness, specific requirements, inconsistent government policy, regulations and use of traditional methods to avoid risks were indicated to be hindrances in literature (Arnoldussen et al. 2017; Venås et al., 2020). These results align closely to our findings of barriers for both contractors and the government. Other scientific research found fragmented employment structure and lack of learning on infrastructural sites as barriers (Clarke et al., 2017). These factors appear to be missing in our findings.

This research found strong proof for the public sector as external driver to enhance emission reduction at construction sites. Kadefors et al. (2021) supports this claim by stating the importance of public procurement in driving carbon reduction goals. Moreover, Karlsson et al. (2020) argues that in the context of zero-emission, policy and procurement need to be aligned. This alignment of policy and procurement was also found to be a governmental driver in our research. According to prior academic research, improved environmental requirements in public procurement tenders are key opportunities for zero-emission construction (Venås et al., 2020). This aligns with the findings of our research, which demonstrates that award criteria and contract requirements in public procurement tenders are key external drivers to achieve emission reduction at construction sites. Anderson (2019) further supports this claim by stating that governments have the opportunity to pave the way for healthy, safe, and affordable zero-emission construction.

The results indicated that communication and cooperation as governance measures was an important policy instrument. Fufa et al. (2019) also indicated the need for open and thorough collaboration between stakeholders to drive emission reduction at construction sites. Furthermore, this finding is supported by our research result that states the importance of more intensive public-private cooperation.

Karlsson et al. (2020) stated that main technological pitfalls are an over-reliance on bio fuels and cost optimizations that can not be scaled up. Geldermans & Jacobson (2015) further supports this claim by stating that many innovative technologies have passed the experimental phase, but are not reaching a larger scale usage. Respondents in our research were also doubtful about the use of bio-fuels and mentioned the need for economies of scale. However, our results showed that the lack of availability of equipment was of more importance and contradicts previous research.

Technological opportunities were mainly found to be electric, hydrogen or hybrid construction equipment. This closely aligns with the findings of prior research that concluded that key opportunities are electrification and hybridisation for construction equipment and heavy transport (Karlsson et al., 2020).

To conclude, although this research has not found all the barriers and drivers that were identified in scientific literature, the findings generally align well with the results from prior academic research. Strong proof was found for external drivers to influence contractors and enhance emission reduction at construction sites. The results illustrate the significance of both external and internal drivers for contractors to motivate private emission reduction at construction sites. Prior research also underpinned the significance of the interplay between both external and internal drivers (Olubunmi et al., 2016).

6.3. Generalization of results

Case study findings can only be generalized according to a previously developed theory (Yin, 2014). During the development of the contractor strategy, it was demonstrated how the case study findings bear upon the theoretical framework, which strengthens the argument for generalization. The results are only generalizable for the Dutch construction industry.

To achieve results that are able to be highly generalized, the research should be replicated in other contexts, such as varying contractors, countries or other infrastructure projects. It is hard to generalize from a small number of case studies (Queirós et al., 2017)

Queirós et al. (2017) also argues that interview studies are inherent to a limited generalizibility of results. A focus group was organized to validate and discuss the results with practitioners. This focus group led to minor adjustments and generally confirmed the results of the research. The scope of the research was geographically limited, indicating that the applicability of the findings in another national context may differ. The goal of this research was to explore drivers and develop a strategy that accelerates the transition towards zero-emission construction sites, rather than uncover exact details about emission reduction in practice. The research had a exploratory nature, rather than descriptive character which supports less need for obtaining results that are highly generalizable.

6.4. Focus group discussion

During the validation focus group, another approach was discussed in contrast to the frontrunner approach that is maintained by the government. The government is also considering having a fixed percentage of project budget for emission reduction for projects. With this fixed percentage of the project budget, the sustainability aspect gets directly removed from the competition between contractors. With this approach you let contractors compete for projects on traditional aspects, such as the lowest price, shortest project duration and highest quality, while still considering the need for emission reduction in the particular project. This prevents that contractors promise sustainability solutions, which sometimes cannot be fulfilled afterwards. Additionally, another disadvantage of the frontrunner approach is that when some parties are being a frontrunner and they get rewarded, the sustainability distance between companies gets larger. And this goes against the perception that everything needs to be a level-playing field in the construction sector. This disadvantage disappears with the approach of the fixed percentage of project budget, because this also stimulates parties that do not want to be a frontrunner, and moves the whole market forward.

