Public procurement of innovation and mission-oriented innovation policy for a zero-emission construction sector in the Netherlands

A Mission-oriented Innovation System analysis of the Dutch mission to transform the GWW-construction sector with zero-emission non-road mobile machinery

Master thesis

Ewout Matthijs Timmermans

1593390

Msc. Innovation Sciences

Department of Industrial Engineering and Innovation Sciences

Eindhoven University of Technology

Supervisors TU/e:

Georgios Papachristos

Néomie Raassens

Emilio Raiteri

Supervisor EVConsult:

Bram Leusink

Eindhoven, June 12th, 2023

I. Abstract

Introduction - The convergence of pressing concerns on global warming, nitrogen- and air pollution creates an acute societal need for a transformation of construction sites towards Zero-Emission (ZE) (Rijksoverheid, 2022). Hence, the use of Non-Road Mechanical Machinery (NRMM) on construction sites should transition from internal combustion engines (ICE) to zero-emission solutions as these do not produce direct tailpipe emissions (SEB, 2022; IPCC, 2022). Yet, the transition towards ZE-NRMM is slow as ICE and their associated practices are locked-in, so to date a limited number of ZE-NRMMs are used in the Dutch construction sector, and barriers exist for scaling them up (Rijksoverheid, 2022; Aalbers, 2022). To change this, the Dutch government formulated the mission to transform the construction sector and reduce its impact by ensuring through public procurement the increased uptake of ZE-NRMM by 2030 (SEB, 2022).

The implementation of missions by governments represents a shift in innovation policy, known as Mission-oriented Innovation Policy (MOIP), and is designed to address pressing societal challenges (Schot and Steinmueller, 2018; Haddad et al., 2019). Whilst the impact of missions is still under evaluation (Hekkert et al., 2023), there is consensus in the literature that demand should be at the core of MOIP (Wanzenböck et al., 2020; Boon and Edler, 2018; Weber and Rohracher, 2012). Mowery and Rosenberg (1979) highlight the influence of market demand on innovation and define demand as an expression of willingness to pay a certain price for the satisfaction of a need or want. By leveraging public organizations as key drivers, Public Procurement of Innovation can effectively enhance innovation dynamics, and incentivize an industry to invest in commercialization to bring innovative solution to the market (Edler and Georghiou, 2007; EC, 2016).

The link between Public Procurement for Innovation (PPI) and MOIP has been established in research (Uyarra et al. (2020); Wesseling and Edquist, 2018; Edquist and Zabala-Iturriagagoitia, 2012). Yet, the effects of PPI instruments on missions remains understudied whilst this is highly relevant to evaluate as it provides insights for policy makers to act upon and create effective PPI instruments to enact transformative change in mission-oriented innovation systems. Hekkert et al. (2020) introduced a framework of 'Mission-oriented Innovation Systems' (MIS) to study the innovation dynamics of mission-oriented systems by assessing the performance of system functions of innovation. The research will analyze the ZE-NRMM mission through the MIS approach, and investigate the effects of public procurement of innovation on the mission. This leads to the focal research question:

''How can public procurement of ZE-NRMM increase innovation to improve the success chances for the mission to create zero-emission construction sites in the Dutch GWW-construction sector?''

As this research question remains too broad to answer at once, narrower sub-questions are developed to guide the research and lead ultimately to the answer of the main research question:

SQ1: *''What technical and social solutions are linked to the mission and what are the underlying mission problems in the GWW-construction sector?''*

SQ2: *''What structural elements are present in the ZE GWW-construction MIS?''*

SQ3: *How do the system functions of the ZE GWW-construction MIS perform and what drivers and barriers are present that either stimulate or hamper the success of the mission?*

SQ4: *''What public procurement of innovation barriers are present in the Dutch GWW-construction sector?''*

SQ5: *"How do PPI barriers influence the systemic barriers of the MIS and what policy instruments can be implemented to improve PPI practices in the GWW-construction?"*

The study adds to the literature of MOIP by testing the application of the MIS framework, the conceptualization of the effects of PPI on underlying functions of the innovation system, and the broader effects of PPI as MOIP on the demand for innovative solutions within missions. In addition, the combined analysis will provide societally relevant policy implications that can address the systemic problems of the MIS that prevent mission success in the Dutch GWW-sector.

Theoretical embedding & methods - The roles of innovation policy and legitimation of policy intervention change as missions aim to address complex societal challenges, which require additional dimensions to appropriately study the innovation dynamics, namely: directionality, coordination, reflexivity and demand articulation (Wesseling et al., 2021; Wanzenböck et al., 2020; Weber and Rohracher, 2012). These dimensions are incorporated in the MIS framework which is defined as: *"the network of agents and set of institutions that contribute to the development and diffusion of innovative solutions with the aim to define, pursue and complete a societal mission"* (Hekkert et al., 2020, p.77). The MIS analysis is conducted in four main steps: Problem-solutions diagnosis, structural analysis, functional and system barriers analysis, and policy implications analysis (Reike et al., 2023). In combination with the MIS, PPI literature is used to address PPI barriers and identify their interrelations with the MIS map the PPI influences on the MIS. Uyarra et al. (2014), and Georghiou et al. (2014) provide a framework with four PPI categories, which are used to identify PPI barriers and related PPI instruments.

The research primarily follows a constructivist worldview, aiming to derive meaning from human behavior and interpretations (Creswell and Poth, 2016). Hence, qualitative research methods were used, including 27 semi-structured interviews with a broad range of stakeholders in the GWW-construction sector. The interviews were transcribed, coded by full line-by-line coding approach, and thematized based on the MIS system functions and PPI categories which led to 1654 codes, and 51 themes. Besides, a literature review was conducted of the GWW-construction sector, ZE-NRMM mission and procurement based on documents primarily from governmental institutions.

Results – The result section provides answers to the five formulated sub-questions, based around the problem-solution diagnosis, structural analysis, the innovation system functions and barriers, the PPI barriers, and the combined analysis of MIS and PPI effects and instruments.

First, the problem-solution diagnosis showed primarily that priority is given to the issue of nitrogen emissions due to the urgent nitrogen crisis in the construction sector, whilst emissions related to global warming and public health are secondary. In terms of solutions for ZE-NRMM the primary path is battery electric and secondary hydrogen based. In addition, the energy infrastructure requires a variety of solutions both grid and non-grid based to provide energy to the ZE-NRMM.

Second, the structural analysis highlights the variety of actors in the GWW-construction, and shows the contrast between actors actively involved in the mission arena (frontrunners), the actors not actively involved in the mission (platoon), and the global context. In addition, the institutions that influence the MIS in the GWW-construction sector relate to project based work, temporality, line-projects and learning, the competitive nature and low profit margins, long-depreciation terms of NRMM, and the Dutch NRMM market is relatively small for international OEMs.

Third, following the individual strengths and weaknesses of the system functions, five systemic barriers were identified in the MIS: (1) Lack of energy infrastructure mobilization hampering ZE-NRMM implementation, (2) Lack of knowledge diffusion creates a growing gap between the MIS arena and the overall MIS, (3) Lack of consistent long-term ZE-NRMM demand from public clients hampers market formation, (4) The Netherlands is dependent on international OEMs for the supply of ZE-NRMM, (5) and change in the regime of heavy ZE-NRMM is lacking in contrast to light & medium heavy ZE-NRMM (5).

Fourth, ten PPI barriers were identified, namely: (1) Competition on price and strict contracts reduces innovation in GWW-tenders, (2) ZE-NRMM tenders are less accessible for SME contractors, (3) Lack of knowledge, capacity, and capabilities in municipal public clients, (4) Lack of high level innovation strategy in smaller public clients, (5) Lack of identification of innovation potential of contractors, (6) Lack of identification and facilitation of energy infrastructure needs of contractors by public clients, (7) Lack of signaling the requirements of public clients for long-term ZE-NRMM to contractors, (8) Risk lack of take up of ZE-NRMM experienced by contractors, especially for the long-term usage, (9) Lack of balance between risks and rewards to incentivize contractors in ZE-NRMM tenders, and (10) Public clients are risk averse, especially municipalities are more risk averse.

Fifth, the PPI barriers reinforce the existing barriers of knowledge diffusion (SF3), market formation (SF5), and resource mobilization (SF6). However, the lack of supply from international OEMs (barrier 4) and the specific barrier for heavy NRMM (barrier 5) are not reinforced by PPI barriers. Besides, whilst PPI instruments implemented in practice only partially overlap with those prescribed in PPI literature, gaps remain in adequately addressing the PPI barriers that reinforce the systemic barriers.

Conclusion & discussion - The answer to the research questions is provided in a five point conclusion.

1. Growing competition on sustainability criteria in the GWW-sector hampers knowledge diffusion, but PPI instruments like innovation-friendly procedures, and follow-up projects to consolidate lessons-learned can lift this barrier.
2. The lack of capacity and capabilities in small public organizations hampers market formation, but PPI instruments like good practice networks, and the introduction of standards for procurement of ZE-NRMM can lift this barrier.
3. The experienced risk of low take up of ZE-NRMM by contractors on GWW-construction projects and the lack of energy infrastructure coordination hamper resource mobilization. Hence, PPI instruments should enable the long-term investment perspective for contractors by guaranteeing take up of ZE-NRMM in platform approach contracts, clearly signal long-term needs of public clients, and embed energy infrastructure identification and facilitation in tender procedures.
4. PPI barriers primarily affect platoon actors, whilst their transformation is essential to accelerate the MIS. Hence, lifting PPI barriers becomes essential to generate wider adoption of ZE-NRMM.
5. No PPI barriers reinforced the lack of supply from international OEMs or lack of regime change of heavy NRMM. International OEMs operate in global context, requiring innovation policy on European level. Heavy NRMM is expected to follow a similar path as light & medium-heavy NRMM, but should be closely monitored.

Nine **practical implications** follow from the conclusions and are formulated as suggestions for the governmental actors to implement policy instruments to tackle the PPI barriers that hamper the mission progress. The implications include: innovation-friendly procedures, collective learning in standard tenders, programmatic approaches in tender planning, good practice networks through umbrella organizations, ZE-NRMM procurement standards, local market consultation, signing and communicating the SEB covenant, platform approaches, and increased coordination of energy infrastructure.

Three **theoretical implications** follow from this study. First, the combined use of the MIS framework and PPI as MOIP is valuable due to the strong relation of PPI barriers with market formation, resource mobilization, and knowledge diffusion. Second, an operationalization is suggested for the strategic regime change function through power vs. interest matrixes as defined by Ackermann & Eden (2011). Third, the study reflects on a discussion of Kirchherr et al. (2023) and Hekkert (2023) on MOIP, adding to the discussion a nuance to the normativity bias and unintended effects of MOIP.

Five **limitations and areas of future research** have been defined. First, all but three of the identified stakeholder types were interviewed which may have led to a slight imbalance in stakeholder representation. These should be included in future research. Second, the Dutch MIS shows strong dependence on European contexts which was not included in this study, and future research should study the ZE-NRMM demand in EU context. Third, this study is qualitative and rather explorative leading to a broad set of barriers, and the quantification of the PPI barriers and effectiveness of PPI instruments would provide a strong validation of its conclusions?. Fourth, synergies with other mission have been under evaluated in this study, but could be valuable to research multiple missions in transition context via policy mix literature. Fifth, energy infrastructure solutions are important in the ZE-NRMM mission, but not mapped in depth and thus future research could solely focus on this challenge.

II. Acknowledgments

With this acknowledgement I express my gratitude and appreciation for everyone closely involved in this master thesis project. First, I would like to emphasize that I am grateful for the continuous involvement, effort, and reflection that all three supervisors have offered. Thank you George Papachristos, Néomie Raassens, and Emilio Raiteri for the diverse insights you have provided. Second, I'd like to acknowledge the effort and role of the exam committee overseeing master student projects, and ensuring the quality of TU Eindhoven graduates. Third, I'd like to thank all EVConsult staff who were always open to help and supported me in this project. More specifically, I thank Bram Leusink as company supervisor, who week in week out encouraged me and reflected with me on the research project which was incredibly valuable. Fourth, I want to thank co-graduate intern Jolijn van Dijk and my friend Maurits van Schaik, with them I had many inspiring sparring sessions and interchanged ideas throughout the research. Last, and certainly not least, I am indebted to all the 27 interviewees that provided valuable insights to the research, and above all their enthusiasm encouraged me to make the most of this research project. Thank you all!

III. Table of contents

IV. Abbreviations

BEV	Battery Electric Vehicle
BPKV	Beste prijskwaliteitsverhouding (English: Beste price quality ratio)
CO_2	Carbon dioxide
CPO	Charging Point Operator
EMVI	Economisch meest voordelige inschrijving (English: Economically most advantageous tender)
ENI	Emissieloos netwerk infra (actor network)
EU	European Union
FCEV	Fuel-cell Electric Vehicle
GHG	Greenhouse Gases
GWW	Grond-, Water-, Wegenbouw (English: Ground-, Water-, Roadconstruction)
HVO	Hydrotreated vegetable oil
ICE	Internal Combustion Engine
I&W	Ministerie van infrastructuur en waterstaat (English: Ministry of infrastruture and watermanagement)
IPCC	Intergovernmental Panel on Climate Change
IPO	Interprovinciaal overleg (umbrella organization provinces)
IS	Innovation System
KCI	Klimaatneutrale en circulaire rijksinfrastructuurprojecten (English: Climate neutral and circular government infrastructure projects)
MIS	Mission-oriented innovation system
MOIP	Mission-oriented innovation policy
NO_x	Nitrogen oxide
NRMM	Non-Road Mobile Machinery
OEM	Original Equipment Manufacturer
PM	Particulate matter
PPI	Public Procurement of Innovation
PSN	Programma Stikstofreductie en natuurverbetering (English: Program nitrogen reduction and nature preservation)
R&D	Research and development

RAW	Rationalisatie en Automatisering Grond-, Weg, en Wegenbouw
RWS	Rijkswaterstaat
SEB	Schoon en Emissieloos Bouwen (English: Clean and Zero-emission construction)
SLA	Schone luchtakkoord (English: Cleanair accord)
SME	Small and medium-sized enterprises
SSEB	Subsidie Schoon en Emissieloos Bouwen (English: Subsidy for clean and zero-emission construction)
TCO	Total cost of ownership
TIS	Technological innovation system
TRL	Technology readiness level
UN	United Nations
UvW	Unie van Waterschappen (umbrella organization water authorities)
VNG	Vereniging van Nederlandse Gemeenten (umbrella organization municipalities)
WDSM	Weg-, Dijk-, en Spoormaterieel (English: Road, Dike and Railway machinery)
ZE	Zero-emission
ZEV	Zero-emission vehicle

1. Introduction

Climate change mitigation remains one of society's most pressing challenges in the 21st century and requires all industry sectors to decarbonize (IPCC, 2022). Decarbonization of the construction sector is vital as it accounts for 23% of global greenhouse gas emissions (Huang et al., 2018). Approximately 5.5% of these emissions originate in construction sites from fossil fuel use in machinery, power equipment, and transport vehicles (Huang et al., 2018; DNV GL, 2019; Desouza et al., 2019). In addition, construction processes generate vast amounts of local NO_x emissions that harm the natural environment and create air pollution in cities (Huang et al., 2018; NREL, 2022). In the Netherlands, NO_x emissions led to disruptions in hundreds of construction projects as the nitrogen crisis prohibited their continuation (Provinciale staten, 2019). Due to the convergence of pressing concerns on climate, nitrogen, and air pollution, there is an acute need for a transition from internal combustion engine (ICE) towards the use of Zero-Emission (ZE) in construction sites (Rijksoverheid, 2022).

ZE solutions can be divided in a variety of technologies: the Battery Electric Vehicles (BEV), Fuel-Cell Electric Vehicles (FCEV), and Non-fossil Fuels Vehicles (Ihonen et al., 2021; WGBC, 2019; Lajunen et al., 2018). Yet, the transition towards ZE-NRMM is slow as ICEs and their associated practices are locked-in, so to date only a few ZE-NRMMs are used in the Dutch construction sector, and barriers exist for their scale up (Rijksoverheid, 2022; Aalbers, 2022; Geels, 2005). To change this, the Dutch government formulated the mission to reduce the impact of the construction sector on global warming, the nitrogen crisis, and local clean air by ensuring through public procurement the increased uptake of ZE-NRMM by 2030 (SEB, 2022; Rijksoverheid 2019).

The implementation of missions by governments represents a shift in innovation policy, known as Mission-oriented Innovation Policy (MOIP), and is designed to address pressing societal challenges (Schot and Steinmueller, 2018; Haddad et al., 2019). Grand societal challenges encompass complex social, environmental, and economic problems that require a much stronger degree of directionality to enact transformative, long-term change in the system (Schot and Steinmuller, 2018; Mazzucato, 2018). The roles of innovation policy and legitimation of policy intervention change as they need to be built around directionality, coordination, reflexivity, and demand articulation (Wanzenböck et al., 2020; Weber and Rohracher, 2012).

Whilst the impact of missions is still under evaluation (Hekkert et al., 2023), there is a consensus in the literature that demand should be at the core of MOIP (Wanzenböck et al., 2020; Boon and Edler, 2018; Weber and Rohracher, 2012). Public procurement of innovation (PPI) has emerged as an effective policy to stimulate demand, especially in markets where the government has a substantial market share (Chiappinelli et al., 2023). By leveraging public organizations as key drivers, PPI can effectively enhance innovation dynamics, and incentivize industry to invest in commercialization to bring innovative solution to the market (Edler and Georghiou, 2007; EC, 2016).

The link between PPI and MOIP has been established in research (Wesseling and Edquist, 2018; Edquist and Zabala-Iturriagagoitia, 2012). Indeed, Uyarra et al. (2020) define roles for the governments regarding different forms of PPI based on the problem-solution space of a specific mission. However, the role of PPI instruments and its role in missions in practice remains understudied, whilst this is highly relevant to evaluate as it provides insights for policy makers to act upon and create effective PPI instruments to enact transformative change in mission-oriented innovation systems. Hekkert et al. (2020) introduced a framework of 'Mission-oriented Innovation Systems' (MIS) that enables scholars to study the innovation dynamics of mission-oriented systems by assessing the performance of system functions of innovation. This framework will be applied to the ZE-NRMM mission within the Dutch Ground-, Water-, Roadway (GWW) construction as 80% of the of the construction budget is publicly procured (TenderNed, 2022; BouwendNederland, 2022), thus making it highly valuable to the study of PPI practices.

Ultimately, this study aims to address the challenges that the Dutch GWW-construction faces in scaling up the implementation of ZE-NRMM to increase mission success. The research will analyze the ZE-NRMM mission through the Mission-oriented Innovation System approach, and investigate the effects of public procurement of innovation on the mission. In the end, the combined analysis will provide the basis for policy implications for PPI that can address the systemic problems of the MIS that prevent mission success in the Dutch GWW-sector. The focal question of this research is:

How can public procurement of ZE-NRMM increase innovation to improve the success chances for the mission to create zero-emission construction sites in the Dutch GWW-construction sector?

As this research question remains too broad to answer at once, narrower sub-questions are developed to guide the research and lead ultimately to the answer of the main research question:

SQ1: *''What technical and social solutions are linked to the mission and what are the underlying mission problems in the GWW-construction sector?''*

SQ2: *''What structural elements are present in the ZE GWW-construction MIS?''*

SQ3: *How do the system functions of the ZE GWW-construction MIS perform and what drivers and barriers are present that either stimulate or hamper the success of the mission?*

SQ4: *''What public procurement of innovation barriers are present in the Dutch GWW-construction sector?''*

SQ5: *''How do PPI barriers influence the systemic barriers of the MIS and what policy instruments can be implemented to improve PPI practices in the GWW-construction?''*

This study adds to the scientific body of literature on MOIP by applying the MIS framework which is relatively novel in the innovation sciences domain (Hekkert et al., 2020). This study will apply the framework to the GWW-construction sector in the Netherlands and the mission for the uptake of ZE-NRMM. This study contributes to the literature in three ways: (1) it serves as a test the application of the MIS framework, (2) it conceptualizes the effects of PPI on underlying innovation system functions, (3) it conceptualizes the broader effects of PPI as MOIP on the demand for innovative solutions within missions.

First, whilst Reike et al. (2023) have applied the MIS framework, its application in this study can corroborate the value of the MIS framework as part of MOIP literature. Second, whilst the link between MOIP and PPI has been researched (Urraya et al., 2020; Wesseling and Edquist, 2018), the effects of PPI on the innovation system dynamics of missions as MOIP remains unresearched in extant literature. Third, the combined use of MIS framework and PPI can provide novel insights in this area and corroborate the broader effects of PPI as MOIP.

The societal relevance of this study lies in the contribution of policy implications for the GWW-sector-system. The transition in the construction sector to zero-emission is a necessity to mitigate climate change, desirable to reduce air-pollution and improve public health, and provide a solution to the acute nitrogen crisis. Therefore, the transformational change towards ZE-NRMM in the Dutch GWW-construction sector requires to address challenges that are as much societal as technological in nature. The ZE-NRMM innovations that are technical in their core are essential to enable the multitude of socially interrelated stakeholders to create zero-emission construction sites. Hence, to create swift mission success, this study may provide valuable policy implications for policymakers on how to further govern and transform the GWW-construction sector with ZE-NRMM.

The rest of the paper is outlined as follows. The second chapter elaborates on the theoretical embedding of the research concepts. The third chapter elaborates on the methodology of the research. The fourth chapter elaborates on the results of the research. The fifth chapter provides a conclusion by answering the research question and a discussion of the results with theoretical and practical implications. In addition, the limitations of the research and future directions for research are discussed. Last, the appendices provide background information on the variety of zero-emission solutions, and variety of tender methods used in the GWW-construction sector.

2. Theoretical Embedding

This chapter elaborates on the relevant frameworks and theoretical concepts that underlie the posed research question. An introduction to innovation systems will be given, which is linked to the Mission-oriented Innovation System (MIS) approach. In addition, Public Procurement for Innovation is introduced in relation to Mission-Oriented Innovation Policy (MOIP).

2.1. Introduction to innovation systems

The Innovation System (IS) approach emerged over the past decades with the combination of evolutionary and institutional theories (Nelson and Nelson, 2002). The IS approach is constructed around the idea that all economic structures and institutions affect both the rate and direction of technological change in society (Edquist and Lundvall, 1993). Accelerating innovation in society is important as it is a key determinant for long-term economic growth (Schumpeter, 1939; Aghion et al., 2005). According to Edquist (2001), it is possible to track the determining factors that affect the development, spread, and adoption of innovation by defining the activities that take place inside the IS. This led to a range of frameworks that provide a lens to analyze and provide policy recommendations in a National, Regional, Sectoral, or Technological setting (Lundvall et al., 1988; Doloreux, 2002; Malerba, 2002; Hekkert et al., 2007).

Yet, the field of innovation policy is evolving swiftly with the rise of a 'third generation' innovation policies to overcome societal challenges (Haddad et al., 2019). These challenge-based policies are built around a central mission, in which the directionality of missions and wickedness of societal problems are emphasized (Mazzucato, 2018; Alford and Head, 2017). These concepts contradict the underlying rationale of innovation systems, as these systems are more open-ended and are based on the fact that each innovation system is unique in terms of institutions due to their path dependence (Arthur, 1989). A mission is often at odds with existing institutions and therefore requires a change of its system trajectory course (Unruh, 2002; Mazzucato, 2018). These existing IS frameworks are unable to capture the dynamics of wicked societal challenges and need to be expanded to accommodate the analyses of a system centralized around a mission. Hekkert et al. (2020) introduced the Mission-oriented Innovation System (MIS) approach, which has been used by a variety of scholars (Bours et al., 2022; Baarends 2022; Arkel, 2021; Wesseling et al., 2021; Reike et al., 2023). The MIS as theoretical framework is elaborated on in the sub-chapters below.

2.2. Mission-oriented Innovation System

The Mission-oriented Innovation System (MIS) approach builds upon the Technological Innovation System of Hekkert et al. (2007) and aims to capture the innovation activities within the MIS, which is delineated by the formulated mission. The MIS is defined as: *"the network of agents and set of institutions that contribute to the development and diffusion of innovative solutions with the aim to define, pursue and complete a societal mission"* (Hekkert et al., 2020, p.77). There are four main analytical dimensions in which differentiate the MIS from other frameworks and enable the study of Mission-oriented Innovation Systems (Wesseling et al., 2021).

First, there is analytical focus on one mission, which relates to technological and societally innovative solutions and associated phase-out of existing technologies (Wesseling et al., 2021). Second, societal challenges are by definition 'wicked', as they involve uncertainty, complexity, and contestation in terms of problem definition as well as solution scope, creating difficult trade-offs in prioritization (Wanzenböck et al., 2019; Rittel and Webber, 1974). Third, missions are embedded in a system, and they have a certain time horizon to which they must be completed or discontinued. The aim of the framework is to mobilize actors, resources, institutions, and infrastructure of the innovation system to deliver on the mission, thereby emphasizing the institutional embedded nature of innovation activities

(Bergek et al., 2015; Edquist, 2001). Fourth, the directionality of a mission provides space for multiple solutions and technologically different types of solutions, as these are not specified by the mission (Wanzenböck et al., 2019; Mazzucato, 2018). Ultimately, due to the wickedness of the problem and directionality of the mission, it is necessary that innovation activities are coordinated to ensure that a coherent set of technological, institutional, and behavioral solutions are developed to support the MIS.

2.3. MIS framework

The MIS based analysis can be conducted in four main steps (Reike et al., 2023; Bours et al., 2022):

1. **Problem-solution diagnosis**: map the scope and complexity of the mission by identifying the problems and solutions associated with the mission.
2. **Structural analysis**: map the actors and institutions of the system that potentially drive or hamper the mission's progress and direction.
3. **Functional and systemic barriers analysis**: map the innovation activities that fulfill functionalities within the system and identify systemic barriers that hamper the development of the system.
4. **Policy implications analysis**: identify policy implications that can address barriers in the MIS.

The steps are elaborated in more detail in paragraphs 2.3.1-4.

2.3.1. Problem-solution diagnosis

The first step of the MIS is to create clarity on the scope and complexity of the mission by setting up a problem-solution diagnosis, which maps the problem(s) that must be solved by means of the mission and the proposed solutions to accomplish the mission (Wesseling et al., 2021). A problem-solution diagnosis helps to examine whether the parties involved recognize the problem, to what extent they agree with each other about the problem, and the priority they give to the problem over other societal problems (Wanzenböck et al., 2020). Based on the amount of divergence and convergence on problems and solutions between actors, it can be understood whether there is a momentum driving the mission or that the system lacks alignment. The same approach can be taken for all actors in terms of priority for technical and social solutions and the overall divergence or convergence among actors in the MIS. Moreover, in the end of the diagnoses the variety of solution paths are related to the set of problems, and it is being judged whether these match or that gaps exist to completely eliminate the problems.

2.3.2. Structural analysis

The second step of the MIS is to analyze the system structure, which includes the actors, institutions, networks, and materiality that affect the mission (Reike et al., 2023; Bergek et al., 2015). There is a special group of actors that are highly involved and influential in defining, steering, and guiding the MIS as it progresses. These actors are central in formulating, mobilizing, and governing the structural components of the system to enact change, they comprise the mission arena (Wesseling et al., 2021). Yet, this is a relatively small group of actors whilst ultimately more support is necessary to develop, adopt, and diffuse solutions that enable mission success, they comprise the peripheral actors (Bours et al., 2022). As the MIS and its mission-arena affect existing institutional structures that relate to the mission, it is important to coordinate innovation activities to create alignment between the various systems and effectively work towards the central mission (Hekkert et al., 2020; Wesseling et al., 2021). In Figure 1, a conceptualization of the mission arena is shown in comparison to the overall MIS and other institutional structures.

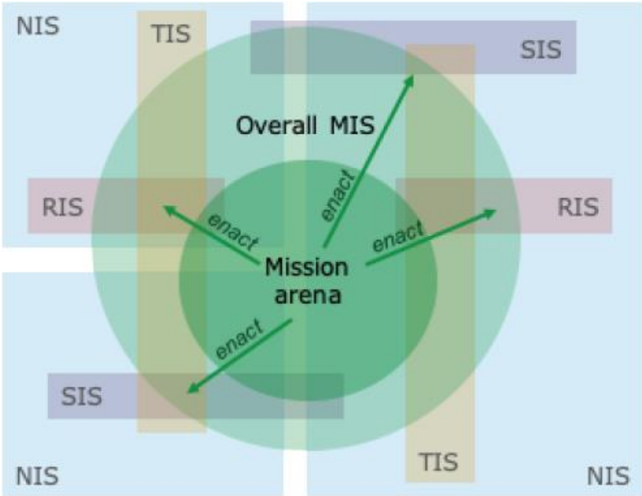


Figure 1: Visualization of the MIS, and its mission-arena which enacts change towards other institutional structures relevant to the mission (Wesseling et al., 2021).

2.3.3. Functional and systemic barriers analysis

The third step of the MIS is to measure the functioning of the innovation system and identify drivers and barriers of the system. The definition of the activities that take place inside the IS and the measurement of their performance, provide insight into the factors that drive or hamper the development, spread, and adoption of innovation (Edquist, 2001; Hekkert et al., 2007; Bergek et al., 2008). The better the system performance, the greater the chance that the mission will be achieved. Whilst the functions are listed separately in Table 1, their interactions are very important as they can interact positively and accelerate growth or interact negatively and slow down the MIS. The development phase of the MIS determines which functions and interactions are more or less important, and this depends on the extent to which solutions are adopted and diffused in the MIS (Hekkert et al., 2011; Wesseling et al., 2021).

Table 1: MIS system functions, adapted from Reike et al. (2023) and Bours et al. (2022).

Function	**Description**
SF1: Entrepreneurial activities	Experiments with (clusters of) solutions to enable learning; entering markets for new solutions; engaging in business model innovations to the diffusion of solutions.
SF2: Knowledge development	Learning by searching and by 'doing', resulting in development and better understanding of new technical and social knowledge on problems and solutions, through R&D, social and behavioral science research.
SF3: Knowledge diffusion	Stakeholder meetings, conferences, governance structures, public consultations, mission progress reports and other forms of disseminating technical and social knowledge for the mission's solutions and societal problems.
SF4A: Problem directionality	The direction provided to stakeholders' societal problem conceptions and the level of priority they give it.
SF4B: Solution directionality	The direction provided to the search for technological and social solutions, as well as having a shared vision to identify, select and exploit synergetic sets of solutions to the mission.
SF5: Market formation	Creating a niche market and upscaling support for technical and social solutions that contribute to the mission.
SF6: Resource mobilization	Mobilization of human, financial and material resources to enable all other system functions.
SF7: Creation of legitimacy	Creating legitimacy for prioritizing the problem and the development and diffusion of its solutions.
SF8: Coordination	Dealing with the diversity of solutions requires coordination between actors to jointly accelerate the system growth towards the mission. Coordinating roles can be fulfilled by governments, companies, NGOs, industry associations or a consortium of these types of actors.
SF9: Regime change	In addition to building up the system, the dismantling of the old system is just as important. The phasing out and unlearning of restrictive practices is considered important. Both institutional frameworks and consumer expectations need to be reshaped to break down the current market and habits.

When the system functions have been analyzed and the function interactions mapped, systemic barriers can be identified. The innovation literature describes these barriers as elements that impede the direction and speed of innovation processes and hinder the development of innovation systems (Wieczorek and Hekkert, 2012). The systemic barriers can be identified based on the structural elements of all ten system functions. A barrier occurs when structural elements (e.g., actors) are not present or when the rules of the game within the system need to change to drive the MIS.

2.3.4. Analysis of policy implications

The policy implications will be based on the identification of systemic instruments that aim to address systemic barriers (Smits and Kuhlmann, 2004). The primary objective of these instruments is to address the underlying causes that prevent swift mission success (Wesseling and Van der Vooren, 2017). Recommendations for these systemic instruments are defined afterwards by exploring gaps in the currently implemented policy instruments that either insufficiently address systemic barriers or do not address them at all. In this study, Mission-oriented Innovation Policy instruments are based on Public Procurement of Innovation, with the aim to increase mission success by addressing PPI barriers. Therefore, subchapter 2.4 provides an overview of PPI literature, and elaborates on PPI barriers as well as instruments.

2.4. Public procurement of innovation

This sub-chapter introduces the public procurement of innovation literature. The PPI theory provides a foundation to research PPI in the mission-oriented context of the GWW-construction and the identification of barriers for PPI in the MIS.

2.4.1. Introduction to Public Procurement of Innovation

Public Procurement for Innovation (PPI) finds it origin in the fact that private companies struggle to reap the benefits of their innovations (Nelson, 1959). As a result, they underinvest in R&D in the early stages, leading to low innovation rates, which is detrimental to economic growth (Arrow, 1962; Reinganum, 1985). The rationale is that through PPI, the public sector can demand innovations that satisfy public needs or societal problems, and with its purchasing power can create critical mass that incentivizes industries to scale up production of these solutions for the greater good (Edquist and Hommen, 2000; Raiteri, 2018; EC, 2023).

Therefore, the demand side potential of PPI is especially relevant for sectors where public authorities command substantial shares of the market (Chiappinelli et al., 2023). As a result, PPI can prove effective in alleviating market and system failures that hinder the conversion of needs into functioning markets for innovative products (Edler and Georghiou, 2007). Therefore, PPI can be seen as the process where a governmental agency makes a purchase or places an order for a service, good, or system that is not yet in existence but may be created in a timely manner with the help of new or additional innovative work by the companies willing to manufacture, supply, and market the products being acquired (Edquist and Hommen, 2000).

As the rationale of PPI is grounded in solving societal problems, Edquist and Zabala-Iturriagagoitia (2012) argue that Public Procurement for Innovation can be exploited as a mission-oriented innovation policy (MOIP) in the mitigation of grand challenges. However, pursuing effective PPI practices as a mission-oriented innovation policy is a radical change for policy makers as is it requires a shift from predominantly supply-side innovation policy towards demand-side policies. This shift requires capabilities to make institutional changes within governments, which can be challenging and leads to barriers for the implementation of PPI (Mazzucato, 2018; Georghiou et al., 2014).

2.4.2. Barriers to Public Procurement of Innovation

Barriers for the implementation of PPI practices and instruments have been bundled by Uyarra et al. (2014) and Georghiou et al. (2014), who define four policy categories in which PPI barriers can occur, shown in Table 2.

Framework conditions

The framework conditions determine the freedom and flexibility public clients have in designing and implementing procurement activities (Georghiou et al., 2014). The freedom in design of procurement activities is influenced by legislative background, and broader governance in terms of (de-)centralization or autonomy that applies across different levels of public bodies and procurement purchase size (Georghiou et al., 2014). The latter can limit public clients in the use of more innovation-friendly procurement procedures, reducing the options to trigger innovation in tenders in the first place (Uyarra et al., 2014). An additional challenge is the ability of SMEs to win public sector contracts and therefore their capacity to provide innovative solutions (Glover, 2008). This is reinforced through framework conditions in public tendering where selection criteria or previous experience favors incumbents of the industry, and exclude SMEs from participating (Cabral et al., 2006).

Organization and capabilities

The organizational aspects and capabilities of public clients is a major root cause for PPI barriers. In contrast to procuring off-the-shelf goods against lowest cost, the procurement of innovation requires a higher level of internal expertise (Rothwell & Zegveld, 1981). The development of closer supplier relationships and market participation are often hampered by insufficient commercial expertise among public clients. Georghiou et al. (2010), in their survey of public procurement in small European countries, discovered a lack of procurement knowledge for more complex innovation related procurement activities, and formal training opportunities for public clients. Especially at decentralized lower levels of governance (e.g., municipalities) challenges occur due to the scarcity of professional procurers, which ultimately leads to a lack of skills for the implementation of innovative procurement strategies (Uyarra, 2010; Cunningham, 2009).

Identification, specification, and signaling of needs

The identification, specification, and signaling of needs by public clients in the choice of individual purchasing decisions provides another root cause for PPI barriers. First, the lack of identification of a certain need by budget holders in public organizations can prohibit procurement of innovation, and primarily occurs when there is lacking knowledge on the innovation potential in the market (Georghiou et al., 2014). Second, the specification of needs in tenders can become a barrier for innovation when specifications are too rigid and narrowly defined, which impedes suppliers from suggesting innovative approach to achieve desired outcomes. Therefore, tender specifications defined in terms of outcomes or performance is considered more appropriate to provide suppliers with more room for innovation (Geroski, 1990). Third, signaling of needs in tender procedures is important to create early interaction between buyer and supplier to be able to better capture innovation (Georghiou et al., 2014). However, throughout the procurement process, the lack of expertise, fear of taking risks, or excessively rigid adherence to procurement regulations and practices might impede engagement and communication between public clients and potential suppliers (Erridge and Greer, 2002).

Incentivizing innovative solutions

Whilst the previous policy categories focus on triggering innovation, public procurement can also incentivize innovative solutions by proactively embracing innovation and acquiring recently developed innovations that are novel to the public organization (Georghiou et al., 2014). Therefore, public government can have a key role as demanding client, to which suppliers will respond with innovative solutions if clear needs and sufficient demand is signaled (Uyarra and Flanagan, 2010). Hence, the lack of demand from public clients causes a barrier, especially in sectors such as the construction industry where the public sector is a first user of innovation (Dalpé et al., 1992). However, even if public clients demand innovation, incentives may be lacking to convince suppliers to invest heavily into the knowledge required to innovate (Cabral et al., 2006). This can be eliminated by adequately incentivizing suppliers via longer contracts or aggregating demand. Yet, risk aversion in public clients due to strong expectations on transparency and accountability can provide an additional barrier to actually implementing these incentives (Tsipouri et al., 2010).

Table 2: Policy measures in support of PPI (Georghiou et al., 2014).

Policy category	**Deficiencies addressed**	**Instrument types**
Framework conditions	Procurement regulations driven by competition logic at the expense of innovation logic.	Introduction of innovation-friendly regulations
	Requirements for public tenders unfavorable to SMEs	Simplification and easier access for tender procedures
Organization and capabilities	Lack of awareness of innovation potential or innovation strategy in organization	High level strategies to embed innovation procurement
	Procurers lack skills in innovation-friendly procedures	Training schemes, guidelines, good practice networks
		Subsidy for additional costs of innovation procurement
Identification, specification, and signaling of needs	Lack of communication between end users, commissioning and procurement function	Pre-commercial procurement of R&D to develop and demonstrate solutions
	Lack of knowledge and organized discourse about wider possibilities of supplier's innovation potential	Innovation platforms to bring suppliers and users together; Foresight and market study processes; Use of standards and certification of innovation
Incentivizing innovative solutions	Risk of lack of take up of suppliers' innovation	Calls for tender requiring innovation; Guaranteed purchase or certification of innovation; Guaranteed price/tariff or price premium for innovation
	Risk aversion by procurers	Insurance guarantees

This study applies the PPI barrier framework of Georghiou et al. 2014 (Table 2), and thereby follows papers that apply the framework such as Selviaridis et al. (2023). The policy categories provide a frame for the barriers of PPI and the instrument types provide directions on how to address these barriers. The identification of PPI barriers in relation to the systemic barriers of the MIS will provide insights in how to better address these systemic barriers by improving the PPI practices of the government. Combining these insights with the appropriate PPI instruments will help with the choice, design, and implementation of PPI policy implications for the Dutch ZE GWW-construction sector. The next chapter contains the methodology of the research in which attention is paid to how these frameworks and concepts are operationalized and studied in the real world.

3. Methodology

The methodology elaborates on the research design, research methods for collection and analysis of data, and the reliability and validity of the research, with the ultimate purpose to answer the main research question.

3.1. Research design

This research primarily follows a constructivist worldview. Rather than testing a post-positivist hypothesis, it aims to derive constructivist meaning from human behavior and interpretations (Creswell and Poth, 2016). Constructivism is based on the belief that individuals develop subjective meanings of their experiences, in which the complexity of these views is emphasized rather than narrowing them into a few categories (Creswell and Poth, 2016). The ontological view is that reality is subjective and multifaceted as seen by participants and endorses the use of quotes and themes of participants to provide evidence for these different perspectives (Creswell and Poth, 2016).

This research is conducted through qualitative methods to enable the research to generate in-depth insights into the motives, opinions, and needs of a target group (Bryman, 2016). Qualitative research suits the constructivist worldview, which requires a detailed understanding of complex issues (Creswell and Poth, 2016). Especially in relation to innovation systems, which have complex dynamics and comprise of multiple stakeholders, both the worldview and qualitative approach will provide valuable insights into the barriers and drivers of the system and the relation to public procurement of innovation.

During the qualitative research, patterns, categories, and themes are built from the 'bottom-up', making it an inductive process (Creswell and Poth, 2016). The barriers and drivers of the system are identified by progressively organizing the data into higher levels of abstraction, and engage in iterative exploration of themes to synthesize the information.

This research adopts a single case study approach, with which a bounded system is explored over time, and includes detailed, in-depth data collection involving multiple sources of information, and ultimately the research reports a case description and case-based themes (Creswell and Poth, 2016). This research explores the case of Zero-Emission GWW-construction in the Netherlands and aims to answer the question: ''*How can public procurement of innovation of ZE-NRMM be improved to increase the success chances for the mission to create zero-emission construction sites in the Dutch GWW-construction sector?''* As this research question remains too broad to answer at once, narrower sub-questions have been setup in the introduction that will be answered throughout the specific phases of data collection and analysis (Bryman, 2016). Sections 3.3 and 3.4 explain the data collection and analysis following the sub-questions.

3.2. Data collection

This section discusses the research techniques used to collect data, comprising a literature review, and semi-structured interviews.

3.2.1. Literature review

This section introduces the literature necessary to map the problem-solution diagnosis (SQ1) and provides an initial understanding of the structural components of the MIS (SQ2). This literature review is partially based on the 'Narrative Review' method where the research aims to provide qualitative interpretations of the relevant literature and enables the researcher to provide a deep understanding of the problem (Greenhalgh et al., 2018). In this study, the literature review primarily enables the researcher to obtain a foundational understanding of the research topic, which serves as the fundamental basis for subsequent steps in the research. Hence, the primary source of information was obtained through government documents which provided context specific information for this study, whilst scientific literature is primarily for the construction sector in general. During the review, the identified literature was screened for inclusion based on the scope of the research, and its quality was assessed by checking whether the source supported arguments with references, and provided appropriate data presentation and evidence (Templier and Paré, 2015).

For the problem-solution diagnosis (SQ1), the goal is to identify the problems and solutions that relate to the mission. In addition, for all solutions the advantages and disadvantages will be mapped together with their Technology Readiness Level (TRL), and innovation type (radical or incremental). These are based on scientific publications, company and technology reports, and Dutch policy documents on zero-emission construction obtained through Google Scholar, Google Search, and Dutch government sites. The latter were also used for the structural map of the MIS, identifying the actors involved in mission formulation, mobilization, and governance, and the broader structural components. The latter 'components' specifically refers to actors, institutions, networks, and materiality related to the mission's problems and solutions. However, as it is virtually impossible to map all materiality (i.e., physical infrastructure) systematically, this study deliberately excludes the operationalization of physical infrastructures, while maintaining the non-tangible infrastructures (knowledge and financial) as these are inherently linked to specific system functions (e.g., knowledge development and resource mobilization). In addition, the literature review provides a basis to grasp how procurement practices in the GWW-construction sector are organized (SQ4), by using data sources such as Dutch government websites and PIANOo (expertise platform for Dutch procurement). The next section will elaborate on the semi-structured interviews.

3.2.2. Semi-structured interviews

The second method used in this research is semi-structured interviews, which are the primary source of data. They provides a deep understanding of the structural components (SQ2), MIS functions performance (SQ3), PPI barriers (SQ4), and policy implications (SQ5). The semi-structured interviews provide deep understanding by using open-ended questions and relying on the interviewer to probe whenever topics of interest come up (Harrell and Bradley, 2009). In this case interviewees are selected through purposive sampling, which is an appropriate sampling method to enhance understanding of the experiences of a select group of people, in this case related to the ZE GWW-construction (Devers and Frankel, 2000). The aim of purposive sampling is to select information-rich or expert individuals that can therefore provide the greatest insights into the research question (Devers and Frankel, 2000).

For the functional performance of the MIS and PPI framework, diagnostic questions are used to ensure that all relevant topics are discussed and to provide concrete insights into how the separate functions are performing (Appendix A). The use of guiding diagnostic questions is an established method to determine system performance and identify barriers (Wieczorek and Hekkert, 2012; Reike et al., 2023; Wesseling et al., 2021). The diagnostic questions of the MIS have been adapted from Wesseling et al. (2021), whilst for the PPI barriers they were set up by the researcher. The diagnostic questions for PPI were set up based on the policy categories and barriers. The diagnostic questions of both MIS and PPI were then transformed into an interview guide which is based on a funnel approach. The questions followed the MIS steps and PPI, and gradually introduces more narrowly-scoped open-ended questions. By using the funnel approach the impact on user perceptions or behavior is minimized, and it reduces the possibility of introducing bias and/or missing important data by avoiding specific questions too early in the interview (Roller & Lavrakas, 2015). Ultimately, the interview guide is used in the 27 interviews, and is added in Appendix B.

The respondents were found and contacted through the expert network of the consultancy company where the researcher performed a graduation internship. In addition, a variety of experts were contacted through LinkedIn based on their function, expertise, and company they work at to complement certain important missing stakeholders. Interviewees include: a Bank, Branch organizations, prime- and SME contractors, engineering companies, knowledge networks, charging points operators, NRMM OEMs, and a variety of governmental bodies. The interviews took place in online video calls and had an average duration of 60 minutes. To comply with the General Data Protection Regulation (GDPR) and standard academic practices, all interviewees and their transcriptions are anonymized. Relevant information that was noted are respondents three letter code (e.g. CON1), company category, function, years of experience in the GWW-sector, and date of the interview (Appendix C).

3.3. Data analysis

This section discusses data analysis following the collection for information from literature and semi-structured interviews. The data of the literature review was analyzed and synthesized to ultimately be presented in the results chapter. The extraction of data is performed in a Word file, which enabled the storage of relevant data from studies, reports, and gray literature. The data is categorized in four distinct groups based on the MIS steps: problem-solution diagnosis, structural components, and procurement practices. This overarching categorization provided structure in the analysis and synthesis of the data. For the semi-structured interviews, the collected audio files were transcribed by OpenAI software Whisper, and checked by the researcher afterwards. Thereafter, the transcripts were coded with full line-by-line open coding approach, thereby all relevant information from the interviews should be captured. The codes were identified and categorized in an Excel file according to the ten system functions of the MIS and four PPI categories, this led to a total of 1654 codes, and 51 themes. All interviews were held in Dutch, therefore all quotes included in the results section are translated.