6.5. Methodology evaluation

In the methodology evaluation the quality of research is discussed.

6.5.1. Reliability

The reliability deals with the quality of research replication (Yin, 2014). If the research was carried was by different researchers with the use of the same methods, would the same results be obtained? (Shipman, 2014) The strategy for literature search was to use specific keywords which allows for replication. The choice of a narrative review over systematic literature review increased the chance of personal bias and reduced the reliability of the research. The research has to deal with subject error, which is the fact that results may differ on different days. Interviewees may change their vision or opinion from day to day. There could also bias coming from the interviewee, when the respondent tries to please the researcher. Additionally, the researcher could be subject to observer error and bias during the interviews, while making the transcriptions and analysing the empirical data. If this process would have been more transparent, the possibility for replication would have increased. Due to the use of an interview protocol the reliability of the research is increased. This interview protocol would allow other researchers to ask exactly the same questions, without any differences in interpretation.

6.5.2. Validity

The validity deals with the question if the results reflect the reality. Has the researcher found out what the researcher claims or thinks it is about? Is the evidence a true record of what is actually going on?

Construct validity identifies the correctness of the operational measures (Yin, 2014). This research aimed to used the theoretical background as a lens to real life practices. The right application of theories in practice can be challenging and might be criticized because of inconsistencies and subjective judgement. To reduce the amount of subjective judgement multiple sources of evidence are used. The results are based on interview data, meeting notes and desk research. A clear chain of evidence (quotes) is used in this study. This allows other researchers to check if the data represents the right concepts. The data was also shared with participants and key informants to review the data after write-up. This procedure corroborates the main findings that are presented as evidence in this research.

The internal validity of this research may be reduced by interference's (Yin, 2014). Data was collected during interview and personal thoughts were formed during this data collection. In this process interference's happen naturally. To reduce this issue the research was checked by key participants to check if wrong interference's occurred.

6.5.3. Credibility

Is there sufficient detail on the way that results were produced for the credibility of the study to be assessed? (Cope, 2014) This credibility and trustworthiness can be the amount of expertise and background of the researcher. The researcher had no research background which might threatened the credibility of the study. However, the study was supervised by experienced researchers which increases the credibility of the results.

6.5.4. Overall evaluation

Qualitative research is criticized by research as being too subjective and impressionistic. Qualitative research lacks transparency how it was conducted, it is difficult to replicate and the ability for generalization to another setting or larger population is limited (Bryman, 2016). The subjectivity was reduced by using multiple sources for the collection of data. However, for the personal views of interviewees it was not always possible to use multiple resources. The data collecting procedures and research process is thoroughly documented to mitigate the lack of transparency. The narrative review for literature review and the interviews are still difficult to replicate for other researchers. A multi-case design would have led to an increase in generalization for a wider population or other settings. Overall, considering the resources and given time span, the researcher believed that the study was conducted quite well concerning the degree of reliability, validity, generalizability and credibility. Readers and researchers are encouraged to follow the line of reasoning throughout the whole study, and not jump to the end to only read the conclusions.

6.6. Limitations of the research

This research has several limitations. Firstly, a embedded single-case design was chosen to conduct the empirical study. The focus was on one contractor with three units of analysis were chosen within this single case study. These are the contractor's main client and two of the contractor's projects. More clients or projects could have been chosen as units of analysis. Choosing more projects over a different period of time would have given the research a more longitudinal character. Additionally, a multiple-case design could have been chosen to observe multiple contractors and more wide-range of data could have been collected. This may have led to other conclusions and other analytical benefits such as an increased breadth of the results. However, with the limited time span of amount of research participants the single-case design was the favoured option.

Secondly, the case study projects were only from one country, the Netherlands. When projects from other countries would have been included the results could have been more nurtured. It would have allowed the researcher to compare practices from other countries in the context of zero-emission construction sites. Every country has their own environmental ambitions in support of the European agreements.

Lastly, this research did not cover the perspective of the equipment suppliers and manufacturers. In this research, the public sector was the client, and the contractors were the service providers. Within the value chain in the construction sector, the equipment suppliers and manufacturers are the service provider and the contractors are the client. However, the perspective of the equipment suppliers and the manufacturers was not a specific part of this study, which is limitation of research

A strong point of research is that interview saturation was reached. Still, it would have been fruitfull to explore different perspectives in the research, such as the suppliers and machinery manufacturers. Approaching these organisations and people involved would have been a time consuming process which was not possible within the limited time frame and magnitude of this research.