3.4. Combined analysis

The combination of the literature review and in-depth understanding developed through semi-structured interviews on how the MIS functions and how PPI practices are conducted will lead to the sought after effects of PPI on the MIS and relevant policy implications which can provide an answer to the main research question. With the combined analysis of the drivers and barriers of the MIS in relation to the Public Procurement for Innovation practices conducted by the government, it can be seen whether PPI effectively addresses barriers in the system and what gaps exist in the governmental procurement policies. Based on the PPI framework from Yeow et al. (2014), policy implications can be set up through their defined instrument types and with complementary input from stakeholders following from the interviews. Figure 2 gives an overview of the steps of research methods.

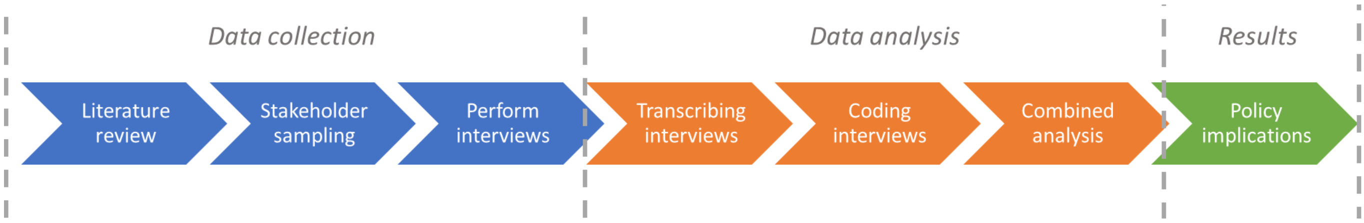


Figure 2: Overview of the methodology based on the researcher's own interpretation.

3.5. Reliability and validity

Reflection upon the research methods to ensure that research outcomes are reliable and valid will be conducted based on four criteria introduced by Lincoln and Guba (1985) that guide this reflection on the trustworthiness of qualitative research. The four criteria of credibility, transferability, dependability, and confirmability will be elaborated on below.

Credibility refers to the internal validity of the research, it reflects on the accuracy of findings and whether the perception of research is consistent with the study's qualitative results (Lincoln and Guba, 1985). The use of multiple data sources within the literature review and extensive interviews contributes to the credibility of this research (Creswell and Miller, 2000).

Transferability refers to the external validity of the research, it reflects on how well the findings can be generalized to a context outside of the study environment (Lincoln and Guba, 1985). In principle, the external validity of this research is high, provided that the generalizability is assessed within the set scope of this research. However, the conclusions will be more difficult to generalize for sectors other than construction as it is a specified case study.

Dependability refers to the reliability of the research, and thus reflects on the replicability. When the same methods would be used, similar results should follow from the research (Lincoln and Guba, 1985). The reliability of the research is enhanced by making it reproducible, which is accomplished by storing collected data in transcriptions and conducting analysis of codes and thematization in Excel (Golafshani, 2003). In terms of replicability, it depends on the time frame in which the research is repeated, as the system dynamics evolve constantly.

Confirmability refers to the degree to which the results of a research can be confirmed by others (Lincoln and Guba, 1985). This ensure objectivity of the research, and can be shown by documenting the procedures on how findings emerge from data and not through preconceptions of the researcher. Therefore, this research extensively documents the literature review and transcripts from the interviews.

4. Results

The results section is split in five subchapters that each answer one of the sub-questions formulated in the introduction chapter. The subchapters covered in the results section are the problem-solution diagnosis, structural analysis, the mission-oriented innovation system, the public procurement of innovation barriers, and the combined analysis of MIS and PPI effects and instruments.

4.1. Problem-solution diagnosis

This problem-solution diagnosis section provides an answer to SQ1 by elaborating on the technical and social solutions that are linked to the mission, and the missions' underlying societal problems that are present in the GWW-construction sector.

4.1.1. Problems

The problem section is divided in three parts that follow from the government program 'Clean and Zero-Emission Construction' (SEB), which aims to deal with the societal problems in the construction sector caused by NRMM (SEB, 2023). The SEB-program has bundled global warming, nature preservation, and public health problems, which find their origin in separate national policies, namely: the Climate Accord, Program Nitrogen reduction and Nature preservation (PSN), and Clean Air Accord (SLA) (SEB, 2023). The SEB-program aims to tackle these problems and has set goals for ZE-NRMM emission reductions in 2030, which are summarized in Figure 3, and ultimately aims for a full zero-emission NRMM fleet in the Netherlands.

The Paris climate accord aims to limit global warming to well below 2 degrees Celsius (UN, 2015). In the European Union, this translated in the goal to reduce GHG-emissions with 55% by 2030 and to ensure success the Netherlands aims for 60% reduction (Rijksoverheid, 2023). The climate goals for the GWW construction find support in the strategy from the Ministry of Infrastructure and Water management, namely the 'Climate neutral and Circular Infra program' (KCI) (SEB, 2023 and KCI, 2021). The KCI program has the concrete goal to ensure that all GWW construction projects are climate neutral and circular by 2030 (KCI, 2021). Within the KCI strategy, five transition paths are defined by the ministry that provide guidance for the market, specifically the 'Road, Dike, and Rail NRMM' (WDSM) transition path is associated with SEB as it focuses on reducing emissions originating from NRMM (KCI, 2021). The SEB-program aims to reduce CO_2-emissions from NRMM with 23% by 2030 and thereby contributes to the societal problem of global warming (SEB, 2023).

The program on nitrogen reduction and nature preservation (PSN) aims to preserve the nature in the Netherlands that is affected by the deposition of nitrogen, which causes loss of nature and affects biodiversity (PSN, 2022). The PSN focuses on the 128 Natura 2000 areas sensitive to nitrogen deposition, allowing for direct measures to reduce or even rule out nitrogen deposition which can affect activities outside of the Natura 2000 area (PSN, 2022). This has impacted the construction industry as NRMM emit nitrogen that can permeate the ground of Natura 2000 areas and therefore thousands of building plans and permit applications came to a standstill in 2019 due to too high nitrogen depositions (SEB, 2023). Due to the expiration of the building exemption in November 2022, all projects need to be re-examined and possibly need to reapply for a nature permit (SEB, 2023). Following the PSN, there are regulated emission reductions set up that require 50% nitrogen reduction by 2030 (PSN, 2022). As zero-emission construction activities can alleviate this problem, the SEB-program wants to ensure continuity of construction projects and preserve nature2000 areas by aiming to reduce 51% of NO_x emission by 2030 (PSN, 2022; SEB, 2023).

The Clean Air accord strives to achieve permanent improvement of the local air quality for health gains to be realized for everyone in the Netherlands, by reducing domestic activities that affect air quality with emission of nitrogen dioxide (NO_2) and particulate matter (PM) (SLA, 2020). The goal of the accord is to have national health gains of at least 50% by 2030 compared to 2016 (SLA, 2020). Domestic construction activities with NRMM affect local air quality with its emissions and therefore the SEB contributes to the SLA by aiming to reduce PM emission with 95% by 2030 (SEB, 2023).

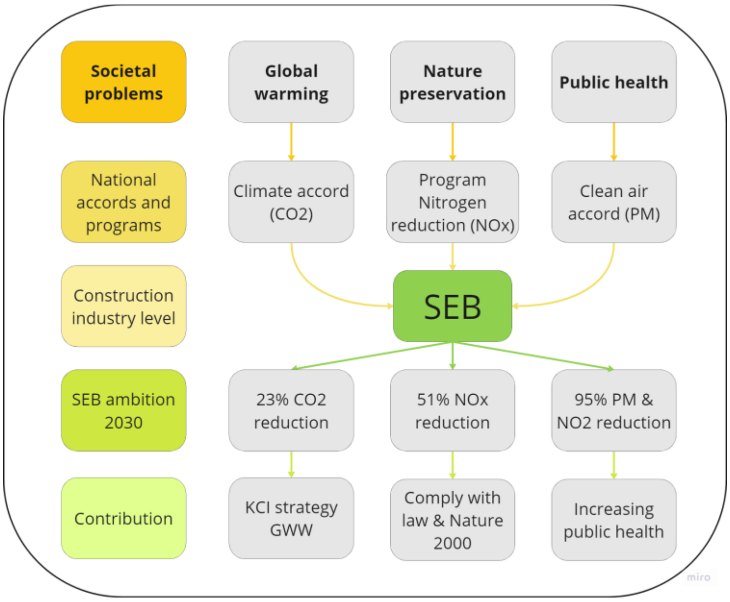


Figure 3: Societal problems in relation to the SEB-program.

4.1.2. Solutions

The solution section is divided in three categories of solutions: NRMM, energy infrastructure, and process solutions. These will be elaborated on below and the full breadth of solutions are summarized in Appendix D.

NRMM solutions

First, different categories of NRMM can be defined following their power range, which are shown with visual examples in Appendix E. Second, for the mission, solutions can be separated in zero-emission solutions and emission reducing solutions. The zero-emission solutions reduce the CO_2, NO_x, and PM tailpipe emissions to zero on-site and emission reducing solutions contribute to zero-emission targets, however these will never enable the long-term complete zero-emission.

Literature considers two main technological trajectories for ZE-NRMM that do not produce direct tailpipe emissions: battery electric NRMM (BEV) and hydrogen electric NRMM (FCEV) (IPCC, 2022; Ratzinger et al., 2021). Besides, this study defines five solutions of emission reducing solutions. First, hybrid electric NRMM that can both operate as an electric (ZE) or fossil fuel-based solution (Ratzinger et al., 2021). Second, NRMM based on methanol fuel, which marginalizes the emissions to near zero (Verhelst et al., 2019). Third, HVO fuel, which can be used in internal combustion engines as alternative form of diesel reducing CO_2-emissions during production, but not the on-site CO_2, NO_x, or PM emissions (WDSM, 2022). Fourth, filters and cleaner internal combustion engines that both reduce the emissions on-site, and are most effective when used together (SEB, 2023). Fifth, kinetic energy, which is attained by capturing the energy released from movements of the NRMM and thus reduces fuel usage (Nokka, 2018).

Energy infrastructure solutions

The supply of energy is an integral challenge for the implementation of NRMM, especially for GWW construction projects that take place at remote locations along line-projects that cover several kilometers of road or dike (ENI, 2023a). This study distinguishes between solutions that are grid-based and non-grid based that facilitate either BEV, FCEV, or both.

First, a distinction can be made between construction sites that can get a new grid-connection, and construction sites that use existing grid infrastructure. With a new grid-connection and charging points sufficient facilitation is provided for ZE-NRMM, except if it is a line-project which is elaborated on below in off-grid solutions. However, if a new grid-connection is not possible, the primary option would be to use an existing grid connection close by. For example, a charging point based on unguaranteed/ underused grid connections, or regular charging points used with an adapter (NET3).

Second, off-grid energy infrastructure solutions can be facilitated with battery swap methods and a mobile charging point on-site (Lajunen et al., 2016). First, battery swap consists of a service where the battery pack is swapped for a fully charged pack, and the former is then charged elsewhere. Second, the creation or usage of a charging point on-site through the use of mobile battery energy storage or hydrogen based energy generator. In addition, solutions have been developed such as the Watthub, which is a heavy duty charging hub that primarily uses locally generated wind and solar energy (ENI, 2023a; Watthub, 2023). Moreover, a similar solution that has been developed is the energy hub, which besides charging provides the fueling infrastructure for hydrogen based NRMM. Besides the energy hub can hydrogen based NRMM also be fueled with tanks brought by trucks to construction sites to refill NRMM (OEM1). Last, fossil-fuel generators are sometimes used to charge ZE-NRMM, however, this is counterproductive and only used in moments of urgent need.

4.2. Structural analysis

The structural analysis section provides an answer to SQ2 by elaborating on the structural elements that are present in the MIS. The section is divided in two sections, first the structural elements (actors, networks) of the overall MIS in the Dutch GWW-construction sector are elaborated on and the second part elaborates on the MIS arena, specifying which actors have a focal role in the mission formulation, mobilization, and monitoring. Last, the institutions of the Dutch GWW-construction sector are listed.

4.2.1. Overall MIS

Within the GWW-construction sector five transition paths consisting of different types of work have been set up where major sustainability impact can be achieved (IenW, 2021). This study focuses on the transition path 'Road-, Dike-, and Railway machinery' (WDSM) because construction machinery is the focal element of this study. This means that marine equipment is excluded as it falls under shoreline and channel maintenance (IenW, 2022). Yet, within the Road, Dike, and Rail Equipment transition path, the diversity of projects is still large and therefore the scope is further delineated based on the comparability of work types, and the actors and institutions involved. In road and dike projects, actors such as Rijkswaterstaat and governmental organizations are active with similar institutions, while in rail projects, actors such as ProRail are in the lead (Bours et al., 2022). Therefore, rail projects are excluded which increases the generalizability of PPI policy implications for the set of projects that are within the scope. Besides, in this study the emissions on construction sites that are accounted for originate from Non-Road Mechanical Machinery (NRMM), which includes stationary generators. Hence, excluded are the construction transport logistics (e.g., transport of materials) and personal transport from and to the construction site.

The GWW-construction sector is a public market where almost all infrastructural assets are owned and managed by the Dutch government on different geographical levels: Rijkswaterstaat (national), 21 water authorities, 12 provinces, and 352 municipalities (Ministry of Interior and Kingdom Relations, 2023). Besides, these government bodies have umbrella organizations to which they are all affiliated, namely: IPO (provinces), UvW (water authorities), and VNG (municipalities) (GOV1). On the market-side, roughly 2100 parties are involved in the actual construction of GWW-projects among which (sub-)contractors, consultancy, and engineering companies (Bours et al., 2022). Besides, there are suppliers of NRMM, knowledge institutions are actively involved, banks for financing, and grid operators/CPO's for energy infrastructure. Therefore, the success of the MIS depends on a diverse set of actors in the complete value chain that need to work together to enable mission success. CON4 emphasizes: ''We notice that you need the entire value chain at the table. So, you need the grid operators, you need the public clients, you need the manufacturers, OEMs, and users.'' – CON4. The following paragraphs highlight the main type of actors active in the GWW-construction sector, and define their role within the MIS which helps understand their role in relation to specific system functions and barriers in the further analysis.

Public clients and the market

The government has an important role as procurer of innovation. It is practically the sole client in the GWW-sector and as such can steer the market with its buying power. In 2019, the government spent 12.2 billion euros on GWW-projects, with the majority coming from municipalities (33%), and relatively smaller parts from provinces (19%), Rijkswaterstaat (18%), and water authorities (14%) (WDSM, 2022). For the realization of projects, public clients depend on market parties for project and (technical) design knowledge of contractors, architects, and consultancy and engineering companies (Rijkswaterstaat, 2019). The market side is fragmented with the majority of (sub-)contractors being SMEs, and 10 major contractors companies having a large share of the market in terms of GWW-budget with up to 50% share in the period 2014-2017 (Rijkswaterstaat, 2019). Therefore, market parties depend on the demand and specifications of public clients. Ultimately, this shows that although public clients can steer the market, there is also great mutual dependence between public and private parties (Dominguez et al., 2009).

Knowledge institutions

In the GWW-construction sector knowledge institutes such as TNO conducts market research for the ministry of Infrastructure and Water management (GOV1). Besides, research and creation of standards for procurement practices is executed by CROW, which is the leading organization that public and private actors within GWW listen to, as MUN2 explains: ''They [CROW] have a unique position in the Netherlands, because they inspire so much confidence. Both towards municipalities, provinces, Rijkswaterstaat, but also towards the contractors. Because everyone accepts what CROW says.'' – MUN2. Moreover, CROW is leading the 'Sustainable GWW 2030' initiative, which aims to make sustainability integral part of planning, tenders, and execution of GWW-projects by creating practical methods to incorporate sustainability which includes ZE-NRMM (CROW, 2023). Last, PIANOo is the Dutch Public Procurement Expertise Centre, and plays a role in enhancing the procurement practices across various public organizations. PIANOo's primary objective is to increase professionalism, improve efficiency, and ensure regulatory compliance (PIANOo, 2023a).

NRMM suppliers

The NRMM market is dominated by a few major OEMs that supply NRMM globally (WDSM, 2022). These OEMs have importers and dealers in the Netherlands that supply the NRMM to the GWW-construction sector (OEM1, BAN1). In addition to the supply from large OEMs, the Netherlands has a few smaller local OEMs primarily supplying light NRMM (OEM2). However, a large share of ZE-NRMM in the GWW originates from retrofit companies that either retrofit existing ICE NRMM or build electric drivetrains into new NRMM that is supplied by OEMs as hull (OEM1, OEM2). OEM2 states: ''I mainly see those parties doing retrofit, buying NRMM that is available with the standard conventional powertrain in it and then dismantle and equip it with a new, often fully electric powertrain.'' – OEM2.

Energy infrastructure suppliers

Construction sites are generally equipped with a grid connection, therefore grid operators are important actors in the MIS. NET3 emphasizes: ''Together with the network operators we look at which propositions are needed. What type of grid connections are needed to cope with this [ZE-NRMM] transition.'' – NET3. Therefore, the importance of grid operators is increasing as with the ZE-NRMM mission the usage of BEV increases energy demand at construction sites requiring larger connections (NET3). BEV also introduces the need for charging points, therefore charging point operators (CPOs) can play a role in supplying energy infrastructure at construction sites. However, they see their role and business case more in rural areas (CPO1).

Networks

A number of networks are active in the GWW-construction sector that are involved in the mission for ZE-NRMM. First of all, 'Zero-Emission Network Infra' (ENI) focuses on accelerating the development of ZE-NRMM with acceptable total cost of ownership (TCO) and clear standards towards 2026 (ENI, 2023b). ENI consists of a diverse set of 40 public as well as private actors that generally have experience with ZE-NRMM (BRA1, NET1). Second, there is a procurement network, the Buyer Group Zero-Emission Construction (Buyer Group ZEB) which is part of PIANOo (PIANOo, 2023). The Buyer Group ZEB focuses on creating a shared market vision, purchasing strategy guide, and a monitoring tool that is useful for both public clients and private contractors in the transition to ZEB (PIANOo, 2023b). Third, two energy infrastructure networks are involved in the MIS, namely ElaadNL which is a knowledge and innovation center in the field of smart charging infrastructure with all major Dutch grid operators involved (ElaadNL, 2023). Fourth and last, a variety of branch organizations that have mostly SMEs as followers and primarily lobby, spread knowledge, or create safety guidelines (BRA1, MUN1, BAN1, NET3, CON2). An example is the KOMAT group within Bouwend Nederland which is an advisory group in which many NRMM directors from contractors are involved (BRA1, CON4).

4.2.2. Mission arena

This subchapter elaborates on the mission arena, which comprises a specific set of actors and networks that are actively involved in formulating, mobilizing, and monitoring the mission. Focal in all aspects is the SEB-program. Supporting entities are ministries, ENI, Buyer Group ZEB, and a distinction in the WDSM frontrunner-platoon strategy is made. These actors have a more prominent role in the MIS, and thus is required to understand before elaborating on the system performance as it is largely dependent on them.

Mission formulation, mobilization, and monitoring

The formulation of the mission from societal problem into an ambitious mission is primarily executed by the Ministry of Infrastructure and Water management through the KCI strategy and WDSM transition path. Yet, the mission has to become actionable as well and this is where KCI and WDSM fall short, they merely provide direction, but lack specific actions that can be taken. The SEB-program is creating a more concrete and precisely described roadmap for ZE-NRMM and thereby making the mission actionable. In that regard, SEB is the focal entity that mobilizes other actors in the mission arena and overall MIS, focusing on the whole value chain involved. In addition, ENI as frontrunner group has in important role in mobilizing more market parties, and the Buyer Group ZEB is primarily mobilizing public clients. Last, mission monitoring is solely executed by the SEB-program based on their roadmap on three levels: monitoring the intended effects (1), the implementation (2), and construction activities within the scope of the roadmap (3) (SEB, 2023). Besides, evaluations of the mission will take place in 2024, 2027, and 2030 (SEB, 2023). Ultimately, focal actors in the mission arena are the SEB-program, Ministry of I&W, ENI, and Buyer Group ZEB.

WDSM frontrunner vs. platoon strategy

The actors in the mission arena and the overall MIS can be distinguished from the SEB-program, following the frontrunner vs. platoon strategy from the WDSM transition-path. In the WDSM transition-path a procurement strategy is implemented where projects are pre-selected as either 'frontrunner' or 'platoon' to stimulate sustainability in certain projects (KCI, 2023a). A crucial element of the strategy is the (financial) rewarding of frontrunners in the market, to create space for the development of ZE-NRMM (KCI, 2023b). From 2023-2024 merely 5% are frontrunner projects, which will gradually increase to 50% in 2025-2027 (KCI, 2023b). With this strategy, a separation is made for both public clients and contractors that either actively pursue the mission as frontrunner and are thus part of the mission arena, and the platoon following the herd are part of the overall MIS. An example of frontrunners is the ENI network: ''ENI, in which we strive to accelerate emission-free working in the GWW-construction sector. We do this with about forty frontrunners, we call it'' – NET1. Ultimately, with this distinction the overall MIS and its mission arena can be visualized as seen in Figure 4.

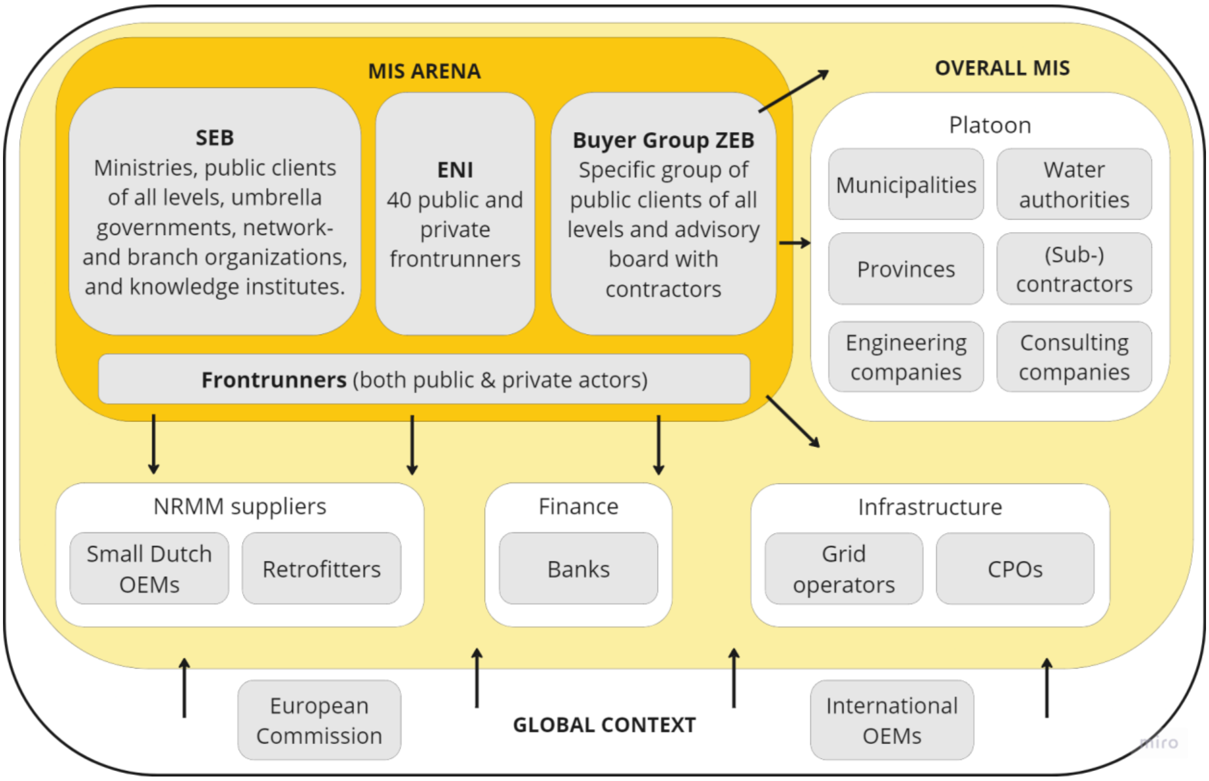


Figure 4: Overview of the structural analysis.