7

Conclusion and Recommendations

This chapter presents the conclusions and recommendations of the research

7.1. Introduction and context

This research was an exploratory study on which barriers slow down and which drivers accelerate the transition towards zero-emission construction sites in the Dutch infrastructure sector. These results were obtained through case study research, founded on semi-structured interviews, desk research and participant observation meeting notes. Thirteen interviews were conducted with representatives from Rijkswaterstaat as client, Ballast Nedam as contractor, a sub-contractor, consultant and developer. The goal of this study was to gain insight into the process of the transition from a government and contractor perspective. Also the role of the state of technology and innovation in the transition process was explored. Eventually, drivers were described and actions were formulated to answer the main research question: How can the transition towards zero-emission construction sites be accelerated?

7.2. Research questions answered

Q1 *Which barriers slow down the transition towards zero-emission construction sites?*

Key barriers were found to be financially and technologically related. Particularly contractors face difficulties in seeing direct financial benefits resulting from emission reduction at construction sites. For contractors, the absence of positive business cases is the barrier that was mentioned most often. The limited availability of zero-emission construction equipment was the most important technological barrier and hinders both governmental policy instruments and contractors. From a government perspective, the lack of international collaboration was found to be the most important barrier. Particular barriers of the government, contractor and technology & innovation were found to be interconnected with a cause and effect link. The barrier of a lack of clear vision and clarity towards the market from the government, seems to be connected to the barrier of the wait-and-see attitude of contractors. The results show that interviewees from the government and the contractor generally do not share the same vision. Both actors prioritized different barriers and categories that slow down the transition. This was found to be an inherent barrier in itself.

Q2 *Which drivers accelerate the transition towards zero-emission construction sites?*

Drivers were mainly found in the theoretical context of the competing market dynamics, the enabling policy environment and the attractiveness of alternative technologies. The results show that contractors are mainly driven by their competitive advantage. This is reflected in tendering projects that include a significant amount of emission reduction in their award criteria, allowing for financing of zero-emission equipment. This influences the market dynamics by fundamentally changing what the market competes on, by including sustainability in this process. From the government perspective, the results show that policy instruments could be a mix between communication and cooperation, incentives and enforcement. Including emission reduction in award criteria in public procurement was found to be the most important external driver for contractors. This not only changes the market dynamics, but also the enabling policy environment. From a technological perspective, an increased availability of zero-emission equipment is a significant driver for more emission reduction at construction sites. The expectation is that as more equipment becomes available, the costs will reduce significantly and this will lead to large scale deployment in the future. This contributes to the attractiveness of zero-emission alternatives.

Q3 *What actions accelerate the transition towards zero-emission construction sites?*

The list of actions for acceleration that was developed by the researcher aimed to formulate actions for both the government and the contractor. When these actions are taken, the first step towards an accelerated transition can be made, by slowly changing the underlying problems of how the construction industry is organised. The actions were aimed to break some of these underlying viscous loops that explain the slowness of the transition and are causing an unsustainable downward spiral. The government as main client could pay attention to work with more positive incentives, enforcement, communication and cooperation. They could focus more on rewarding frontrunners by creating competitive advantage through award criteria in infrastructure projects. Zero-emission could also become part of the contract requirements, when enough zero-emission equipment is available on the market. The government as legislator/policy maker could pay attention to alleviate financial burdens for contractors. They could also phase-out old diesel equipment and secure zero-emission equipment in laws and regulations. Contractors could pay attention to benefit from competitive advantage by tendering projects where the government rewards zero-emission with award criteria. They could educate and train construction workers to become familiar and experienced with the new equipment. Contractors could also actively contribute to platform approaches. If the actions from the list are taken, a trend upwards can be created towards an accelerated transition.

The main research question,

How can the transition towards zero-emission construction sites be accelerated?