4.2.3. Institutions

Missions are often misaligned with the institutions existing in the GWW-construction sector, and their deeper understanding is necessary, as success might require to change current routines and practices. Three main institutions influence the MIS in the GWW-construction sector, namely the sector is project based, GWW has temporal line-projects, it is a highly competitive market with low profit margins, both public and private organizations are risk averse in projects, and NRMM has long depreciation terms.

Project based work, temporality, line-projects and learning

The GWW-construction sector is characterized by a project-driven approach. As NET1 mentions: "Both governments and contractors are used to working on a project basis. Characteristic of construction is that something is delivered, a bridge or a building and then we just move on."-NET1. Projects can be defined as short-term alliances between organizations that invest resources in an innovative way, but only with a temporal commitment to achieve the project goals and at the same time govern the underlying risk and necessary interorganizational integration (Turner and Müller, 2003; Packendorff, 1995). Besides, the GWW-construction sector deals with projects that are not focused around one location, but in many cases can be along kilometers of road or dike, and thus make it difficult to create appropriate energy infrastructure from one grid-connection (NET3, GOV2, CON1, WAT1, REN1). This is emphasized by NET3: ''Line projects are a real challenge, especially the temporary nature of it.- NET3. Lastly, the project-driven approach inherently creates learning dynamics within project settings and as an effect knowledge is often not effectively retained or build-up over time (NET1, INS2). INS2 emphasizes: ''At the end of the project you may have learned a lot, but the next project will go to someone else and you will be busy with something else. What we have learned disappears and everyone starts from scratch on the next project and learns everything all over again." - INS2.

GWW-construction is a competitive market with low profit margins

The Dutch GWW-construction sector has low profit margins because it is competitive in nature due to the vast amount of contractors. For example, BRA1 mentions: ''Profit margins in GWW-construction are already thin'' – BRA1. CON1 adds: ''We are of course operating in a competitive market'' – CON1. A report from the government confirms this, as the average profit margin of the eight largest Dutch construction companies in the period 2008 – 2017 averaged 0.3% (Rijksoverheid, 2019). Ultimately, taking into account the 2100 active market parties, the market is saturated, making it highly competitive, and reducing the profit margins due to the competition with multiple contractors on one tender.

Long depreciation terms of NRMM

NRMM is depreciated over multiple years, and in general the higher the investment, the longer the depreciation term is, which is something inherently associated with these large investments (Aalbers, 2022). The depreciation period is in general within the range of 6-8 years, but can be to 10-15 years for specialistic NRMM (CON1; CON3). CON3 mentions: ''There are of course machines that have a standard 10 years for depreciation, which is not out of the ordinary'' – CON3.

The size of Dutch NRMM market

The size of Dutch NRMM market is relatively small in international context for international OEMs (OEM1, OEM2, BRA1, GOV3, CON3). OEM1 explains: ''We look at France, England, Germany, Spain, Italy, large sales areas in Western Europe. We then look at what [NRMM] can be sold the most there, with the most equal legislation, and we adjust our machine accordingly. After all, we cannot develop a product for the Dutch market alone, that simply does not work.'' – OEM1.

Concluding, the MIS structural components have been set out, and the overview of both actors, networks, and instructions active in the GWW-construction sector will help understand how these influence the MIS system functions performance. Section 4.3 elaborates on the individual performance of system functions in terms.

4.3. Mission-oriented innovation system

The mission-oriented innovation system section provides an answer to SQ3 by elaborating on the individual performance of the ten systemic functions for innovation (see section 2.3.3), and is summarized in Table 4. Thereafter, it is elaborated how the system drivers and barriers interrelate.

4.3.1. SF1: Entrepreneurial activities

Entrepreneurial activities are characterized by a variety of experiments and pilots with ZE-NRMM, but a general lack of entrepreneurial activities experienced, especially by the platoon. However, actors also emphasize that more entrepreneurial activities may not lead to better development of the MIS as pilots lack continuity.

A variety of ZE-NRMM experiments and pilots are taking place in the Netherlands

A variety of experiments with ZE-NRMM are observed, most prominently mentioned in the interviews are the Sterke Lekdijk and Groene Boog (CON1; CON3; CON6; GOV2; GOV3; WAT1; NET1). The Sterke Lekdijk is a frontrunner project that started in 2019, WAT1 mentions: ''When we started our tender in 2019, there was not a single piece of [ZE-]equipment in the Netherlands.'' – WAT1. Besides, the project uses both hydrogen and battery electric NRMM, WAT1 explains: ''One of our innovation partners invested in the development of a hydrogen crane. In addition to the electric crane that was already there. So, we have both a hydrogen crane and two electric cranes running at our first project.'' – WAT1. Ultimately, one of the contractors took initiative and started the Zero-emission Network Infra ENI network (WAT1; CON6).

In the Groene Boog project (A16 Rotterdam), the contractors used battery electric ZE-NRMM such as excavators, concrete mixers, transfer cranes, shovels, and asphalt machines (KCI, 2023b; GOV2; GOV3; CON1; CON3). Other experimental projects that took place are 'KOP' (BEV), Innova58 (BEV), Laurensmeerdijk (FCEV), dike project GOLWA (BEV), A1 Twello (100% ZE), and ViA15 (KCI, 2023b; CON6; GOV1; SME1). Ultimately, it shows that both BEV and FCEV experiments and pilots take place in the Netherlands in a variety of GWW projects.

In addition to the ZE-NRMM experiments, there are projects focused on energy infrastructure solutions. There are two known examples, namely the 'Watthub A15' and within the Sterke Lekdijk project (WAT1, CON1, NET3). WAT1 explains: ''This is a research project in which we create a stand-alone energy supply on the construction site, which has a combined hydrogen and electric fueling station for our project, to overcome where TenneT cannot deliver.'' – WAT1. Ultimately, less experiments take place that specifically focus on infrastructural challenges, and in this case the Watthub A15 was a market initiative which shows urgency on this topic.

Sufficient experiments for frontrunners, platoon less involved, and a lack of continuity

The consensus of the interviewees leans towards insufficient experiments to reach the mission goals for 2030, however, frontrunners seem to be more inclined to say there are sufficient experiments within their organization, as MUN1 mentions: ''If I consider [municipality] Arnhem, I think there are [sufficient pilots]. We do everything necessary. We actually started with Hugo de Groot as a pilot project last year. If you look nationally, I don't think so, then you see that it is very limited.'' – MUN1. Thus, as MUN1 mentions, in the overall MIS it is insufficient. CON6 also emphasizes: ''You may have a few big companies involved. But you have subcontractors, suppliers, producers, everything. It's such a complex industry. Are we doing enough? No, I do not think so.'' – CON6. Thus, especially smaller platoon organizations are not involved, and SME1 experiences this as well: ''No, I don't think there are sufficient experiments going on right now.'' – SME1.

Although there are mixed perspectives whether there are sufficient pilots, there are strong statements that more pilots won't provide the necessary continuity for the MIS to develop (NET1, MUN2, CON4). NET1 mentions: ''I think there are sufficient pilots, the misery of the construction industry is that we are dying in the pilots, that's not the problem.'' – NET1. Moreover, MUN2 emphasizes: ''I am convinced that when you talk about zero-emission equipment. That you should actually offer continuity. And pilots tend to be more like, 'nice we'll try something'. Thereafter, we will learn lessons from that and from those lessons we will come up with new things. And maybe do a second or third pilot and afterwards you've burned away five years. But where is the continuity?'' – MUN2. Concluding, although many pilots are taking place, actors do not experience sufficient pilots as these do not create any continuity in the work provided.

4.3.2. SF2: Knowledge development

Knowledge development is characterized by frontrunners gaining knowledge by learning-by-doing, but the platoon experiences less knowledge development on ZE-NRMM. More specifically, technical knowledge on ZE-NRMM is sufficiently developed in the GWW-sector, however, knowledge on energy infrastructure and its wider impact on the energy transition, safety, and monitoring is lacking.

Sufficient knowledge development frontrunners, platoon is lacking

It is observed in the interviews that frontrunners, often large prime contractors, and among governments mainly Rijkswaterstaat are having more knowledge development (SME1, CON5, CON2, NET1, GOV2, BRA1). As BRA1 states: ''If you look at knowledge expertise around zero-emission equipment, then the front runners are in any case miles ahead.'' – BRA1. And SME1 adds to this: ''The large parties that do business directly with the government. They are working on all innovations.'' – SME1. Therefore, a contrast rises for the platoon, often smaller SME actors that do not have the same or any knowledge development on ZE-NRMM (SME1, SME2, ENG2). As CON2 emphasizes: ''Some large contractors have invested heavily in that knowledge. If you look at us, we have to get that from our partners for the time being, because we're not that big here [in NL], that means we don't have an entire sustainability department that can think it out.'' – CON2. Ultimately, the frontrunners gain ZE-NRMM knowledge, and the platoon is lacking.

Sufficient technical knowledge, but lacking on energy infrastructure & system, safety, and monitoring

Generally, stakeholders are convinced that sufficient knowledge has been developed on technical level, the technical feasibility of creating ZE-NRMM is present (GOV1; SME1; ENG2; CON4; WAT1). As SME1 emphasizes: ''You have now passed the point where there is now enough knowledge in the market to do it. The proof of concept is there and it is no longer possible to say it can't be done.'' – SME1. Yet, on three other areas the knowledge development is lacking.

First, energy infrastructure knowledge is lacking, although successful implementation of ZEV has been done at GWW projects, the infrastructure remains challenging due to grid congestion and lacking infrastructure at remote locations (NET2; NET3; ENG2; CON2; GOV1; MUN2; SME1). NET3 emphasizes the complexity: ''For a dike reinforcement project, you go over a route of 30, 40, 50 kilometers and you always need a connection at a different location for a certain period of time and that is where the complexity lies.'' – NET3. And CON2 mentions the lacking knowledge: ''If you are going to work with [battery] electric equipment, you have to charge it at some point. I don't think all contractors have the inhouse knowledge to be able to do that.'' – CON2. In addition to the project level, the wider system level impact of the energy grid that will unfold as ZE-NRMM is more widely implemented is unknown (ENG2, INS2). INS2 emphasizes:

''If everyone goes to electric [NRMM] at once, we have a huge problem. Because we don't have the charging infrastructure and then it all collapses. But is that the case, is there a pace at which this can be achieved? Is there perhaps a smart solution by charging things later and then we might not burden the power grid that much at all? I have not yet seen any scenarios in which success pictures like that look at, will we make it?'' – INS2.

Second, ZE-NRMM adds new areas of safety to construction as it requires new infrastructure and works with high voltage, for which currently, there is a lack of knowledge. CON5 explains: ''There are simply completely different safety risks that apply, compared to traditional equipment, such as diesel equipment. Just think about connecting the charger or changing hydrogen tanks, whole new training schemes have to be developed for it'' – CON5. A variety of actors emphasize the need for more awareness and safety guidelines (BRA1; CON4; CON5; CON6; GOV1; ENG2). These guidelines are in development through branch organizations, as BRA1 states: ''Safety, for example, is one of them. We are busy and many stakeholders are involved. With regard to safety and ZE-NRMM'' – BRA1.

Third, insufficient knowledge on monitoring of actual emissions on constructions sites is present (CON4; CON5; CON6; GOV1; WAT2). CON6 mentions: ''The first projects are of course now in progress and then you still have to find where on the machine you monitor the actual emissions. – CON6. Yet this knowledge is necessary to be able to track emission targets on project level and to create clarity for contractors how they can comply, as CON5 mentions: ''In terms of monitoring, that is also a question that goes around a lot. How are they [government] actually going to test this? How are they going to monitor this whether we are over or under the [emission] limit? – CON5.

4.3.3. SF3: Knowledge diffusion

Knowledge diffusion is characterized by the diffusion of knowledge between frontrunners, but lacking diffusion to the platoon. Although SEB and ENI share lessons learned publicly, practical lessons learned-by-doing often stick to actors involved in the project, and due to the competitive nature of the industry are not shared as it can provide a competitive advantage in tenders. In addition, Buyer Group ZEB has an important role gathering and diffusing procurement knowledge to educate public clients. And last, knowledge diffusion between OEMs and retrofitters is limited.

Knowledge is stuck with frontrunners or within projects, and diffusion is hampered by competition

Knowledge diffusion primarily takes place in frontrunner projects and the contractors involved, which creates a basic level of knowledge among all frontrunners on the implementation of ZE-NRMM in GWW-projects. Focal actors and initiatives facilitating knowledge diffusion between actors which are emphasized in the majority of interviews are: ENI, branch organizations (KOMAT workgroup), ElaadNL, and the SEB-program. However, the knowledge is hardly diffused to the wider GWW-sector, and thus does not reach the actors in the platoon. NET1 emphasizes: ''Is sufficient knowledge being developed? Yes, I think so, but the misery is in the construction sector that knowledge only sticks to the frontrunners.'' – NET1. Additionally, ENG2 states:

''There is expertise in the ENI, the transition paths, KCI, SEB and Rijkswaterstaat, among others. There are certainly people working on the subject, and although there is variation in knowledge the basic level is good. But I think that in the end a very large part of the GWW-sector is still unfamiliar with the possibilities or what it takes to realize something [zero-emission].'' – ENG2

Yet, a multitude of stakeholders emphasize the importance of sharing the lessons learned in projects to enable the wider transition towards ZE-NRMM, ensure safety, and learning based collective themes (WAT1; NET1; CON1; MUN1; ENG2). In addition, it is emphasized that sharing lessons learned will enable a more effective learning curve as not all contractors have to reinvent the wheel (CON5; ENG2; NET1). ENG2 emphasizes: ''I think by sharing the project experiences much more widely with each other would greatly contribute. Especially, by building upon those previous project experiences, to look at project X which was already executed last year, and take the lessons learned to project Y to ultimately arrive at new insights'' – ENG2. However, due to the competitive nature of the GWW-sector, sharing the lessons learned is not something that contractors are enticed to do (CON1; CON2; SME1; WAT2). CON1 explains: "I have no illusions that we will all share knowledge with each other. Because we are of course in a competitive market.'' – CON1. Moreover, in some occasions previous experiences in using ZE-NRMM can provide a competitive advantage in tenders and is thus kept closely to the heart (SME1; SME2; CON1). SME1 says: ''Things like that happen a lot in competition, so little knowledge about this is shared between contractors. It can give you an advantage in a tender, so you invest and you don't really want someone else to run off with your idea.'' – SME1.

Yet, it is emphasized that GWW-projects can also be a foundation to share knowledge among contractors, especially larger, multi-year projects (WAT2, ENG2, NET1, NET3, CON6). CON6 emphasizes this: ''In a lot of projects, at least the larger projects, you are no longer each other's competitor. But suddenly you're just colleagues. Where, of course, a great deal of knowledge sharing and dissemination also takes place. In the end you all need each other. It would be weird to keep the knowledge to yourself, because you will meet once again.'' – CON6. This aligns with the definition of projects being short-term alliances between actors who have a shared temporal commitment to achieve the project goal, and thus will be more likely to share knowledge.

The buyer group ZEB is diffusing know-how for procurement practices of public clients

The goal of the Buyer Group ZEB is to develop a purchasing and ZE-NRMM purchasing strategy, with a market vision, a purchasing strategy guide, and a monitoring tool (PIANOo, 2023b). GOV2 explains that Buyer Group ZEB is a platform for knowledge sharing: ''The Buyer Group is such a platform where you exchange knowledge and which includes fellow public clients and Rijkswaterstaat.'' – GOV2. The Buyer Group ZEB consists of public clients that are primarily involved in frontrunner projects that implement ZE-NRMM and share the procurement experiences. As WAT1 from Sterke Lekdijk explains: ''This way of working, that will now be included in the buyers group, the experiences of it.'' – WAT1. However, WAT2 explains that it is currently still a select group: ''They [public clients] are part of such a buyers group, but then you haven't caught everyone yet, because that's a select group'' – WAT2. Therefore, it can be questioned whether the platoon is reached with this initiative.

Retrofitters gain knowledge on ZE-NRMM, but less valuable to OEM and if so diffused through patents

The Netherlands has a variety of retrofitters active, of which some are affiliated with large international OEMs for the supply of NRMM hulls and CE licenses. Yet, limited knowledge sharing is taking place as retrofitters do not acquire knowledge relevant for mass production, as OEM1 explains: ''They [retrofitters] are helpful and do it with us, but I think it [ZE-NRMM] has to come mainly from ourselves. They do have good ideas, but they have ideas for niche products in niche markets and not for mass production.'' – OEM1. Meanwhile, OEMs consider ZE-NRMM to be challenging and source knowledge to their organization by buying people and successful patents from retrofitters (OEM1), which makes it the only knowledge diffusion taking place between those parties. OEM1 specifically mentions: ''[Interviewee mentions specific retrofitter] makes a number of electrical machines, so we have partnership. If it's really good, if their model is extremely successful, we buy the patents. – OEM1.

4.3.4. SF4: Guidance of the search

SF4A: Problem directionality

The government provides problem directionality in the GWW-construction sector through the KCI strategy and WDSM transition path. Yet, underlying motives that trigger actors are primarily the nitrogen crisis which hampers construction projects, and secondary are public health (PM) and climate (CO_2). Large companies are more intrinsically motivated to tackle these problems than smaller actors in the GWW-sector. Ultimately, the government can steer contractors in the sector through tenders, but it is challenging to steer on synergies between other missions such as circularity.

Government provides problem directionality through the KCI strategy and WDSM transition path

Focal programs and accords that are providing problem directionality in the GWW-construction sectors are primarily the KCI strategy and transition path WDSM (GOV1; GOV2; CON6; ENG2; GOV1), and in addition the climate accord is mentioned as important origin of importance for these initiatives (CON1; ENG2; GOV3). Besides, actors that operate in projects in more rural areas emphasize the Zero-emission-zones (GOV2 CPO1; CON1), and clean air accord (MUN2). Yet, there are underlying motives to start working with ZE-NRMM where health and climate are put on secondary importance as the nitrogen crisis is hampering construction projects.

Nitrogen crisis is primary motive to work with ZE-NRMM, health (PM) and climate (CO_2) are secondary

Thirteen interviewees including contractors, SMEs, national, and local governments all mention that they give priority in projects to nitrogen emissions due to the urgent nature of the Dutch nitrogen crisis. CON2 explains: ''I see that this urgency is extremely high among our customers due to nitrogen, with which I mean Rijkswaterstaat, the municipalities and the provinces.'' – CON2. The urgency in the nitrogen crisis is caused by the standstill in 2019 of thousands of building plans and permit applications due to too high nitrogen depositions and on top of that the expiration of the building exemption in November 2022, which caused all projects to be re-examined (SEB, 2023). Yet, this means that the parties in the GWW-sector are motivated to use ZE-NRMM to overcome high deposition, in contrast to intrinsically help nature preservation. Moreover, the government explains the struggle by prioritizing nitrogen whilst other emissions are as important: ''Natura 2000 has decided that for us, because no construction project can be pursued because of nitrogen sooner or later. Therefore, it is the first requirement that you must meet. While that's not fair, because we aim to tackle all three [CO_2, NO_x, PM] in all those programs. They are all important. But nitrogen is the one holding you back.'' – GOV1.

Public health is secondary to nitrogen and especially in rural areas receives higher priority than CO_2-emissions as it has a direct impact on the local citizens and workers. Interviewees mention that ZE-NRMM has beneficial effects due to less noise and especially reduced health issues and greater comfort for construction workers (MUN2, BRA1, CON4, GOV3, OEM2). MUN2 emphasizes: "Happiness at work has gone up because with zero-emissions they [construction workers] no longer stand in diesel air all day, and that they no longer went home with a headache in the evening" – MUN2. However, the branch organization points out that these health benefits are secondary to the general public opinion in contrast to climate and global warming, which they think is a shame. In addition, climate and global warming are seen as organizational goals rather than project-related goals. Interviewees that do mention climate as important motive feel a strong urge to take responsibility as organization to contribute to a more sustainable society (MUN2; WAT2; ENG1; CON3; CON4; CON6).

Priority of societal problems depends on project nature, and synergies are recognized but hard to steer

It can be more beneficial to either focus on circularity or ZE-NRMM depending on the nature of project work. For example when not much NRMM is used in the first place in the construction activities and more material is used in the project it would be optimal to focus on increasing circularity and putting priority over ZE-NRMM (WAT1/2, ENG2, GOV1, BRA1, REN1). However, synergies between these societal problems are also recognized and emphasized by stakeholders (GOV1/2, WAT1/2, CON4, ENG1). WAT2 emphasizes: ''So, above all, finding the synergy between the solutions that can contribute to the social problems that exist. In addition to the fact that it must be emission-free. If we work with other material where the material is more durable, but also lighter. Then the transport also has less emission and we have a win-win for both sides.'' – WAT2**.** However, these synergies remain hard to create in practice and especially difficult to steer from a government policy perspective (GOV1; GOV2). As GOV2 mentions: ''There is talk about that [synergies], but in practice this is of course very complicated, to effectively target and steer it.'' – GOV2.

SF4B: Solution directionality

The transition path WDSM and SEB Roadmap provides direction to the market. The Dutch market prioritizes BEV over FCEV, the latter is only considered for heavy NRMM and HVO is seen as an intermediary solution. However, large international OEMs seem to focus more on FCEV, as it has more potential internationally in remote areas. In addition, energy supply remains a search and lacks directionality in Dutch GWW-projects. Ultimately, the lack of direction in both technological and infrastructural solutions puts smaller and local actors into a wait-and-see attitude.

Transition path WDSM and SEB Roadmap provide solution directionality

The transition path WDSM provides directionality in terms of technological solutions that should be adopted to achieve the mission. The transition path emphasizes the transition towards ZE-NRMM with battery electric equipment, putting hydrogen electric solutions at a lower priority except for projects where a grid connection is not possible (WDSM, 2022). In addition, it discredits the use of biofuels (e.g., HVO) as a solution because it does not lead to a theoretical reduction of CO_2 following EU-regulation, and it does not tackle the NO_x and PM emissions (WDSM, 2022). Moreover, WDSM emphasizes that in the first year's cleaner ICE NRMM (stage IV/V) should be stimulated along the phase-out of more polluting NRMM stage classes (WDSM, 2022).