To accelerate the transition, the underlying problems within the construction industry need to be reorganised, by breaking the vicious loops that lead to unsustainable behaviour. The actions for acceleration, formulated by the researcher, aimed to break some of these underlying loops that are causing a downward spiral. To speed up the transition, the interviewees indicated the need for incentivizing emission reduction at construction sites by rewarding frontrunners and creating competitive advantage through award criteria in infrastructure projects. Contractors can accelerate the transition by tendering these emission reduction projects to enhance their competitive advantage. The interviews also indicated that the government could play a greater stimulating role than it does at present. As main client it is important that they challenge the market to operate in a zero-emission way as much as possible. As legislator/policy maker it is important to create boundary conditions for contractors to enable them to invest and construct zero-emission. Clarity and continuity of future policy is of significant importance. Enforcement of emission reduction by law becomes a possibility or option when enough zero-emission equipment is available at construction sites. Contractors also have their own responsibility to accelerate the transition towards zero-emission construction sites. At the moment, contractors could actively tender zero-emission projects and increase their experience with available small and medium sized electric equipment.

To conclude, the government can use policy instruments to incentivize, communicate and cooperate with and enforce the private sector to enhance private emission reduction efforts. Moreover, contractors could also take social responsibility, instead of considering emission reduction at construction sites only as a governmental matter. Contractors could embrace the transition towards new ways of construction which includes emission reduction at the sites. This involves acknowledging the need for emission reduction, seizing and recognizing emission reduction opportunities and receptively positioning themselves towards the governments using policy instruments. Eventually, the combination of more intrinsic motivation by contractors and an active use of policy instruments by the government can lead to an accelerated transition.

7.3. Recommendations for further research

The following recommendations for further research were formulated:

- Future research can focus on quantifying the effects of drivers and actions on the emission reduction in the infrastructure context. Exploring benefits can contribute to a better business case and increased motivation for private emission reduction efforts. Moreover, this can create additional opportunities and increased motivation for other contractors to increase emission reduction at construction sites.
- Policy instruments were explored to externally drive emission reduction from a government perspective. Additional research is required before implementing policy measures such as incentives or regulations. Future studies can focus on the implementation and effectivity of policy measures in terms of enhancing emission reduction at construction sites.
- This research focused on emission reduction in The Netherlands. Future studies can investigate drivers for emission reduction in a different international context.
- Investigate multi-regime interaction between contractors. Using a model that is less hierarchical and includes multiple relations between more actors in the construction is also recommended. Barriers, drivers and actions for acceleration can then be formulated for suppliers, manufacturers, sub-contractors, banks and network operators. Investigating the role of network operators in this research is also crucial, as there is no point of having demand side innovation when there is no supply side need.
- It is recommended to also look at smaller clients, besides Rijkswaterstaat. Because the main client is the largest, it also means they are never moving the fastest. Other smaller clients are often faster and more innovative compared to the largest client.
- It is recommended to try to scientifically capture the actions for acceleration in virtuous loops. The theoretical background was mainly based on viscous loops, that are causing a downward spiral. It would be particularly useful when actions for acceleration can be captured in virtuous loops, causing an upward spiral.
- It is recommended to investigate a transition towards a more process orientated construction industry. This research did not address the debate about moving away from projects, towards a process orientated industry (e.g. robots building everything). In construction there is always a tension and connection between projects and process, as the industry might can not get away from projects, because then there would be no construction industry anymore. The construction industry is all project oriented and this research implicitly assumed that this orientation will stay the same.
- This research mainly focused the traditional concept of construction sites, where everything is assembled on-site. When this construction process changes in the future, where mostly everything prefabricated-off site, this might change the relation between companies and transport. This changes the existing supply chain, new players may come in and existing supply chains may not be so relevant anymore. It is urged to further scientifically address this complete construction process.
- It is recommended to not only look at new builds, but further investigate the existing building stock. This research primarily focused on new builds, while another problem in the industry is what the people need to do with the existing building stock.

7.4. Recommendations for professional practice

The recommendations for professional practice overlap with the actions for acceleration, which were extensively elaborated in the answer of sub-question 3 (section 6.1.2).

The government can use policy instruments to incentivize, communicate and cooperate with and enforce the private sector to enhance private emission reduction efforts. Moreover, contractors should also take social responsibility, instead of considering emission reduction at construction sites only as a governmental matter. Contractors should embrace the transition towards new ways of construction which includes emission reduction at the sites. This involves acknowledging the need for emission reduction, seizing and recognizing emission reduction opportunities and receptively positioning themselves towards the governments using policy instruments.

Likewise, governments as well have an important responsibility in stimulating and facilitating emission reduction efforts. In order to achieve this, governments should actively stimulate emission reduction through incentives, communication and cooperation and enforcement to create top-down demand for emission reduction at construction sites.