The SEB-program follows the directions provided in WDSM, and builds upon them by concretizing a roadmap for the market in the power categories (Appendix E) with each a different ingrowth path (SEB, 2023). The roadmap is divided into three levels of ambition, namely: minimal, basic, and the ambitious path, an example of the minimum-level is provided in Appendix F.

Dutch market prioritizes BEV, FCEV is considered for heavy NRMM and HVO as intermediary solution

The actors involved in the mission perceive BEV as the main solution pathway for the implementation of ZE-NRMM in the Netherlands (OEM2; SME1; NET3; CON1; CON4; CON5; WAT2; BAN1). Especially, actors consider the light and medium-heavy NRMM to be moving towards full battery electric solutions, whilst for the heavy NRMM hydrogen is still considered. ''I think you can draw a line that medium-heavy construction equipment. Excavators to around 180 kilowatts or 20 tons, that they can be properly electrified. However, with heavier construction equipment, it is clear that we do not yet know exactly what energy forms will be for the powertrain [of NRMM].'' – NET1. The solutions both have advantages and disadvantages in the GWW-construction sector. Advantages of BEV are better availability of infrastructure, which is limited for FCEV (OEM2). Yet, with FCEV it is easier to get a full-working day, whilst with BEV the battery is drained before the end of the day and thus has idle-time (WAT1). Moreover, HVO is considered to be an important intermediary solution in this transition by most contractors (CON1; CON3; CON4; CON5). As CON1 mentions: ''HVO is a very important intermediate solution for us, especially for heavier and specialistic equipment''. However, HVO is not nearly as effective for mission success if it is not used in higher stage NRMM (VI/V) because this filters NO_x and PM.

International OEMs focus more on hydrogen electric NRMM

An important factor to take account of is what major international OEMs are considering as solution pathways, as these ultimately will provide most supply of NRMM. OEM1 specifies that they both experiment with BEV as well as FCEV, but that in an international perspective the FCEV seems the more likely pathway to go down as it enables the NRMM to work in remote locations without infrastructure (OEM1). As OEM1 explains: ''Hydrogen is very important to us because it is more useful in areas where there is little infrastructure, areas that are very remote. Hydrogen is quite a big one for us... we're reasonably aiming for that.'' – OEM1. OEM2 confirms this by mentioning that OEMs like JCB are investing a lot into hydrogen electric NRMM. An example of the recent campaigns of JCB shows their focus: 'There is an alternative – It's HYDROGEN!' (JCB, 2023). However, OEM1 adds that ultimately some of the large OEMs that manufacture relatively more light and medium-heavy equipment might focus more on BEV (e.g., Volvo) and others will choose FCEV as ultimately having both solutions causes too much diversity in a manufacturing organization (OEM1).

Lack of direction in energy infrastructure solutions at GWW-construction sites

In terms of energy infrastructure solutions, there is no clear pathway that stands out. As GOV2 mentions: ''Charging infrastructure is still quite a search process.'' – GOV2. The crux is that some GWW-projects may be suitable for a new grid connection, but those are scarce as grid congestion is a major issue and construction sites are temporary and thus often cancels out that option (NET3). GOV2 adds that line-projects are less suited: ''Like the A16, which is a stretch of about ten kilometers, you cannot install a permanent connection every half a kilometer. It all becomes too complicated and too expensive.'' NET3 emphasizes that new solutions are thought out like unguaranteed grid-connections, or using existing charging infrastructure of cars with adapters. In addition, off-grid solutions are available like battery swaps, mobile battery storage, and transporting hydrogen to construction sites. However, the urgency on the topic is enormous as contractors start initiatives themselves to supply energy, as CON1 explains: ''Because we couldn't wait for the market, we have set up a WattHub ourselves, which is a large infrastructural charging hub to charge heavy machinery. We are building it to be able to provide our own electricity for our construction projects.''. Ultimately, the enormous variety of energy supply solutions and infrastructural complexity leaves parties with a lack of overview and knowledge on what the best solution pathway is.

4.3.5. SF5: Market creation

Market creation is characterized by the lack of consistent demand from public clients in the Netherlands, and energy regulations that hamper the arrangement of energy infrastructure at construction sites. In addition, the Netherlands is a frontrunner in regulations surrounding ZE-NRMM whilst the EU is lacking strictness in their regulations.

Adoption rate of ZE-NRMM increasing, lack of consistent demand from governments hampers scale-up

The adoption rate of ZE-NRMM is increasing in the Netherlands due to a variety of attributes that support the niche market, such as the SSEB subsidy for ZE-NRMM (GOV2; GOV3; MUN1; NET2; NET3; CON1; WAT2) and the requirement of nitrogen permits (SME2; CON4; CON5; CON6; ENG1).

The SSEB subsidy helps with the initial investment, GOV2 explains: ''This is partly made available in the form of a subsidy, in which 40% of the additional costs can be subsidized.'' – GOV2. THE SSEB subsidy is mainly seen as trigger and especially helpful for SMEs to make investments (CON2; SME2). However, the SSEB is not sufficient as it is a one-off incentive, whilst for NRMM machines it is more important that there is sufficient guarantee of usage, as CON6 mentions: ''At the moment we have a government that works very much with subsidies. That's nice, but that still doesn't create a market.'' – CON6. The nitrogen crisis requires permits, which can be granted if you work zero-emission and thus creates a niche market for ZE-NRMM as CON6 explains further: ''So if that can be done without emissions, then you have to do that in order to also be able to tackle your nitrogen problems. We are not getting a permit now and then the work will come to a standstill.'' – CON6.

The increase in the adoption rate is due to signals at OEMs that see an increase in their ZE-NRMM sales (OEM1; OEM2). ''Right now in terms of sales, it's under 5% of the total number of units we're selling. Only we do see that there is more demand and more growth.'' – OEM1. CON4 adds that frontrunners are buying more and the platoon is also starting to consider ZE-NRMM: ''So you now notice that the frontrunners who believe in it [ZE-NRMM] have now ordered. And those who, I'll call them the platoon for now, are starting to account and estimate in quotes, in those TCO calculations, so I hope and I suspect things are moving faster now.'' – CON4. However, scale-up is not taking place or too little requests in tenders, following NET1: Frontrunners in tenders are doing very well. But scale up is taking place too little. It [ZE-NRMM] should be much more requested in tenders. – NET1.

The latter is one of the main barriers emphasized by other interviewees for the scale-up not taking place. The lack of consistent request or requirement of ZE-NRMM in tenders and thus lacking consistent demand from the government (GOV1; GOV2; GOV3; WAT1; WAT2; CON2; CON4; CON5; ENG2). GOV3 explains: ''The most important barrier is if we as public clients are too volatile. So the one time you ask for emission-free and the next time you don't, they [contractors] want certainty'' – GOV3

To tackle this barrier, the SEB-program has started the SEB-covenant, which requires all public clients to commit to a certain ingrowth path as explained in SF4B, to make sure that demand will be more consistent (SEB, 2023; GOV1). This helps to provide long-term perspective to the market, and create certainty around ZE-NRMM usage (CON1; CON2; CON6; SME1). Yet, there are a variety of parties that argue the covenant to be not ambitious enough, too informal, and thereby not creating sufficient urgency (CON2; GOV3; WAT1; INS2).

''I think SEB offers too much space, I find that too unambitious, and it puts too little pressure on the market. And there is still a lot of room for [public] clients to choose a low level of ambition. And if you have signed the covenant, well it remains a covenant, so what is its worth... But on the other hand it is the covenant that you should adhere to, so yeah, what is it then... These are semi-soft rules.''- INS2

Ultimately, there is a typical demand-supply challenge, as GOV3 explains: It's a kind of chicken and egg problem, if there's no demand then the manufacturers won't offer it. – GOV3. Therefore, the government aims to create demand, as GOV2 mentions: We will mainly focus on more projects to use zero-emission material, so we're going to build that out gradually now. The hope is that this will eventually gain such mass that the producers will also scale up. That's actually what we're looking for at the moment. – GOV2. However, it can be questioned whether the Dutch NRMM market can create significant demand to solve the chicken-egg problem.

The Netherlands frontrunner in EU, EU NRMM legislation lacking and international OEMs wait-and-see

The Netherlands is trying to create a market for ZE-NRMM with formal and informal policies supporting niche market creation. However, The Netherlands is a frontrunner in Europe on ZE-NRMM, with other countries still lagging behind on this type of policies or not even considering it (REN1; OEM2; BRA1). OEM2 mentions: ''the Netherlands is just very much ahead of this kind of legislation and these kind of emission regulations'' - OEM2. However, as both OEM1, and OEM2 mention and which is also recognized by CON1, the EU-regulation is more important: ''Developments in the EU are quite leading, because our machines do not come from the Netherlands. Our machines almost all come from abroad. What that means, if the EU starts moving in those emission standards, then those machine builders will have to go along.'' – CON1. Since 2020, the EU has instituted the NRMM directive which is a formal regulation to which all OEMs that supply to the EU have to comply with, however, this directive is merely focused on reducing emissions, excluding CO_2-emissions and lacks ambition (BAN1). Ultimately, these non-strict regulations allow the use of ICE NRMM, for which there is sufficient demand globally and therefore insufficient market formation for international OEMs to move towards ZE-NRMM (OEM1). As OEM1 emphasizes, stricter regulations are necessary: ''a phase-out deadline is necessary for them to start moving.'' – OEM1. The Dutch government is aware of this but struggles to find methods to make the EU prioritize this problem, as GOV2 mentions: ''So we are actually still looking for ways to make a bigger impact internationally and to grow demand there as well.'' – GOV2.

Strict energy regulations hamper energy supply arrangements at ZE GWW-construction sites

GWW-projects with ZE-NRMM are affected by the strictly regulated Dutch energy market, which makes the procurement of energy infrastructure less flexible, non-discriminatory, and strict in terms of privacy-policies. First, NET3 explains how the privacy law in the Netherlands is in the way of a more efficient process to connect contractors with local actors that have grid capacity left that can be used during ZE-construction:

''What we do run into from the grid operating side is privacy legislation. Suppose a contractor or a combination of contractors says to a grid operator: 'We are going to strengthen the dike in your area and we have to go there and those places.' In that case, a grid operator is not allowed to tell them that they observe three companies who also happen to be located along that dike, who still have grid capacity left. They can't say, 'hey maybe go knock on that door', that has to be done on their [the contractors] own initiative. And only if a company says yes, we want to cooperate in this, then the network operator may also interfere. So, yes that privacy legislation that is in place is really in the way of grid operators.'' – NET3

Second, the energy market is non-discriminatory, which means that applications for grid connections cannot be prioritized. For example, if a non-Nature2000 area construction project has approval for a grid-connection to execute it with ZE-NRMM, it might be at the expense of construction project affected by a Nature2000 and hence being cancelled as it could not obtain a similar grid-connection (CON1). Yet, no priority can be provided to these Nature2000 construction sites. NET3 emphasizes: That's not allowed. You have a non-discriminatory policy with the grid operators. This means that they are not allowed to prioritize based on the characteristics of a connection. – NET3.

Third, CPO1 emphasizes that an opportunity for ZE-construction in the energy market regulations could be to enable contractors to generate 'Renewable Energy Units' (HBEs). CPO1 explains: If the contractor himself arranges Infrastructure at its location, then they could potentially generate 'Renewable Energy Units'. Those are HBEs, and could have serious impact on the business case. – CPO1. HBE's can have a major impact on the business case as you could generate profits by selling or trading these, however, following the NEA regulations this does not apply to construction sites (NEA, 2023; EVConsult, 2023).

4.3.6. SF6: Resource mobilization

Resource mobilization is characterized by the insufficient supply of ZE-NRMM in the Netherlands, which makes the Netherlands dependent on supply from international OEMs. In addition, ZE-NRMM requires higher investments from contractors, and to create a business-case long-term usage guarantees are required. Last, there are a variety of energy infrastructure mobilization challenges.

Insufficient supply of ZE-NRMM in the Netherlands, mission success depends on international OEMs

Twenty-two out of the twenty-seven interviewees emphasize the limited availability of ZE-NRMM in the Netherlands. As CON6 mentions: ''Because more and more sustainable tenders are being put on the market and the amount of ZE-NRMM can't really keep up'' – CON6. SME2 continues by emphasizing the long waiting times: ''We can order a crane there, but then you'll have it in two years. While we already have to carry out projects emission-free. The market is not yet set up to provide all contractors with electrical equipment.'' – SME2. However, a distinction is made, light NRMM is more readily available than heavy NRMM. CON3 mentions: ''For the light equipment, quite a bit of electric [NRMM] is available.'' – CON3. For heavy equipment, CON5 explains: ''There are certain machines, also for road construction, that only exist in a stage 3 in the Netherlands. Or a stage 4. Before they are electric, we may be past 2030, I think. And that is simply because machines of this kind are not yet being built in all of Europe. Electric or with a higher stage class'' – CON5.

Currently, the Netherlands depends mostly on retrofitters, but the reality is that this will not be sufficient (BAN1; BRA1; NET3; REN1; GOV3; OEM1; OEM2). As GOV3 mentions: ''The retrofit market is running at full speed, but look with retrofit you won't save the future. So the manufacturers, they actually have to change.'' – GOV3. BRA1 adds upon that by saying: ''There are retrofitters and they make the equipment from a diesel machine and create a emission free machine. However, that is totally insufficient to make emission-free equipment on a large scale. That's what we need manufacturers for.'' – BRA1. Therefore, to achieve mission success, the Netherlands is dependent on the ZE-NRMM supply of large international OEMs, as domestic retrofit will not be sufficient.

However, the ZE-NRMM supply from large OEMs will take up a few years to get the know-how, build production lines, and acquire sufficient raw materials (OEM1; OEM2). As OEM2 mentions: ''But raw materials are also a challenge in these types of processes, especially for components that are not yet being produced on a gigantic scale.'' – OEM2. BRA1 adds upon that emphasizing the time before a production line is setup: ''To set up a production line for such a manufacturer will take at least 10 years.'' - BRA1.

ZE-NRMM higher initial investment, business-case requires long-term usage guarantees

Many of the interviewees emphasize the high price of ZE-NRMM, which is often experienced as 2-3 times higher than traditional NRMM (GOV2; GOV3; NET2; BAN1; REN1; CON1; CON2; CON5; MUN1). However, a nuance has to be made as there are also experiences that light NRMM is more competitive in initial investment than heavy NRMM, as MUN2 mentions: ''But the lighter the equipment is, the more competitive the price, and in fact, how it can sometimes be even cheaper than traditional equipment.'' – MUN2. In addition, OEM2 explains that their serial production cranes are up to 25% more expensive, which is significantly less than retrofit prices and thus retrofit has a large impact on the prices.

The government realizes this and that is why the SSEB subsidy has been initiated, to ensure that there is a business case: ''On the other hand, you also want to make a closed business case for the contractor. So that subsidy contributes to that again. Because if they see, well, with that subsidy and maybe some extra project money it can be done, then they can also get in, because they obviously cannot get involved in a loss-making initiative.'' – GOV2. Therefore, the retrofit market is quite dependent on this kind of subsidies. Yet, the SSEB subsidy is part of the larger investment of 900 million in the transition path WDSM, which is a significant contribution to help both the market and public clients (GOV1; GOV2). However, there are reports and actors that believe this allocation of funds will be insufficient to reach the goals of 2030, but it remains a discussion: ''No, it is also expected that it is insufficient. There are estimates that the entire transition in additional costs are 3 billion.''- MUN1.

Still, even with additional funds from the government, SMEs and local governments struggle with the additional costs of ZE-NRMM and cannot make the necessary investments. As MUN1 mentions: ''Why are the other municipalities not yet moving, because the use of emission-free equipment costs much more money, and many municipalities do not have the money to deploy all those machines.'' – MUN1. Besides, BRA1 explains for SMEs: ''If you are an SME, then in the current contracting market it is only profitable if emission-free equipment is supplied from the manufacturer.'' – BRA1. And CON6 emphasizes the associated risks for SMEs: ''Smaller entrepreneurs will not take that risk, cannot cover the risks involved''. – CON6. However, many actors agree that ultimately there needs to be consistent demand on the long-term to write-off the investments on multiple projects and thereby being able to justify the investments (CON1; CON2; CON4; CON6; OEM2; BRA1; ENG2; WAT2). Moreover, contractors need this long-term security from the government in order to provide the same security to their subcontractors who own a lot of the equipment (CON1; CON6).

Energy infrastructure mobilization challenges

The challenge with construction sites where ZE-NRMM is implemented is that it requires much more energy than a traditional construction site. As BAN1 explains: ''The transition to zero emissions is quite difficult as the equipment often uses a lot of energy.'' – BAN1. Traditional construction sites often get a grid-connection on the low voltage grid, but as a consequence of the increased energy consumption of ZE-NRMM, NET3 explains that this is insufficient: ''Construction sites are often small consumption and the complexity is also that you are now going from small consumption to large consumption. Whilst small consumption is a low voltage grid. – NET3. NET3 continues to explain the friction that this causes, as the higher-voltages grids have much more grid congestion: ''That's [low voltage grid] not where the problem lies. The problem and the congestion are on the medium voltage and high voltage grid.'' – NET3.

The scarcity that arises due to the net congestion on high voltage grid has caused a temporary hold on new applications for grid-connections, which impacts ZE GWW-projects (WAT1; REN1; NET3). As WAT1 explains: ''Since November last year [2022], Tennet has set out a nationwide stop. Meaning major electricity connections may no longer be issued, so that means getting that power to the construction site is going to be your biggest challenge'' -WAT1. In addition to the challenge of getting a grid connection, CON1 adds that the challenge is even more complicated in line-projects: ''Projects are sometimes 30 km long and then you also need electricity, at 15 places, then you have to drag batteries and components back and forth.'' – CON1. Moreover, in the case that contractors are able to get a grid-connection, the first question is whether the electricity is actually green (CON1; CPO1; ENG1). The second effect is that often many months or even years have passed causing major delays to the project, as SME2 summarizes:

''It all starts when you apply for your construction connection. So acquiring a power connection at your construction site. That is something that a [public] client can actually arrange at the start of the project, before the tender. But in the case that we have to do it, and given the current capacity of the grid, it can simply take two years before we have a heavy construction connection. By then the project is actually either already in progress or finished.'' – SME2

Lastly, when looking at FCEV NRMM, the infrastructure in the Netherlands is even more limited in contrast to electricity, causing even more of a challenge. As ENG1 emphasizes: You can see that if you go towards zero-emissions, electric predominates compared to hydrogen. Mainly because it is somewhat easier to apply in relation to the infrastructure that is required. – ENG1.

4.3.7. SF7: Creation of legitimacy

Creation of legitimacy is characterized by the mixed ambitions for the ZE-NRMM mission in the GWW-construction sector. Especially smaller actors in the platoon, both public and private, have less support, and besides there is lacking support from international OEMs.

Mixed ambitions for the ZE-NRMM mission among actors in the GWW-construction sector

Following the interviews, a general consensus arises that frontrunners, which are often larger actors, are more ambitious and supportive of the mission than the smaller actors who are often part of the platoon. WAT2 emphasizes the mixed ambition: ''You see a whole different world there. There are just these really progressive actors. They say, oh we would like to do that [ZE] for you, and there are also parties that simply prefer to continue to work traditionally.'' – WAT2.

Frontrunners that are ambitious vary among government levels, for example Rijkswaterstaat, HwbP, some large provinces, and the largest municipalities are ambitious in ZE-NRMM mission. GOV1 mentions: ''Rijkswaterstaat, for example, will sign up for the ambitious level.'' – GOV1. Moreover, INS2 mentions the high ambition from the ministry and SEB-program: ''there is quite a high commitment by the ministry with the SEB.'' – INS2. In the market, most large prime contractors are supportive of the mission. CON4 mentions: ''I see that as frontrunners, so Heijmans, Ballast Nedam, Vriezer van de Wiel, and DuraVermeer. They're ahead.'' – CON4. However, GOV1 explains that the mixed ambition can also be seen in the expected signing of the covenant:

''The covenant will initially be offered to ministries, including public clients, local authorities, including water authorities, knowledge institutes and trade associations. We expect ministries, including contracting government agencies, to sign the ambitious level. We also expect that there are certain municipalities that are already doing a lot of work on this, also signing as frontrunners. All other parties are not immediately expected to sign up for the ambitious level.'' – GOV1.

Furthermore, CON3 explains why there might be a discrepancy between larger and smaller companies in their ambition and support: ''I have always worked for large companies and they are more aware and they feel more socially responsible than the smaller companies. Only when they know that there is no longer work for them because they don't go along, then the need emerges more and then they will get to work with it. This applies to safety rules, but it also applies to sustainability.'' – CON3. SME2 confirms this statement from CON3: "I think contractors don't really understand the problem yet of what it actually means to be able to work completely emission-free in seven years' time."- SME2. But later mentions that urgency for ZE-NRMM is rising: ''It is finally starting to live a bit because we now see that we have to stop projects.'' – SME2. Moreover, SME2 experiences that the government is pushing the problem to the market: ''They [public clients] often come up with the request to work emission-free, otherwise you are not allowed to tender and that's it. It's really kind of shifting the problem to the other side.'' – SME2. SME2 is not the only one experiencing this, as many branch organizations that mostly have SMEs as followers are wary of the speed to which the ZE-NRMM transition is unfolding, as GOV2 mentions: ''Then you also see that certain branch organizations express their doubts. We don't want to go too fast and we don't want to have to write off our existing equipment too quickly.'' – GOV2. INS adds to this that there is slight skepticism surrounding the SEB-program: ''So they're really pushing it, we have to go on, we're going to make agreements. But that underlying skepticism, a bit of mistrust as to whether things will work out if we just keep going, that is a problem.'' - INS2. Moreover, interviewees add that the outcome of provincial elections in March 2023 also shows that support for emission reduction in general, but especially nitrogen is extremely low in the countryside areas (CON6; MUN2; SME1). Therefore, questions rise even for frontrunners whether government policy will be consistent over the long-term, it creates uncertainty (CON6; BRA1).

4.3.8. SF8: Coordination

Coordination is characterized by the SEB-program with its roadmap and covenant as focal coordinating initiative. However, there is lacking coordination for energy infrastructure at ZE GWW-construction sites and lack of intergovernmental tender monitoring, planning, and coordination.

The SEB-program with its roadmap and covenant are the focal coordinating initiative for the mission

The SEB roadmap and covenant are important coordination initiatives from the government towards the market to jointly accelerate system growth towards the mission. This can be argued as the SEB-program provides support for multiple system functions, and is the most widely carried initiative in terms of the variety of public and private actors involved. The most important aspects of SEB are facilitating research (GOV1), providing direction in the diversity of solutions (see chapter SF4B), creating a shared ingrowth and phaseout path via the covenant that will be signed by all public clients (see chapter SF5), which includes monitoring and reflection moments planned to track and evaluate the mission progress (SEB, 2023).

The monitoring that the SEB-program envisions takes place on three levels, namely: monitoring the emissions reduction effects of the SEB Roadmap, monitoring the implementation of the SEB Roadmap by supervising activities of involved public clients, and monitoring the actual construction activities of ZE GWW-projects (SEB, 2023). In addition, evaluation moments based on these monitoring levels are planned in 2024, 2027, and 2030, which enables reflection and better steering of the mission (SEB, 2023).

Lack coordination energy infrastructure for ZE GWW-construction projects from public clients

Energy infrastructure mobilization at ZE GWW-construction projects is a major challenge (see SF6). Following the interviewees, a general consensus rises that these complex infrastructural problems cannot be left to be solved by the market. Involvement and coordination from public clients can be valuable and is often required (WAT1; MUN1; ENG1; ENG2; SME2; CON4; CON5; INS2; BRA1; NET2; REN1; NET1; NET3; GOV1; GOV2). As CON5 states: ''They want the project, they want something built. We can only do that if the facilities are there to build and something of a grid connection is arranged by the government. That is not something a contractor can say that we do, like we want power here, so we get power here. Unfortunately it doesn't work that way.'' – CON5. In addition, ENG2 emphasizes that tender planning through programs is required, and foresees potential monopoly situations if no coordination is provided by the government, as contractors will arrange energy infrastructure contracts with energy providers themselves and thereby monopolize certain regions with no grid-connections (ENG2).

In frontrunner projects, the energy infrastructure arrangements are primarily arranged by the public clients, only MUN2 has a strong opinion that infrastructure should be arranged by the contractor

(MUN2). In contrast, a prime example of facilitating and coordination is municipality Arnhem: ''In this sense, we go one step further. We have now installed a number of charging points with very large charging points, to which we can really connect several machines and multiple contractors can also use it there.'' – MUN1. WAT1 also emphasizes the importance to be proactive: ''Organize already at the start everything that you can do from the client's side, for example, arrange energy supply at the construction site. Because if you don't arrange that in time, the contractor can no longer get to work.'' – WAT1

Lack of tender monitoring, planning and intergovernmental coordination of GWW-projects

First of all, currently there is a lack of oversight and monitoring of the mission progression, as GOV2 states: ''In fact, there is not yet a very good overview of the numbers [of ZE-NRMM] that are deployed. So, the idea of the transition path is that we gradually increase the number of frontrunner projects and the share of zero-emission work that is carried out in them, but we have not yet measured whether we are on track.'' – GOV2.

The lack of monitoring is evident on mission level and in tenders, as INS2 mentions: ''Where it gets complicated, is that such a party [contractor] has offered it [ZE-NRMM], and then will do the actual work outside and then he must do what he has offered. But then you now see that we only rely on their blue eyes, while in practice it usually does not always lead to the right solution.'' – INS2. This problem partially originates from the fact that contractors experience challenges when writing in on ZE-tenders, as they have limited ZE-NRMM but want to write in on all ZE-tenders, CON4 explains: ''You only have a few machines, and you are writing in on three [ZE-]tenders at the same time. You promise your machine in three different places. Yes, if you are rewarded with all three, then you have a problem.'' – CON4. Ultimately, this issue can be tracked back to tender coordination throughout different government levels, which is hardly taking place. As WAT1 explains: ''Much more coordination is needed, but ultimately you get to the point where every government is responsible for its own tenders and makes their own choices.''- WAT1. However, CON6 recognizes that public clients are thinking about more coordination: ''So you also see [public] clients thinking about why shouldn't we align our tendering schedules much more? So that they don't overcrowd the market at the same time and have nothing available a while later.'' – CON6.

Specifically, umbrella organizations can be useful in these coordination issues, like the Union of Water Authorities, Association of Municipalities, Interprovincial Consultation (MUN1; CON6; ENG2; GOV3). However, these organizations are involved to some extent, and especially municipalities lack coordination, as MUN1 explains: ''Governments, very limited, where you can really see a distinction between Rijkswaterstaat, provinces and water authorities where it does happen, but hardly any within municipalities.'' – MUN1. In addition, CON1 mentions that the lack of coordination is also harmful for nitrogen affected construction projects: ''There are clients who say, I would like to have this carried out zero-emission and I am going to put a very sustainable tender on the market. Then you have another client who has no choice because it is located next to the Natura 2000 area and who asks for the same. I [contractor] only have one electric crane, which project will I use it for? In fact, some kind of coordination is needed for that.'' – CON1. Ultimately, there is a lack of coordination, but as CON4 and ENG1 emphasizes, the government is the only actor that can influence and coordinate the system.

4.3.9. SF9: Regime change

Regime change is characterized by a clearly defined phaseout in the SEB roadmap, but, in reality, there is a lack of phase out of harmful NRMM based on fossil fuels and international OEMs that are locked into fossil-based practices.

SEB phaseout path defined in roadmap and covenant

The SEB roadmap and covenant have a defined phase-out path for harmful NRMM that is based on fossil fuel and have less emission reducing technologies installed such as filters (SEB, 2023; GOV1; INS2; BRA1; CON5). Actors think that the phase-out path from SEB does help to create regime change, however, in general they agree that there is a lacking phase-out (CON1; CON4; BAN1; GOV2; SME1). For example, GOV3 mentions: "Because there is still quite a lot of room to use fossil material. In particular, the heavy material is phased-out quite late." – GOV3.

Lack of directionality in solution pathways creates wait-and-see attitude platoon and slows phase-out

Still the market misses some directionality as there is not one clear solution pathway for GWW projects, both on which technology performs best and the ongoing search for optimal energy infrastructure solutions (INS2; SME1; SME2; NET3; MUN1; MUN2; OEM1; ENG2; GOV1; CON; CON6).

''But I think it's mainly a bit of a wait-and-see attitude. Will it really be all electric? Or can we immediately switch to hydrogen? Or what is the best solution for the future? You see that those big machines, especially the heavy machines can't really switch to electricity anyway. So that you actually prefer to go for alternative fuel or hydrogen.'' – CON6

Whilst larger actors have uncertainty, they still pursue the mission if they are more involved in the frontrunner projects. For smaller and local actors the lack of directionality is more worrisome and they will put their priority elsewhere: ''If you have a small municipality, you cannot just free someone up to deal with this problem. Because it is still so new and so many municipalities say 'I'll just wait and see what happens nationally first''. – MUN2. Especially SMEs and subcontractors are waiting, and little phase-out takes place. MUN1 mentions: ''Well, that platoon needs to get moving, but the platoon is still really waiting''. An important aspect that is hampering the phase-out of harmful NRMM is the long depreciation time of NRMM, and therefore contractors have to write-off early, inducing a loss to be able to replace it now (GOV2; GOV3; BAN1; ENG2; CON3). As BAN1 explains: ''But with construction that stuff [NRMM] is all very expensive, so that is financed for a certain term. And to break that halfway, that is of course terribly expensive. So they have to sit out that period for a while.'' – BAN1.

International OEMs locked-in to practices based on fossil fuel

OEMs are locked into current practices and routines that are focused around fossil fuels, with assets invested accounting to 100 billion for OEM1 and therefore a sudden change of direction would be impossible (OEM1). BAN1 emphasizes this: ''Existing OEMs have a completely different challenge. They have a lot of structure, capital, people, knowledge, know-how in the production of those fossil-powered machines, and therefore are much less agile to stop that'' – BAN1.

The lack of phase-out can be observed with OEM1 current practices: ''We sell around 25 models in the Netherlands. Of those 25 models, roughly 5 production lines are completely electric. Well, that's really nice, so then you have roughly 20%, but if you look worldwide. I won't exaggerate, I think about 450 production models, of which we have roughly, say, 10 electrified.'' – OEM1. Moreover, OEM1 specifies that due to the lack of supply, contractors are nudged towards buying fossil fuel NRMM again: ''If a customer wants to buy electric, and we would produce that model. Then there are such long delivery times and waiting times that the customer already says I will just order a diesel model.'' – OEM1.

4.3.10. MIS strengths and weaknesses overview

Following the separate elaboration on the performance of the systemic functions, a high-level overview of all strengths and weaknesses is provided in Table 4, which is based on the themes elaborated in sections 4.3.1-4.3.9.

Table 4: Overview of the strengths and weaknesses of the MIS.

System function	**Strengths (+) and Weaknesses (-)**
SF1: Entrepreneurial activities	(+) A variety of ZE-NRMM experiments and pilots are taking place in the Netherlands. (-) Platoon less or not involved in experiments. (-) Experiments and pilots don't provide continuity.
SF2: Knowledge development	(+) Sufficient knowledge development frontrunners. (+) Sufficient technological knowledge ZE-NRMM developed. (-) Insufficient knowledge development platoon. (-) Lacking knowledge development energy infrastructure and system, safety, and monitoring.
SF3: Knowledge diffusion	(+) Buyer Group ZEB diffusing procurement know-how to public clients. (-) Knowledge is stuck with frontrunners or sticks to actors within projects. (-) Knowledge diffusion hampered by competition and potential competitive advantage in tenders. (-) Retrofitters gain knowledge, but limited diffusion towards OEMs.
SF4A: Problem directionality	(+) Government provides problem directionality through KCI strategy and WDSM transition path. (+) Nitrogen creates urgency to work with ZE-NRMM, public health and climate are secondary. (-) Not always clear what to focus on, priority of societal problems depends on nature project activities. (-) Whilst synergies are recognized, they remain hard to steer for the government.
SF4B: Solution directionality	(+) Transition path WDSM and SEB roadmap provide solution directionality (+) Clear direction BEV for light and medium-heavy NRMM, and HVO as intermediary solution. (-) Lack of directionality heavy NRMM, consideration between BEV or FCEV. (-) Lack of direction in energy infrastructure solutions at GWW-construction sites
SF5: Market formation	(+) Adoption rate of ZE NRMM increasing. (-) Lack of consistent demand from government hampers scale-up. (-) NL frontrunner in ZE-NRMM regulations, but EU legislation is lacking and not strict. (-) Strict energy regulations hamper energy supply arrangements at ZE-GWW construction sites.
SF6: Resource mobilization	(-) ZE-NRMM requires higher investment, business-case depends on long-term usage guarantees. (-) Insufficient supply of ZE-NRMM in the Netherlands, mission success depends on supply international OEMs. (-) Variety of energy infrastructure mobilization challenges.
SF7: Creation of legitimacy	(+) Frontrunners ambitious and support ZE-NRMM mission (-) Platoon and OEMs not ambitious and less support ZE-NRMM mission (-) Provincial elections cause uncertainty regarding nitrogen and government policy.
SF8: Coordination	(+) SEB-program with its roadmap and covenant focal in coordination of the mission (-) Lack coordination from public clients in providing energy infrastructure for ZE GWW-construction projects (-) Lack of tender monitoring, planning, and intergovernmental coordination of GWW-projects.
SF9: Regime change	(+) SEB-program defines phase-out path (-) Lacking phase-out of harmful NRMM due to multi-year depreciation, especially heavy-NRMM (-) Lacking phase-out in the platoon due to wait-and-see attitude (-) International OEMs locked-in to practices based on fossil fuel

4.3.11. MIS systemic barrier analysis

In the systemic barrier analysis, the functional interrelations between the strengths and primarily weaknesses are analyzed to identify systemic barriers. The aim is to identify how different MIS barriers are interrelated and may result in system lock-in. Through the analysis, four systemic barriers have been identified: Energy infrastructure challenges hamper ZE-NRMM implementation (1), Lack of knowledge diffusion from MIS arena to overall MIS (2), Lack of consistent long-term demand from public clients hampers market formation (3), and The Netherlands depend on international OEMs for supply ZE-NRMM (4). A complete overview of the MIS is provided in figure 5, and the further paragraphs will explain the systemic barriers individually.

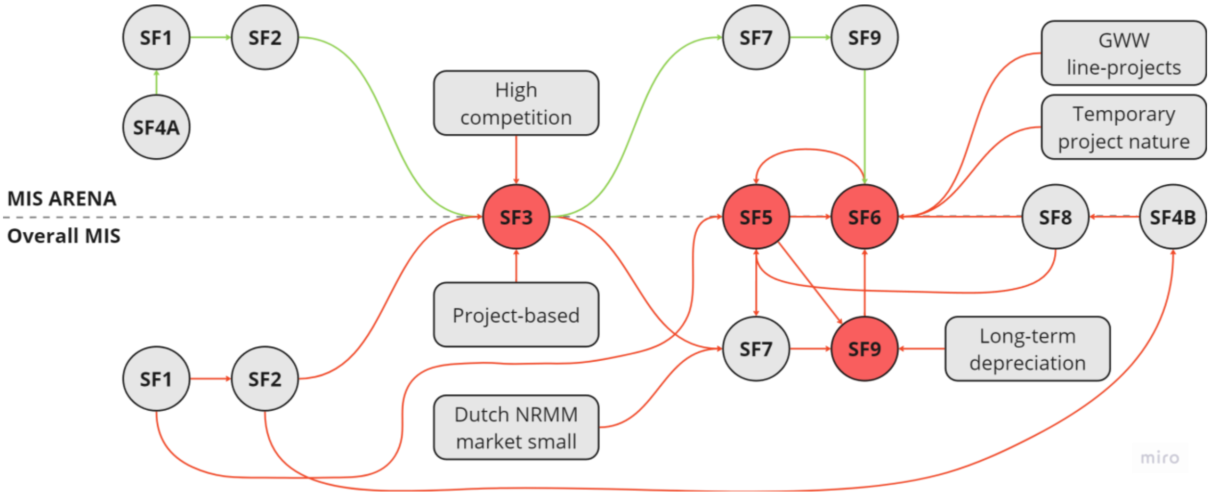


Figure 5: Overview of the system performance in the MIS arena and the overall MIS (Green lines represent strengths, red lines represent weaknesses)

Systemic barrier 1: Lack of knowledge diffusion creates growing gap between MIS arena and overall MIS

The first systematic barrier is the lack of knowledge diffusion between the MIS arena and the overall MIS, and as a result the platoon is lacking in the ZE-NRMM transition in contrast to the frontrunners in the MIS arena. The lacking development of the platoon in the overall MIS can be observed through weaknesses in entrepreneurial activities (SF1), knowledge development (SF2), knowledge diffusion (SF3), creation of legitimacy (SF7), and regime change (SF9) (Figure 6).

The frontrunners in the MIS arena experience sufficient experiments (SF1) and develop knowledge by implementing ZE-NRMM and learn by doing these projects (SF2), as these are stimulated by a variety of programs that create direction (SF4A). In contrast, the platoon in the overall MIS lacks experiments and does not have sufficient knowledge development (see 4.3.1 and 4.3.2). Knowledge diffusion from the MIS arena to the Overall MIS could prevent this gap, however the highly competitive nature of the GWW sector, and the knowledge development taking place in separate projects prevent knowledge diffusion to the overall MIS. As a result, an observed lack of support for the mission (SF7) and regime change (SF9) taking place outside of the MIS arena is observed. Ultimately, one of the main systemic barriers leading to this gap is the lack of knowledge diffusion (SF3).

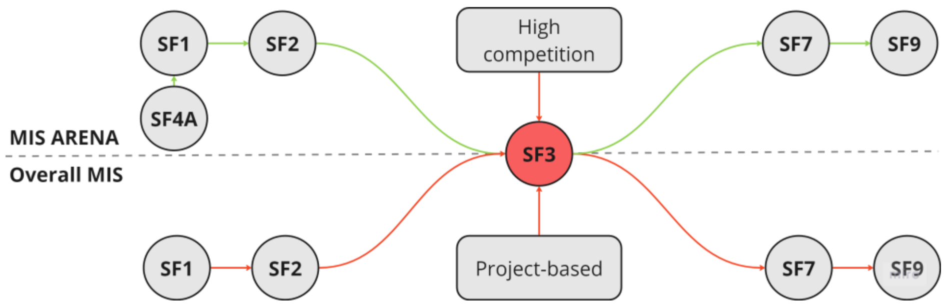


Figure 6: Interrelated MIS functions SF4A, SF1, SF2, SF7, SF9 create a systemic barrier on knowledge diffusion SF3 between MIS arena and the overall MIS

Systemic barrier 2: Lack of consistent long-term ZE-NRMM demand from public clients hampers market formation

The second systemic barrier is centralized around market formation and resource mobilization, specifically the lack of consistent long-term demand from public clients. First, experiments and pilots (SF1) do not provide continuity as these are singular in nature, which affects the mobilization of resources (SF6) as ZE-NRMM has higher investment costs and requires a long-term guarantee of usage. However, the latter is not provided by the current market formation (SF5) as there is lack of consistent demand and no coordination between governmental tender agendas (SF8). This ultimately leads to a reinforced loop where market formation is the systemic barrier that hampers mission progress (Figure 7).

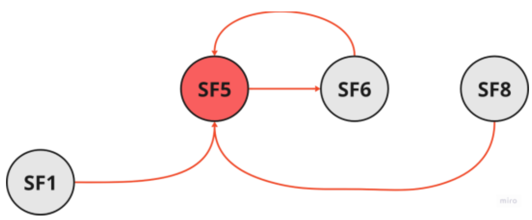


Figure 7: Interrelated MIS functions SF1, SF6, SF8 create a systemic barrier on market formation SF5 in terms of consistent long-term ZE-NRMM demand

Systemic barrier 3: The Netherlands dependent on international OEMs for supply ZE-NRMM

The third systemic barrier is also centralized around resource mobilization (SF6), specifically the lacking supply of ZE-NRMM from international OEMs. An important factor is that the Dutch NRMM market is relatively small in contrast to the rest of Europe. As a result, the demand in the Netherlands has little impact on the practices of large international OEMs, and yet the Netherlands is partially dependent on their supply as it cannot solely rely on its domestic market. However, this is problematic as the Netherlands is frontrunner in Europe on the policies for ZE-NRMM, whilst the EU regulations on ZE-NRMM are lacking (SF5). Yet, the international OEMs focus on the European regulations and therefore a lack of support and legitimacy for the mission is observed (SF7). This leads to international OEMs sticking with current practices based on fossil fuel, and thus a lack of regime change is taking place (SF9). The lack of regime change causes a lack of ZE-NRMM supply from OEMs to the Netherlands (SF6). Figure 8 provides an overview, however, due to the institution of this specific systematic barrier PPI will not be able to trigger OEMs, as this requires more scale outside of the MIS.

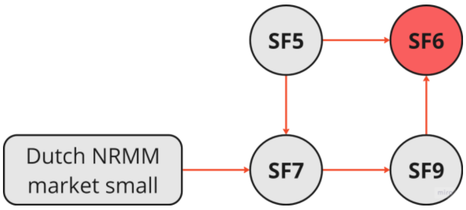


Figure 8: Interrelated MIS functions SF5, SF7, SF9 create a systemic barrier on resource mobilization SF6 due to lack of ZE-NRMM supply.

Systemic barrier 4: Lack of energy infrastructure mobilization hampers ZE-NRMM implementation

The fourth systemic barrier is centralized around resource mobilization (SF6), specifically the mobilization of energy supply and the associated infrastructure at ZE GWW-construction sites. The lack of knowledge development (SF2) on energy supply, the required infrastructure, and overall impact on the energy system cause a lack of solution directionality in optimal energy supply solutions (SF4B). In addition, in ZE GWW-projects there is a lack of coordination and division of responsibilities between government and market parties in terms of facilitating energy infrastructure (SF8), which together leads to lacking mobilization of energy infrastructure. Besides, regulations hamper the mobilization of grid connections through third parties (SF5). Last, due to the inherent temporary nature of construction projects high investments in infrastructure are hard to justify, and the nature of line-projects causes an extra barrier to the mobilization of energy along construction sites spanning several kilometers. Ultimately, the interrelated weaknesses cause a systemic barrier in the resource mobilization of energy supply and infrastructure of ZE GWW-projects (Figure 9).

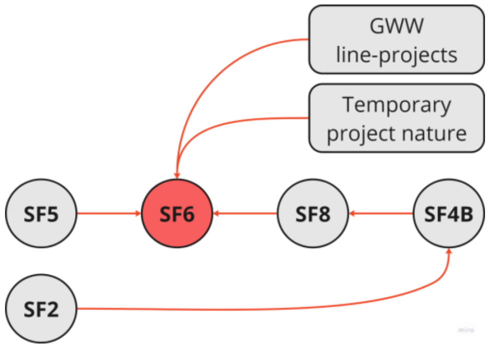


Figure 9: Interrelated MIS functions SF2, SF4B, SF5, SF8 create a systemic barrier on resource mobilization SF6 in terms of energy infrastructure.

Systemic barrier 5 – solution specific: Regime change of heavy ZE-NRMM lacking in contrast to light & medium-heavy ZE-NRMM

In addition to the systemic barriers Reike et al. (2023) account for solution specific barriers, which also applies in this study as the regime change of heavy NRMM is lacking in contrast to light & medium-heavy NRMM. This distinction is made as solutions may be in a different stage of development and hence more or less actors may be lobbying for it which affects the legitimacy and resources (Reike et al., 2023). Therefore, the well-known development stages of technological transitions (S-curve seen in Figure 10) is applied to the different power categories of ZE-NRMM (Hekkert et al., 2011). Following the analysis, light & medium-heavy NRMM are in the take-off phase as commercial applications have entered the market in the Netherlands, and interviewees emphasize that their adoption rate is higher. Heavy NRMM is in the development phase as its adoption rate is lower due to the dependency on retrofit and international OEMs (see 4.3.5.).

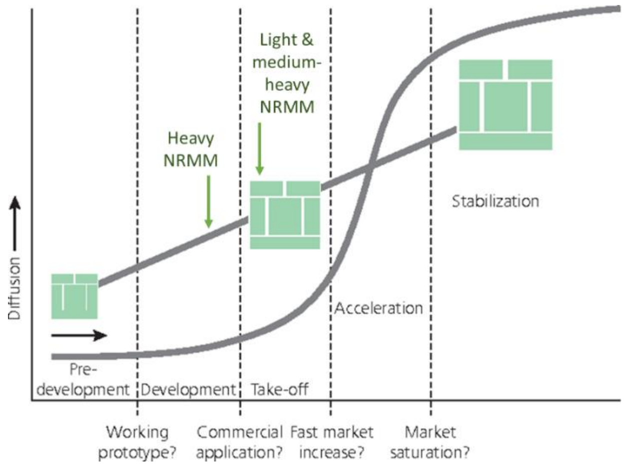


Figure 10: Stage of development light & medium-heavy NRMM vs. heavy NRMM (Hekkert et al., 2011)

More specifically, heavy NRMM is performing worse than light and medium-heavy NRMM on the systemic functions: solution directionality (SF4B), market formation (SF5), resource mobilization (SF6), and thereby influencing the regime change (SF9). The lack of solution directionality (SF4B) for heavy NRMM between BEV and FCEV affects mobilization (SF6) of heavy-NRMM (see chapter 4.3.4.2.). In addition, market formation (SF5) is lacking as the SEB covenant phase-out path is less steep, leaving room for fossil fuel based heavy NRMM (4.3.9.). Last, heavy-NRMM has longer depreciation terms in contrast to light and medium-heavy NRMM slowing down the phase-out (SF9) (see chapter 4.2.3.). Ultimately, this leads to slower transition and phase-out of heavy NRMM in contrast to light and medium-heavy NRMM, shown in Figure 11.

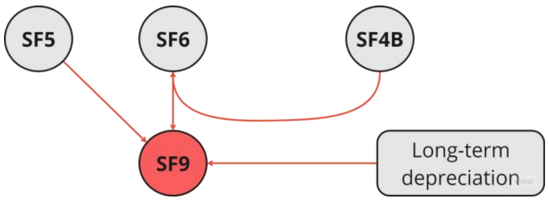


Figure 11: Interrelated MIS functions SF4B, SF5, SF6 create a specific systemic barrier on regime change SF9 of heavy ZE-NRMM

Following the above listed systemic barriers and as summarized in Figure 5, the major systemic barriers relate to the functions knowledge diffusion (SF3), market formation (SF5), resource mobilization (SF6), and regime change (SF9). The following subchapter identifies the PPI barriers, and thereafter it is analyzed how and if these influence the MIS systemic barriers.