The absence of significant client demand for emission reduction efforts makes it hard for contractors to purposefully invest in emission reduction features, cause their clients are essentially not willing to pay for it, nor asking it on a large scale. More effort could be made by the government to increase a sense of urgency amongst contractors related to emission reduction. Award criteria can be effectively combined with subsidies to create incentives for contractors to get familiarised with emission reduction at construction sites. Facilitating subsidies can also enable contractors to alleviate financial burdens and see the merits of zero-emission. When the current momentum is being used, an increased long-term focus on emission reduction at construction sites can be achieved and important steps to speed up the transition can be made.

Gradually, zero-emission should become part of the contract requirements. These contractual requirements can become increasingly strict overtime. For instance, setting minimum standards or aiming for a particular reduction percentages in projects. The exact implementation of emission reduction is best to be left to the design freedom of private parties. This allows contractors to come up with better and smarter solution than governments could prescribe. Enforcement of emission reduction by law becomes a possible option when enough zero-emission equipment is available at construction sites. The combination of more intrinsic motivation by contractors and a active use of policy instruments by the government can pave the way for creating more resilient and future-proof way of construction.

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A

Definitions

Zero-emission construction site
A construction site in which zero-emission construction machinery or equipment is used for all construction activities, and zero-emission vehicles are used to transport people and goods to and from the site (Bellona, 2019).

Fossil-free construction site
A construction site in which no fossil fuels are used for construction activities. This occurs in operations where biodiesel or biogas, fuels not of fossil origin, replace conventional diesel fuels. Biofuels cannot be classified as zero-emission fuels, as the combustion of biofuels leads to the local emission of air pollutants (Bellona, 2019).

Zero-emission construction logistics
Using zero-emission vehicles to transport people and goods to and from the construction site (Bellona, 2019).

Zero-emission construction machinery and equipment
Machinery or equipment which emits zero pollutants when being used (Bellona, 2019).

Mobile machinery
Machinery that is used in the B&U (English: civil and utility construction) and GWW (English: civil engineering, road construction and hydraulic engineering) sector , including floating vehicles such as dredgers. This definition also includes construction logistics vehicles used for transport to and from construction sites. SEB (2021). Mobile machinery (or NRMM: non-road mobile machinery) involves a broad range of machinery developed for specific operations in off-road environments. Construction machinery (e.g. industrial trucks, handling and lifting equipment, mobile cranes and earthmoving machinery) (European Commission, 2021).

Construction logistics
Organising, planning, directing and executing the supply and disposal of building materials, construction workers and construction equipment to and from the construction site. Construction logistics also include construction concepts and digitalisation insofar as they contribute to above factors (SEB, 2021).

Control mechanisms
All measures to achieve sustainability, for example by facilitating, subsidising, stimulating, requiring and prohibiting. The implementation of control mechanisms and guidelines are in constant development, such as for tendering, policy and the fuelling and charging infrastructure for mobile machinery and construction logistics (SEB, 2021).

Supervision, enforcement and monitoring
The means to verify agreements on emissions, for example through enforcement based on monitoring and registration of actual emissions of machinery. Monitoring includes the calculation and measurement of emissions in practice, as well as the measurement of the effects of the measures. For example, does the number

of clean machines and sustainable tenders actually increase? Manuals for the implementation of monitoring and enforcement are in constant development (SEB, 2021).

B

Literature list

No.	Author(s)	Year	Title	Source Journal	Intended purpose
General					
1	Schum-peter & Backhaus	2003	The theory of economic development.	MA: Harvard	Innovation definition
2	Bredillet	2007	Project management: achieving competitive advantage	Book - Publisher: Pearson	Project life cycle stages
3	Davies et al.	2013	On-site energy management challenges and opportunities: a contractor's perspective	Building Research & Information	General shortcomings and key opportunities for on-site energy management by contractors
Low or zero-emission construction sites					
4	Clarke et al.	2017	What kind of expertise is needed for low energy construction?	Construction Management and Economics	Identify obstacles for low-energy construction. Recommendation of radical transition pathway.
5	Fufa et al.	2018	Estimated and actual construction inventory data in em-bodied greenhouse gas emission calculations for a Norwegian zero emission building (ZEB) construction site	International Conference on Sustainability in Energy and Buildings	Hierarchy of the largest on-site emission contributors.
6	Fufa et al.	2019	Lessons learnt from the design and construction strategies of two Norwegian low emission construction sites	IOP Conference Series: Earth and Environmental Science	Understand the main challenges and opportunities from the construction phase of emission-free building projects.