4.4. Public procurement of Innovation

The public procurement of innovation section provides an answer to SQ4 by elaborating on the PPI barriers in the Dutch GWW-construction sector. An overview of PPI barriers is provided in Table 5.

4.4.1. Framework conditions

The PPI barriers originating from framework conditions are characterized by competition on price and strict contracts, difficult RAW-systematic to fit ZE-NRMM, tenders with ZE-NRMM are less accessible for SMEs, and public clients struggle with requesting ZE-NRMM in tenders and the level-playing field requirement.

Competition on price and strict contracts reduces innovation in GWW-tenders, RAW-systematic difficult to request ZE-NRMM

Based on the interviews, general consensus is that tenders are still focused primarily on price, even when the tender requests for sustainability (MUN1; REN1; OEM1; CON3; CON4). CON4 states: ''Those pilot projects, that's where you get a piece of EMVI in the tender. You then bet on that, but in the end it still comes down to the bottom line for the lowest price. So it is not yet sufficiently embedded in the call for tenders.'' – CON4. As a result, contractors remain focused on price, delivering the standard available products and do not include innovation in their solutions (NET1; REN1; SME1; CON6). CON6 emphasizes: ''You also notice sometimes there is simply tenders awarded purely on price. Well then you should not come up with innovations, then you just have to deliver what is available as standard and go with the available solutions that are already out there'' – CON6.

Besides, tender contracts with a fixed scope and price experience less innovation (INS2; WAT1; CON5). INS2 explains: ''We are moving away from the practice of tendering, where we want to have a fixed price for a fixed scope of work at the end of the tender. The moment you do that, you actually suppress every bit of innovation.'' – INS2. In addition, traditional contracts that are specific and 'air-tight' reduce innovation and can create a basis of distrust among stakeholders (INS2; WAT1; CON2; CON3; CON5). WAT1 explains that they do not work with traditional contracts as it creates distrust: ''We also don't have a traditional contract, which unfortunately often starts from mistrust. Then you won't trust the contractor, so there is a risk that you will close everything off [in the contract]'' - WAT1. INS2 explains further how innovation is limited with strict contracts: ''It's about new technology, innovations, that are used and these are things you will have to deal with in the beginning. Then you can be tough when you make a contract: "You should have delivered this, if you didn't, then I'll throw you off the work." But by doing that I will of course kill the development in my tender, because then no one will stick their neck out.'' – INS2.

ZE-NRMM tenders are less accessible for SMEs

ZE-NRMM tenders are less accessible to SMEs, as there is often more room for innovations in large projects, which may be out of reach in terms of capabilities and investments of SMEs (SME1; MUN1). As SME1 explains: ''The small contractors often do not bid for the projects that the larger contractors bid for, because those risks are simply too great. They don't register large projects anyway, because the financial risk, if something goes wrong, they go under.'' – SME1. Moreover, SME2 explains that investments in ZE-NRMM are relatively larger for them, which prices them out of the market in tenders: ''These are very expensive investments for an SME. For us, these are really big investments. And when we bid during a tender, we have to include some of those investments. So you end up with a higher cost price. And that actually sometimes prices yourself out of the market.'' – SME2. Ultimately, SMEs have relatively less accessibility to contracts with ZE-NRMM, but it is not necessarily caused by tender conditions, but financial challenges.

4.4.2. Organization and capabilities

The PPI barriers originating from organization and capabilities is characterized by lacking capabilities of public clients, especially municipalities lack knowledge and capabilities. In addition, larger public organizations more often have a high-level innovation strategy, but within smaller public organizations innovation and purchasing strategies are often lacking or non-existent.

Lacking knowledge, capacity, and capabilities municipal public clients

Procurement of ZE-NRMM requires new capabilities and skills for public procurers on an organizational level. WAT2 compares it as follows: ''We have to move from a business case to value case. Well, that is actually the movement you need to make as an organization.'' – WAT2. However, there is a general consensus among interviewees that public procurers currently lack capabilities (BAN1; GOV1; GOV3; CON5; CON6; SME1; SME2; INS2; WAT1; WAT2; ENG2; MUN1; MUN2; NET1; NET3). GOV1 explains:

> ''The public clients are the ones who still find it very complicated, so it's not just the contractors. The contractors want an investment perspective and policy. The clients, including all co-governments, so water authorities, municipalities, everyone, we must ensure that they can also implement it.'' – GOV1

Yet, a nuance can be made, as the capabilities vary among different levels of governments. In general, the larger the government, the more resources are available, and the more knowledge and capabilities are present for procurement of ZE-NRMM (ENG2; CON5). ENG2 mentions: ''You can say that the bigger the client, the better they are in principle. Because of their size, they probably also have people who are familiar with the subject''. – ENG2. CON5 is aligned with that statement: ''The larger government clients are simply better at this so far, because of course they also have more experience. But the other way around, also more capacity to do research into what will be possible, compared to, well, the smaller government clients.'' – CON5.

Thus, the least capabilities and knowledge is present within smaller municipalities (SME1; CON1; CON5; MUN1; MUN2; NET1; INS2). As CON5 emphasizes: ''While smaller municipalities simply have too little knowledge of what is possible, and thus they often fall back on the traditional [tender methods], which they know that work.'' – CON5. MUN1 emphasizes that for them as frontrunner it can already be challenging: ''That is of course already a challenge for us. Let alone for parties who are even less aware of this.'' – MUN1. To add upon that, INS2 emphasizes that even the standard RAW, which is used by most municipalities, can be complicated for them: ''There is a large group of municipalities for whom a standard RAW is already complicated enough.'' – INS2. Therefore, a pitfall for municipalities that want to start with ZE-NRMM is that they literally copy tenders from larger projects, but WAT1, WAT2, CON5, and NET3 emphasize that doing so leads to failure as projects are not the same. In addition, MUN1 mentions that smaller municipalities lack the capacity to implement ZE-NRMM from their budget: ''Why are the other municipalities not yet moving, because the use of emission-free equipment costs much more money, and many municipalities do not have the money to deploy all those machines.'' – MUN1.

Ultimately, the lack of knowledge, capacity, and capabilities is an important barrier as municipalities put most tenders in the market (33%), often as RAW, which is thereby the most used tender method with around 10,000 a year (INS2). Therefore, NET1 emphasizes the need for sharing lessons learned regarding procurement: ''In the Netherlands we have 342 municipalities, so each contracting authority has to learn in its own way how to do this. Therefore, I think it's very important to share lessons learned on how to do that, it is crucial.'' – NET1. However, it seems that municipalities lack a specific platform to share their lessons learned, and depend on the buyer group ZEB (MUN1; CON4; ENG2). CON4 notices: ''For example at the municipalities, that the municipality of Arnhem must tell the municipality of Amsterdam what their lessons have been learned. And that is actually a shame. So there is not enough platform to share that knowledge.'' – CON4. Besides, MUN1 emphasizes the lacking role of VNG: ''For example VNG, the Association of Dutch Municipalities, you don't see them taking an active role is in this'' – MUN1.

High level innovation strategy present in larger public clients, lacking strategy smaller public clients

In general, larger public clients and frontrunners have a high-level innovation strategy present in the organization that supports the use of ZE-NRMM, whereas smaller public clients often part of the platoon lack an innovation strategy. For example, Rijkswaterstaat has a clear innovation and procurement strategy in which sustainability is integrated: ''Sustainability is part of all projects that Rijkswaterstaat puts on the market. In the preparation, we map out the sustainability opportunities and challenge the market to come up with sustainable solutions. The bar will continue to be raised in the coming years'' (Rijkswaterstaat, 2023a). In addition, within the water authorities there are often clear strategies originating, as WAT2 explains: ''The water authority often has a water management program. These are actually long-term objectives that a water authority has.-WAT2. WAT2 explains later that within these programs also sustainability is incorporated: ''We have a climate- and energy-neutral program plan, which also includes zero-emission equipment.'' – WAT2. However, WAT2 also adds that this kind of programs differ between the water authorities, and some are not that well developed: ''As water authorities, we are often very different in these types of programs. I think there are water authorities that certainly do the same, but also smaller water boards that are certainly not that far yet, that really differs.'' – WAT2.

Smaller public clients lack even more in high-level innovation strategy, and the frontrunners are highly dependent on a few people that take initiative within the organization (MUN1/2, GOV2, WAT2, SME1). ENG2 observes: ''You have many clients that are still really looking for that [strategy]. A party that has it very clear for itself is for example, the municipality of Arnhem. They have formulated very clear ambitions and objectives.'' – ENG2. MUN1 (from Arnhem) confirms, and adds that policy came after their bottom-up initiative, but normally you need the policy before something happens:

''In Arnhem you can also see a road map very clearly. We were discussing with the alderman that we wanted to gain knowledge and get ahead of this policy right away, and then you get the space within such a municipality to be able to do this. But normally you need policy first to be able to do this, so our policy basically follows now. That's how we started. We actually started the projects from the bottom up. Normally it is top down.'' – MUN1.

MUN2 adds to this that there is a lack of direction from the directors and that it requires 'a weirdo' in a municipality to pull ZE-NRMM off: ''I am surprised that our leaders, heads of departments, heads of sectors, boards don't indicate much anymore, guys this has to be done, period. There is not always enough guts for that, but that also has to do with that not every municipality has such a weirdo as me who keeps advocating for it''. – MUN2. This shows that within municipalities the implementation of ZE-NRMM depends on specific people that are driven by the topic, and that it does not follow from high-level innovation or purchasing strategies. In the end a high-level top-down strategy is required. MUN1 adds: ''Not everyone is intrinsically motivated or has other priorities. So at some point it must be centrally organized somewhere from the top down.'' – MUN1.

4.4.3. Identification, specification, and signaling of needs

The PPI barriers from identification, specification, and signaling of needs is characterized by ZE-NRMM implementation requiring more interaction before, during, and after tenders between public clients and the contracting market. Besides, the specification of needs in ZE-NRMM tenders lacks uniformity between public clients, and there is a lack of signaling long-term needs of public clients.

Lack of identification innovation potential contractors

First, before tenders are put on the market, consultation with the market is required to orient what is possible and create a dialogue (MUN1; NET1; GOV1; CON1; WAT1; MUN2; SME2). SME2 emphasizes the lack of knowledge of innovation potential: ''I don't think a client always knows very well what it takes to be able to carry out a work without emissions.'' – SME2. WAT1 emphasizes the need for orientation to enable public clients to set out a tender that reaps the intended results: ''Also orientate yourself very well on what is actually possible in the market and thereby don't over ask what is possible. Because if you ask the wrong things, you will get the wrong answer. – WAT1. MUN1 emphasizes the same need for dialogue before a tender between contractors and the public client:

''It is important that this dialogue already takes place before such a tender is launched on the market. That was a very important signal that these five contractors indicated, and asked how we could talk about this further and it was concluded that we were going to organize a contractors' day. So, then we will not focus specifically on a project, but we focus specifically on the issue, namely zero-emission construction.'' – MUN2.

A similar need from SME2 is observed for a dialogue outside of a specific project, but focused on zero-emission as a topic, which is currently not met: ''It would be nice if you could just, without there being a project, sit down with clients and just start sparring. And that we can say, look, this is what we as a contractor encounter and that we can learn from each other. Because, as I said, a client has to know what it means for us to become more sustainable. So I think that's not happening sufficiently yet, but that it is extremely valuable to do so.'' – SME2. NET1 also questions whether this is happening sufficiently: ''I think first you should ask is there enough dialogue? Between public parties and private contractors about the ways in which innovations can be developed further.'' – NET1. In addition, SME1 adds that this is not common practice, and ultimately the lack of market dialogue before a tender is creating a barrier for the ZE-NRMM implementation.

Lack of identification and facilitation of energy supply needs by public clients before tender

Second, also before the tender is put on the market, the public client should identify the energy infrastructure supply possibilities, however, this is not yet a standard practice (CPO1; MUN1; GOV2; NET2; WAT1). WAT1 explains how lack of communication and arrangements can occur:

''If you now ask the market for 100% zero-emission on a project, you are almost asking to be fooled. Because everyone wants to have that job and then you get answers: 'yes we will do that and then it's like sorry but did you arrange that connection for me or should I have done that? No, I can't do that, I do have the equipment, but I need the electricity." Those are the silly discussions you get, you tempt each other into having that discussion, because the contractor is there to take on work, that's what he lives for .'' – WAT1

GOV2 explains that the role of public clients is growing, as they need to identify the energy needs and possibilities before a tender is put on the market: ''This actually happens even before the project is licensed. So, the government should play a bigger role in that. This means that you have to make an estimate at an early stage of how much energy you think you need. And then also have to request a connection at an early stage.''-GOV2. However, BRA1 explains that, today, there is hardly any attention for infrastructure in tenders: ''There is to this day in tenders, little or no attention for it [energy needs] Whilst, energy infrastructure has become a precondition.'' – BRA1. Moreover, NET3 (grid operators) and CPO1 confirm that public clients should facilitate this, but for example CPO1 is now hardly involved in tenders by public clients: ''No, not much has happened yet. I've already heard some things and seen pilot. But we have never been involved in that.'' – CPO1. Ultimately, the identification of energy infrastructure needs becomes part of the role of public clients for implementation of ZE-NRMM, yet it happens too little, and thus hampers progress.

Lack of signaling the requirements of public clients for long-term ZE-NRMM to contractors

Third, contractors require clarity regarding the long-term plans of public clients surrounding the implementation of ZE-NRMM in projects, thus lack of signaling of these needs by public clients creates a barrier for the implementation (WAT1; WAT2; MUN1; GOV; CON1; CON5; SME2). To understand this, GOV1 clarifies the contractor investing perspective: ''Those contractors mainly want a consistent policy'' – GOV1. GOV1 continuous: ''The problem is that the market wants an investment perspective, because you can never write equipment off on one project. So the investment perspective is needed.'' – GOV1. MUN1 emphasizes this: ''A contractor has a very strong need for that point on that horizon. What do you expect from me as a contractor? When are you going to ask [ZE-NRMM]? When should I start investing to ensure that those machines are there?'' – MUN1. CON5 emphasizes this perspective: ''But then it's still one project and you won't be able to write off the equipment on one project. I think guarantee of use is also the hardest part of the whole story'' – CON5. WAT2 emphasizes the importance of communicating their ZE-NRMM plans: ''As a water authority, communicate very clearly where you want to grow towards, so what your ingrowth path is [for ZE-NRMM]. – WAT2. WAT2 exemplifies by saying: ''Like, contractors be aware, in that and that year these and these equipment types need to be zero-emission.'' – WAT2. Ultimately, lack of long-term clarity will be elaborated upon in relation to the risk of lack of take up in 'incentivizing innovative solutions'.

4.4.4. Incentives for innovative solutions

The PPI barriers to incentivize innovative solutions are characterized by risk experienced by contractors for lack of take up, especially for the long-term usage of ZE-NRMM. There is a lack of balance between risks and rewards to incentivize contractors in ZE-NRMM tenders. FInally, larger public clients are less risk averse, whereas municipalities are very risk averse.

Risk lack of take up experienced by contractors, especially for the long-term usage of ZE-NRMM

Contractors experience lack of take up in the current tender market, ZE-NRMM is requested too little to have a long-term guarantee of usage, and write-off the ZE-NRMM equipment (CON1; CON3; CON5; CON6; SME1; SME2; MUN1; MUN2; GOV1; ENG2; NET1). This adds to the explanation of the previous barrier in chapter 4.4.3. that ZE-NRMM needs to be written of over multiple projects. As CON6 explains: ''At Heijmans, we are now investing heavily in emission-free material. And everything that comes with it. But if that means that we will soon have no projects where we can use it. Then it is wasted money.'' – CON6. CON5 agrees with this statement, mentioning: ''Well, in terms of purchase, I think the risk is mainly that the investment is now very large, and the deployment of those pieces of equipment is often still relatively low, so that many machines are just standing still.'' – CON5. Therefore, contractors argue they need a long-term guarantee of take-up in projects. SME2 mentions: ''But we do want the guarantee that we will also have work for the next two years.'' – SME2. CON3 has the same emphasis: ''And then on the long-term that there are guarantees made or that you have a certain guarantee of work.'' – CON3. CON2 explains that they are involved in a project that is taking place over eight years and thereby provides the guarantee of usage: ''Because it is a project that will take place over eight years and has a bit more turnover and you as the main contractor can register for it and you have that certainty in the longer term. That already gives more incentive to go to zero-emissions.'' – CON2.

Lacking balance between risks and rewards to incentivize contractors in ZE-NRMM tenders

The ZE-NRMM incentives in tenders lack effectiveness in occasions where insufficient weight, or disproportionate rewards, or even fines are used (CON5; CON6; WAT2). WAT2 explains that contractors need two things to implement ZE-NRMM: ''You have to give a contractor the chance to make that move, so I think clarity is one. And two is, you can give a financial incentive or some sort of bonus.'' – WAT2. The former point has been covered, but the financial incentive is important as ZE-NRMM is more expensive, as MUN1 emphasizes: ''If your [construction-]work becomes 20% more expensive in one go, because that can happen by working zero-emission, with EMVI you have actually already been able to tackle that a bit because you have money to spare, so you a point system for that.'' – MUN1.

As MUN1 and the majority of interviewees emphasize, the economic most responsible tender (EMVI), the best price quality ratio (BPKV), and environmental cost indicator (MKI) are appropriate tender mechanisms to rewards working with ZE-NRMM. However, these have to be used correctly in order to create the appropriate incentives. The MKI-indicator is a general sustainability tool that also includes material analysis, and therefore to incentivize ZE-NRMM, more weight has to be given to the construction phase part (CON1; CON2; GOV1; GOV2; ENG2). ENG2 specifically mentions: ''Then you have to pull those loose. You can say that instead of A1 to A5, the entire life cycle, we will now focus purely on A4 and A5. In this way you can also steer in your tender where you place the focus.'' – ENG2. In addition, the same accounts for EMVI and BPKV. Interviewees emphasize the importance of providing sufficient weight to it and let it stand out in the overall tender. ENG2 emphasizes: ''Also add sufficient weight that it can also be a distinctive challenging criterion in which parties can distinguish themselves.'' – ENG2. Last, CON5 adds that disproportionate weights can lead to the usage of higher stage classes with HVO instead of ZE-NRMM:

''There are tenders where you can score points on what kind of equipment you use. Then it is about stage 4, stage 5. Stage 5 with HVO and thereafter zero-emission. But the gap or the points you can score between them are the same. So, from stage 5 diesel to stage 5 HVO. That gives you the same discount as from HVO to zero-emission. While HVO to zero-emission costs us maybe ten times as much money.'' – CON5

However, there are situations in which contractors are de-incentivized for their efforts when they cannot comply with the tender contract. Yet, the implementation of innovations like ZE-NRMM are inherently associated with extra risks as you experiment with new practices. Therefore, fines in contracts are de-incentivizing contractors to implement ZE-NRMM and will stick with traditional NRMM. CON1 explains the risk when losses are incurred: ''We gain that experience ourselves in the projects, but of course we also take a risk. Sometimes we take on our own costs, if there is no help from the client.'' – CON1. INS2 elaborates more in-depth:

''You often see that if you receive a 10 euro bonus, say, that the moment you fail to deliver it, you will be fined 15 euro, you are always worse off if you cannot deliver it, that can then be put into effect. But if you [contractor] started with all good intentions, with such an innovative piece of equipment, and it still doesn't seem to work completely. Should I [public client] hit you right away with those fines? How realistic is that then?''- INS2.

Ultimately, this leads to the fact that public clients cannot put all the risk with the market, but have to carry some of it themselves, as GOV3 emphasizes: ''Where does the risk lie that they are left with an investment that they cannot earn back? If you as a society want to develop this innovation further, then you must be prepared to bear part of the risk.'' – GOV3. However, public clients are generally risk averse.

Larger public clients less risk averse, municipalities highly risk averse

In general, public clients are risk averse, especially municipalities, however there are exceptions in larger organizations where risks are taken in frontrunner projects and primarily Rijkswaterstaat has an exemplary role in the GWW-construction sector (SME1; MUN2; WAT; CON4; GOV2; ENG2). As SME1 observes: ''I think Rijkswaterstaat is doing a good job with it. In my opinion, it is actively involved. And you see that the lower you go, the less involved they become, provinces, water authorities, and municipalities. In that sense, Rijkswaterstaat has an exemplary role for public clients and sets the trend''.

– SME1. **MUN2 and WAT2 emphasize that municipalities are risk averse:** ''Municipalities are the most risk averse. Let that be clear. – MUN2''.

''And then it is a number of municipalities, who want to take more or less risks, and who accept more or less risks. That's what makes it so difficult, you see some large municipalities: Amsterdam, Rotterdam, Eindhoven. They are very far into it, they are making very good progress, but the risks get more expensive. We say we think it's worth the money, because we take sustainability seriously. That does not apply to everyone. Municipalities that have to turn every dime. They'll think twice, and think it's not a necessity so I'll postpone it. – WAT1.

MUN2 adds that public leaders need to be more daring, and that so far leadership has been insufficient: ''I am surprised that our leaders, heads of departments, heads of sectors, boards don't indicate much anymore, guys this has to be done, period. And that there is not always enough guts for that.'' – MUN2. **Ultimately, the risk averseness of public clients causes progress to hamper with ZE-NRMM.**

4.4.5. PPI barriers overview

Table 5 shows an overview of the PPI barriers observed following the result chapters 4.4.1.-4.4.4.

Table 5: PPI barrier overview.

System function	**Barriers**
Framework conditions	(-) Competition on price and strict contracts reduces innovation in GWW-tenders. (-) ZE-NRMM tenders are less accessible for SME contractors.
Organization and capabilities	(-) Lack of knowledge, capacity, and capabilities in municipal public clients. (-) Lack of high level innovation strategy in smaller public clients (e.g. municipalities).
Identifying, specifying and signaling of needs	(-) Lack of identification of innovation potential of contractors. (-) Lack of identification and facilitation of energy supply needs contractors by public clients. (-) Lack of signaling the requirements of public clients for long-term ZE-NRMM to contractors.
Incentivizing innovative solutions	(-) Risk lack of take up ZE-NRMM experienced by contractors, especially on the long-term usage. (-) Lack of balance between risks and rewards to incentivize contractors in ZE-NRMM tenders. (-) Public clients risk averse, especially municipalities are more risk averse

4.5. Combined barrier and governance analysis MIS & PPI

The combined analysis of MIS & PPI section provides an answer to SQ5 by elaborating on the PPI barriers that hamper the mission progression, and identifies which PPI instruments are implemented and/or missing. In addition, policy instruments that can tackle PPI barriers are identified.

4.5.1. PPI barriers reinforcing the systemic barriers

The PPI barriers formulated in chapter 4.4.5. primarily hamper the MIS development through the function: knowledge diffusion, resource mobilization, market formation, creation of legitimacy, and regime change.

Systemic barrier 1: Multiple PPI barriers reinforce the growing gap between the MIS arena and overall MIS progress

Following the analysis of the PPI barriers, there are multiple barriers that reinforce the growing gap between the MIS arena and overall MIS progress, especially due to lack of knowledge diffusion, market formation, creation of legitimacy, and regime change following from procurement practices (Figure 13).