No.	Author(s)	Year	Title	Source Journal	Intended purpose
7	Anderson	2019	Zero Emission Zero Waste Construction Sites in California Commercial Construction: A Case Study	California Polytechnic State University	Use for the perspective that governments have the opportunity to pave the way for healthy, safe, and affordable zero-emission construction.
8	Andresen et al.	2019	The Norwegian ZEB definition and lessons learnt from nine pilot zero emission building projects	IOP Conference Series: Earth and Environmental Science	Learn the importance of an integrated design process, choosing locally sourced materials with low embodied carbon, having clear goals and associated assessment methods.
9	Hong et al.	2019	A Framework for Reducing Dust Emissions and Energy Consumption on Construction Sites	Energy Procedia	The importance of real-time monitoring
10	Venås et al.	2020	No or low emissions from construction logistics – Just a dream or future reality?	IOP Conference Series: Earth and Environmental Science	Understand the main challenges and opportunities in low or no emissions construction logistics.
11	Karlsson et al.	2020	Reaching net-zero carbon emissions in construction supply chains – Analysis of a Swedish road construction project	Renewable and Sustainable Energy Reviews	Understanding the need to speed up the implementation of decarbonisation in road construction, the role of procurement and policy measures. Key opportunities and main pitfalls in road decarbonisation.
Contractor behaviour to drive carbon reduction					
12	Wong & Zapantis	2013	Driving carbon reduction strategies adoption in the Australian construction sector - The moderating role of organizational culture	Building and Environment	Understand that stringent regulations may not necessarily induce adoption of carbon reduction strategies.

No.	Author(s)	Year	Title	Source Journal	Intended purpose
13	Wong et al.	2013	Towards understanding the contractor's response to carbon reduction policies in the construction projects	International Journal of Project Management	Understand the contractor's response on carbon reduction policies. Contractors may not adjust their attitudes for the sake of avoiding 'penalty'
14	Wong et al.	2014	Driving construction contractors to adopt carbon reduction strategies – an Australian approach	Journal of Environmental Planning and Management	Use for the perspective that rewarding schemes, training and education and levies on carbon as effective drivers of carbon reduction.
15	Zhang & Zhou	2016	The effect of carbon reduction regulations on contractors' awareness and behaviors in China's building sector	Journal of Cleaner Production	Use for the vision that increasing carbon reduction awareness and the adoption of carbon reduction regulations is an possible way to encourage contractors' carbon reduction behaviors.
Procurement by governments					
16	Kadefors et al.	2021	Designing and implementing procurement requirements for carbon reduction in infrastructure construction – international overview and experiences	Journal of Environmental Planning and Management	Factors that should be considered in the design on carbon requirements and policies to drive long-term innovation.
17	Baron	2016	The Role of Public Procurement in Low-carbon Innovation	OECD	Green public procurement
Emission reduction in construction					
18	Anthonis-sen et al.	2015	Using carbon dioxide emissions as a criterion to award road construction projects: a pilot case in Flanders	Journal of Cleaner Production	Award criteria emission reduction
19	Ahn & Lee	2013	Importance of Operational Efficiency to Achieve Energy Efficiency and Exhaust Emission Reduction of Construction Operations	Journal of Construction Engineering and Management	Construction project emissions
20	Peña-Mora et al.	2009	A framework for managing emissions during construction	National Science Foundation Cairo	Construction project emissions

No.	Author(s)	Year	Title	Source Journal	Intended purpose
21	Waris et al.	2014	Criteria for the selection of sustainable onsite construction equipment	International Journal of Sustainable Built Environment	Construction equipment selection
22	Ren et al.	2012	The measurement of carbon performance of construction activities: a case study of a hotel construction project in South Wales	Smart and Sustainable Built Environment	Carbon dioxide sources during construction
Innovation in the construction industry					
23	Havenvid	2015	Competition versus interaction as a way to promote innovation in the construction industry	IMP Journal	Project characterization
24	Dubois & Gadde	2002b	The construction industry as a loosely coupled system: implications for productivity and innovation	Construction Management & Economics	Innovation in the construction industry
25	Slaughter	1998	Models of construction innovation	Journal of Construction Engineering and management	Invention versus innovation differences
26	Bygballe & Inge-mansson	2014	The logic of innovation in construction	Industrial Marketing Management	Understand innovation in construction
27	Blayse & Manley	2004	Key influences on construction innovation	Construction innovation	Understand the key influences on construction innovation
Methodology					
28	Bryman	2016	Social research methods	Book. Publisher: Oxford university press	Interview design and coding
29	Yin	2014	Case study research: design and methods	Book. Publisher: SAGE Publications, Inc	Design case study
30	Wilson	2014	Essentials of business research: A guide to doing your research project	Book. Publisher: Sage	Design of the research
31	Bryman & Bell	2011	Ethics in business research	Business Research Methods	Keyword search
32	Bryman & Burgess	2002	Analyzing qualitative data	Book. Publisher: Routledge	Analysing the qualitative data

C
Interview protocol

The separate interview protocols per respondent group (A, B and C) will be elaborated in further detail in a later version of this thesis.

Interview Guide

I. Introduction

Introduce myself, communicate the goal and duration of interview (approximately 1 hour), discuss confidentiality, ask permission for recording the interview and communicate that the transcription of the interview will be shared with respondents

II. Introduction questions

What is the role that you fulfil in the organization that you work for?

What is your view on zero-emission construction sites?

III. Questions on barriers and drivers
Theme: barriers, drivers and transitions

To your understanding, what is the current state regarding emission reduction at construction sites in Dutch infrastructure projects?
- What do you think is/are the reason(s) for this?

[for case study related respondents the following questions will also be related to the case]

What do you think are the factors that hinder emission reduction at construction sites in Dutch infrastructure projects?

Can you think of any factors that impede the reduction of emissions at construction sites in Dutch infrastructure projects, in relation to:
- Governmental perspective
- Contractor perspective
- Technological perspective (machinery / logistics)

What do you think are the factors that stimulate/accelerate contractors in the transition towards zero-emission construction sites in Dutch infrastructure projects?

Can you think of any factors that stimulate/accelerate contractors in the transition towards zero-emission construction sites in Dutch infrastructure projects, in relation to:

- Governmental perspective
- Contractor perspective
- Technological perspective (machinery / logistics)

What do you want to advice contractors who want to make a realistic start to reduce emissions at construction sites on the short term?

IV. Questions on technical innovations
Themes: innovations, transitions

Where do you see the future of construction sites headed?

[Choose the correct protocol to continue depending on the respondent group:
A - Client
B - Contractor
C - Sub-contractor, developer, consultant]

A. Separate protocol - government
Themes: legislation, emissions, contracts and procurement, cooperation and financial investments

B. Separate protocol - contractor
Themes: emissions, contracts and procurement, cooperation and financial investments

C. Separate protocol - sub-contractor, developer, consultant
Themes: emissions, contracts (tenders), cooperation and financial investments

V. Interview closure

The respondent will be thanked for his/her time and informed that in a few weeks the transcripts will be sent to him/her.

VI. Post-interview actions

Transcribe interviews
Analyse transcriptions

D

List of respondents

Table D.1: List of interviewees

Organisation	Role/position	Interview type
Ballast Nedam	Tendermanager	Project - A1
Ballast Nedam	EMVI Coordinator	Project - A1
Ballast Nedam	Technical manager	Project - Amaliahaven
HOCHTIEF	Tendermanager	Project - Amaliahaven
Flux Partners	EMVI specialist	Project - Amaliahaven
Ballast Nedam	Corporate Social Responsibility Director	Strategic
Ballast Nedam Materieel	Manager Maintenance & Development	Strategic
Ballast Nedam Development	Development Manager	Strategic
Rijkswaterstaat	Programmamanager Transitiepad Bouwplaats en Bouwlogistiek	Strategic
Rijkswaterstaat	Adviseur Innovatie & Markt	Strategic
Rijkswaterstaat	Directeur Transitie	Strategic
Rijkswaterstaat	Innovatie adviseur Ruimte & Duurzaamheid	Strategic
B. de Vos B.V.	eigenaar/owner	Strategic

Table D.2: List of validation focus group participants

Organisation	Role/position
Ballast Nedam	Managing Director
Ballast Nedam	Executive Director
Ballast Nedam Infra B.V.	Directeur
Ballast Nedam Materieel	Bedrijfsdirecteur
Ballast Nedam Materieel	Manager Maintenance & Development