First, entrepreneurial activities (SF1) and knowledge development (SF2) for actors in the platoon consisting of SMEs are hampered due to the reduced accessibility and chance to win ZE-NRMM tenders in contrast to larger contractors. Moreover, knowledge diffusion (SF3) towards the platoon is hampered due to the highly competitive nature of the GWW-construction sector, especially as tenders increasingly so include ZE-NRMM criteria on which contractors can differentiate and win the tender. As a result, contractors do not merely compete on price, but on sustainability and thus want the competitive edge on ZE-NRMM as it will be rewarded in future tenders. Ultimately, the competition on sustainability reduces knowledge diffusion towards other contractors in the platoon, whilst this is essential for the progression and success of the overall MIS.

Second, the creation of legitimacy for the prioritization of the mission (SF7) is hampered due to three causally related PPI barriers. Starting with the lack of signaling long-term procurement goals and strategies by public clients, which leaves contractors in the dark on what to expect in the coming years. Yet, ZE-NRMM are multiyear investments that need to pay off in future tender contracts for years to come, the lack of clarity therefore makes contractors put their investments on hold until there is more clarity. Therefore, the lack of signaling long-term needs of public clients causes the second PPI barrier, namely that contractors experience the risk of lack of take up of their ZE-NRMM innovations, which hampers mission progression and the mobilization of resources (SF6). However, the lack of signaling public clients and their needs is caused in itself by the lack of high-level innovation strategies within those public organizations. As a result, within the platoon organizations, there is a lack of direction and thus the ZE-NRMM is not prioritized in procurement practices.

Third, the regime change (SF9) is hampered by three non-related PPI barriers that prevent public clients from requesting and contractors from working with ZE-NRMM. First, the lack of identification of innovation potential of contractors prohibits public clients from requesting ZE-NRMM in tenders. Second, the lack of balance between risk and rewards that should incentivize contractors to work with ZE-NRMM in tenders leaves them to work with fossil-fuel NRMM. This can be the lacking financial incentive or disproportionate incentive for ZE-NRMM, which ultimately affects the mobilization of ZE-NRMM. Third, public clients are generally risk averse, especially municipalities have a wait-and-see attitude towards the implementation of ZE-NRMM. This affects regime change, as they wait with ZE-NRMM implementation and thus do not embed this in tenders. Ultimately, the lacking creation of legitimacy and regime change hamper the resource mobilization of ZE-NRMM.

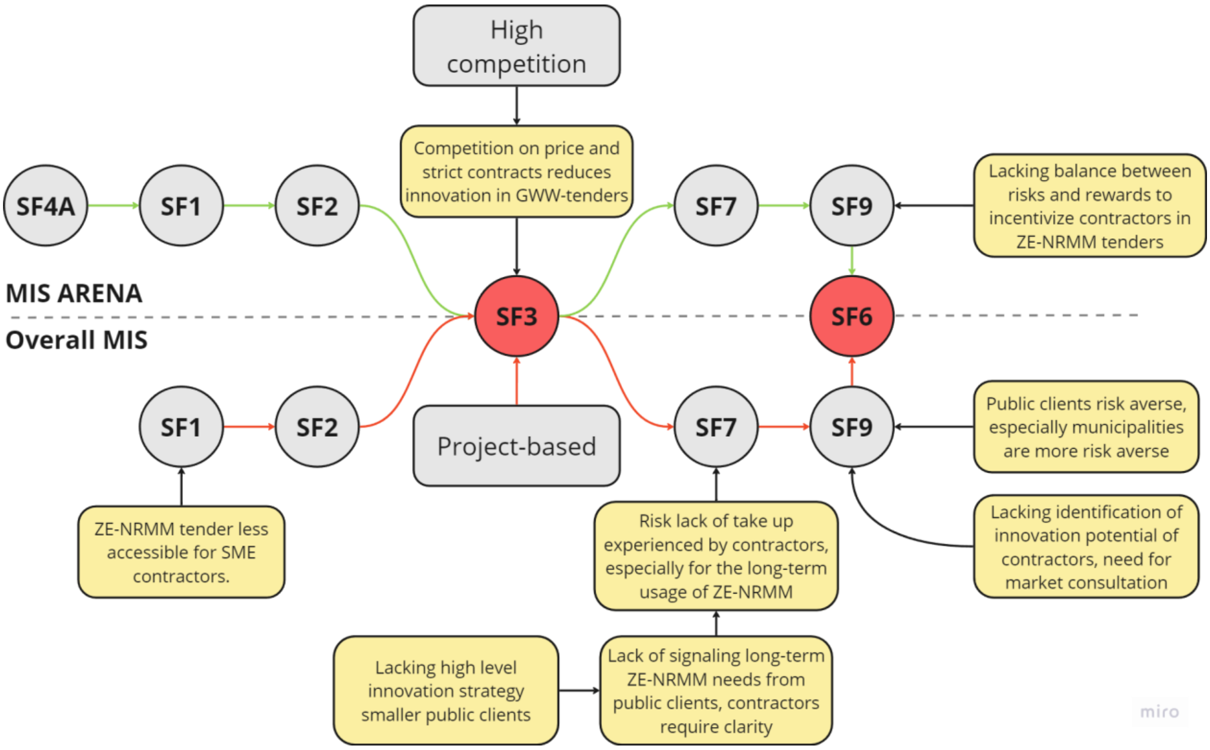


Figure 13: Systemic barrier 1 reinforced by multiple PPI barriers that increase the growing gap between MIS arena and overall MIS

Systemic barrier 2: Lacking capabilities public clients, and especially municipalities affect ZE-NRMM market formation

Following the analysis of the PPI barriers, the lack of knowledge, capacity, and capabilities of smaller public clients hamper consistent demand affecting the market formation (Figure 14). Especially, municipalities that have a major share of tenders in the GWW-construction sector lack capabilities to request ZE-NRMM in RAW-tenders. However, to get the MIS to the next development phase, the acceleration, it is required that these public clients increasingly start requesting ZE-NRMM.

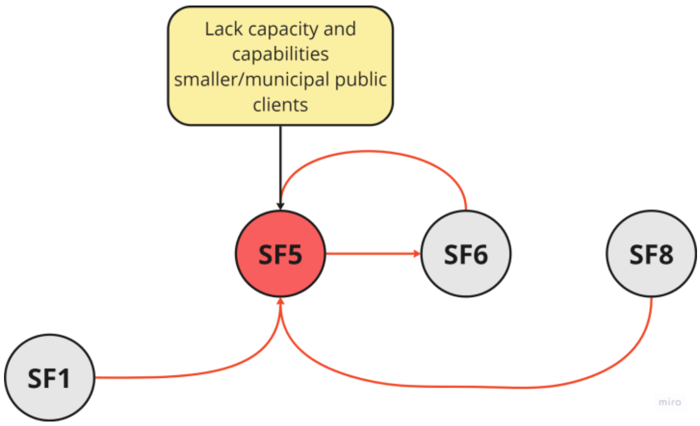


Figure 14: Market formation SF5 reinforced by the lacking capabilities of public clients, especially municipalities hamper market formation

Systemic barrier 3: the Dutch NRMM market too small for international NRMM OEMs

Following the analysis, no PPI barriers have been identified that reinforce the hampering resource mobilization caused by lack of supply of ZE-NRMM from international OEMs (Figure 15). It can be argued that due to the global context in which international OEMs operate, their strategic focus applies to a wider context than specific countries (e.g., Europe). In addition, the Dutch NRMM market is a negligible part in the sales of international OEMs, and hence international OEMs are not influenced by country specific missions. As a result, any PPI barrier or instruments on the country specific level of The Netherlands will not influence the international OEMs.

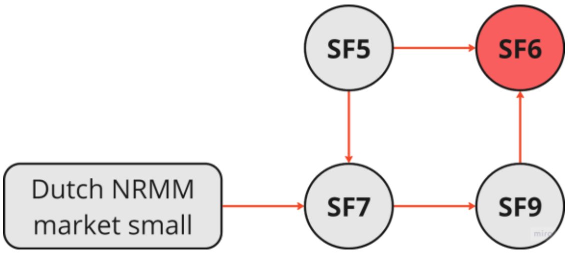


Figure 15: Resource mobilization SF6 not reinforced by any PPI barriers due to international context of the NRMM supply

Systemic barrier 4: Lacking identification and facilitation of energy supply needs reinforces energy infrastructure mobilization challenges for ZE GWW-projects

Following the analysis of the PPI barriers, the lack of identification and facilitation of energy supply needs of contractors by public clients before tenders hamper the mobilization of energy infrastructure at GWW-construction sites (Figure 16). The lack of identification and facilitation of energy supply in the form of a grid connection or accessibility to charging infrastructure by public clients puts the responsibility towards contractors, however, due to the scarcity of grid connections and long application times, projects get delayed or cannot be executed with ZE-NRMM as it is too late to mobilize sufficient energy resources.

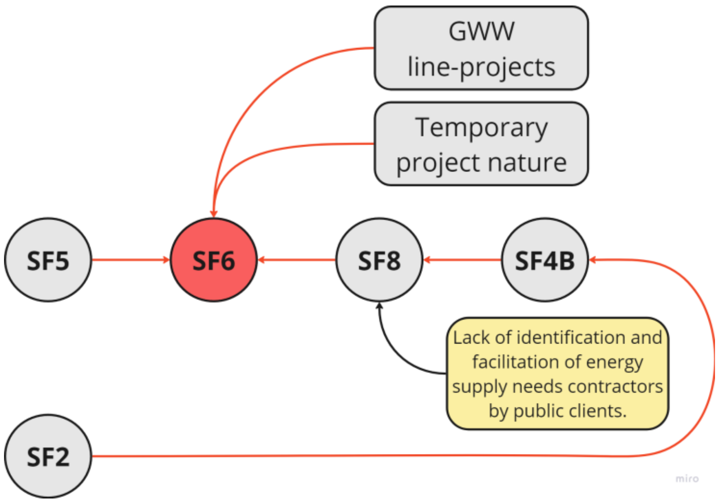


Figure 16: Resource mobilization SF6 reinforced indirectly through coordination SF8 by the lack of identification and facilitation of energy infrastructure by public clients

Systemic barrier 5 - solution specific: lacking regime change heavy NRMM

Following the analysis of the PPI barriers, no PPI barriers have been identified that specifically reinforce the lack of regime change surrounding heavy NRMM. Yet, systemic barriers 1-4 do apply to heavy NRMM as well, because these apply to full range of ZE-NRMM. For example, the lack of take up experienced by contractors, especially in the long-term usage of ZE-NRMM does reinforce the lacking creation of legitimacy and thus regime change for (heavy) ZE-NRMM (as seen in Figure 13). However, it is argued that the weaknesses in the system functions SF4B, SF5, SF6 and long-term depreciation causing this systemic barrier are not interrelated with PPI barriers. For example, the weakness in SF4B is due to the uncertainty in the solutions for heavy NRMM going towards hydrogen or battery electric, that lead to a lack of investments in heavy ZE-NRMM (SF6), and thus hamper regime change. Therefore, no PPI barriers apply to systemic barrier 5 except from those that are general to ZE-NRMM following from systemic barrier 1-4.

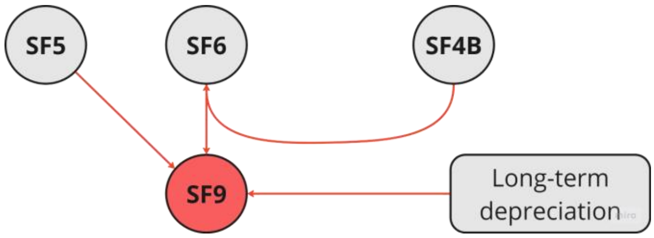


Figure 17: Systemic barrier 5 – solution specific: heavy NRMM regime change not reinforced by PPI barriers

A summary of the MIS system including the PPI barriers is provided in Figure 18. The PPI barriers reinforce the systemic barriers of knowledge diffusion (SF3), market formation (SF5), and resource mobilization (SF6). However, two systemic barriers are not influenced by PPI barriers, namely the lacking ZE-NRMM supply of international OEMs due to the global context in which they operate (Systemic barrier 3), and the lacking regime change of heavy NRMM due to the nature of the weaknesses that cause the barrier (Systemic barrier 5). In addition, as systemic barrier 5 applies only to heavy NRMM, mission success is more dependent on solving the four systemic barriers.

Three PPI barriers are focal and more prominent in hampering the performance of the three system functions, which became apparent from the interviews as these were mentioned more excessively. The three focal PPI barriers are: the competition on price and strict contracts hampering knowledge diffusion, the lack of capacity and capabilities of smaller public clients hampering market formation, and risk lack of take up experienced by contractors affecting resource mobilization. Furthermore, the PPI practices in general hamper the active involvement of the platoon actors that are in the overall MIS, which need to be more involved to complete the mission successfully. Therefore, to lift the barriers more coordination is required from the government in PPI practices to lift these barriers with appropriate policy instruments.

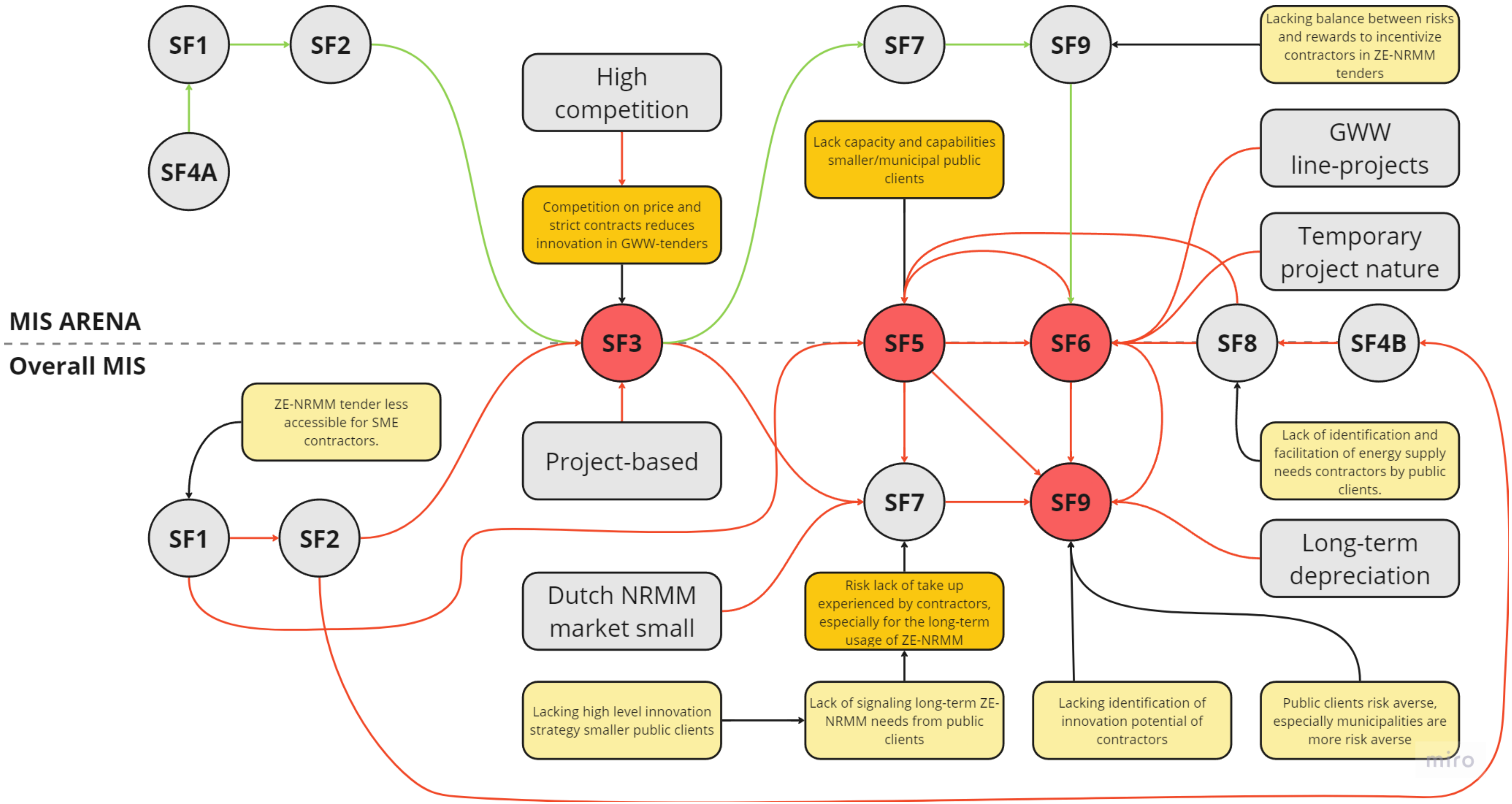


Figure 18: Complete overview of systemic barriers of the MIS, their interrelations, and PPI barriers. (Green links represent strengths, red links represent weaknesses, and black links represent PPI barriers).

4.5.2. PPI policy instruments overview

In order to provide adequate improvements for the current PPI practices by the government, an overview is provided based on the interviews, the policy instruments that have been implemented by the government that align with the PPI instruments from the literature, the instruments that work in practice but are not listed in the literature, and the instruments that seem to be missing. An overview is provided in Table 6 and Appendix G elaborates on a number of tender methods.

PPI instruments in practice

There are multiple instruments implemented in practice by public clients and the government to stimulate ZE-NRMM. First, for framework conditions, the use of innovation-friendly regulations is observed in the mission arena by the use of build-teams, innovation partnerships, and two-phase contracts (WAT1, CON4, CON6, MUN1, GOV3, INS2). These methods adhere to the level-playing field requirements, whilst reducing competition, and steering away from strict functional descriptions and prices for construction work in tenders. Ultimately, these tender methods are experienced to increase innovation in the frontrunners group and emphasized by CROW that these can be used on all levels in which public clients operate (INS2). However, these require more advanced capabilities of public clients than a traditional tender contract and are thus not widely used (INS2).

Second, for organization and capabilities, good practice networks such as the Buyer Group ZEB that spread ZE-NRMM procurement guidelines and e-learning facilities lift the knowledge and capabilities of involved actors in the mission arena (GOV2, WAT1, BRA1, NET3). However, due to the lack of knowledge diffusion this does not reach the majority of public clients, therefore standards in RAW-contracts could enable wider implementation of ZE-NRMM through municipalities (INS2). In addition, the government has planned subsidy for co-governments (e.g., municipalities) to cover additional costs of innovation, which will be introduced in 2023 and helps overcome financial barriers of municipalities (GOV2). Moreover, an example of enabling public clients to incorporate high-level strategies to embed innovation procurement in their organization is through HwbP. HwbP as an umbrella organization for water authorities put ZE-NRMM on their agenda, thereby prioritizing and signaling towards the involved water authorities its importance which led to the introduction of procurement that incorporate ZE-NRMM (WAT1; WAT2).

Third, innovation platforms are deemed effective for the identification, specification, and signaling of needs, and a primary example is ENI. ENI both includes public clients and contractors and work together on collective themes to gain knowledge on the needs of both sides within ZE-NRMM construction projects (NET1). Yet, ENI mostly includes mission arena actors, whilst local public clients depend on local contractors, and therefore public clients conduct local market consultations to gain insights in the innovative capacity of contractors (MUN1, MUN2, WAT1). In addition, foresight and market study processes are facilitated by the SEB-program, especially the roadmap provides a concrete technology roadmap (SEB, 2023). Besides, the identification and facilitation of energy infrastructure in ZE-NRMM projects happens pre-tender by public clients, which increases success.

Fourth, guaranteed price tariffs used in tenders to incentivize innovative solutions and stimulate ZE-NRMM. Besides, there are examples of platform tenders such as Sterke Lekdijk, where a programmatic approach is taken rather than a project-based approach. This enables to create a multiyear contract that provides the necessary long-term usage guarantee for contractors (WAT1).

Table 6: Overview of the PPI barriers, prescribed instruments by the literature and instruments implemented in practice. Instruments with *Italic layout* differentiate from the literature.

PPI category	**PPI Barriers**	**Prescribed instruments**	**Implemented instruments in practice**
Framework conditions	(-) Competition on price and strict contracts reduces innovation in GWW-tenders	Innovation-friendly regulations	-Build-team, innovation partnership, two-phase contract.
	(-) ZE-NRMM tender less accessible for SME contractors.	Simplification and easier access for tender procedures	-None
Organization and capabilities	(-) Lack knowledge, capacity and capabilities municipal public clients	Good practice networks and subsidy additional costs of innovation	-Good practice networks: Buyer Group ZEB, e-learning, procurement guidelines. -Subsidy for additional costs of innovation co-governments in 2023. *- Introduce RAW standards for ZE-NRMM procurement*
	(-) Lacking high level innovation strategy smaller public clients (i.e. municipalities)	High level strategies to embed innovation procurement	*-HwbP put ZE-NRMM on their agenda, influencing the related water authorities to incorporate it in their organization.*
Identification, specification and signaling of needs	(-) Lacking identification of innovation potential of contractors.	Innovation platforms to bring suppliers and users together	-ENI (as an innovation platform) *-Public clients that work with ZE projects hold market consultations*
	(-) Lack of identification and facilitation of energy supply needs contractors by public clients.	Use of standards	*-Pre-tender identification and facilitation of energy infrastructure.*
	(-) Lack of signaling long-term ZE-NRMM needs from public clients, contractors require clarity.	Foresight and market study processes	-SEB roadmap and covenant
Incentivizing innovative solutions	(-) Risk lack of take up experienced by contractors, especially for the long-term usage of ZE-NRMM.	Guaranteed purchase of innovation	-Platform approach (programmatic I/O project based approach)
	(-) Lacking balance between risks and rewards that incentivize contractors in ZE-NRMM tenders	Guaranteed price/tariff for innovation	-None
	(-) Larger public clients less risk averse, municipalities highly risk averse.	Insurance guarantees	-None

5. Conclusion and Discussion

In the conclusion and discussion chapter an answer to the research question is provided, and the theoretical and practical implications that follow from the research are discussed. In addition, limitations of the research are addressed and avenues for future research are given.

5.1. Conclusion

This research investigated the Dutch GWW-construction sector's mission for zero-emission construction sites implementing ZE-NRMM, and examined how Public Procurement of Innovation (PPI) can be improved for mission success. This study used the Mission-oriented Innovation System (MIS) approach combined with literature on PPI barriers and instruments. By formulating sub-questions the research investigated the MIS problem-solution space, structural components, system functions, and identified systemic barriers. Furthermore, PPI barriers and their influence on the MIS systemic barriers were investigated, along with PPI instruments. The results, presented in sections 4.1-4.5, were derived from qualitative methods and data sources, primarily 27 stakeholder and expert interviews. Ultimately, this yielded five points that provide an answer to the research question elaborated on below.

First, the competition on price, strict contracts, and growing competition on sustainability criteria in the GWW-sector hamper knowledge diffusion from the mission arena to the overall MIS. Therefore, PPI instruments should enable knowledge diffusion via innovation-friendly tender procedures and follow-up of projects to consolidate lessons-learned.

Second, the lack of capacity and capabilities in smaller public organizations hampers market formation as there is no consistent demand for ZE-NRMM. Therefore, PPI instruments should enable public clients to build capabilities through networks of good practice, and for public clients that lack the capacity the barrier can be overcome through the introduction of standards for procurement of ZE-NRMM.

Third, the experienced risk of lacking take up of ZE-NRMM by contractors on GWW-construction projects, especially for the long-term, hampers the investments necessary to mobilize ZE-NRMM. In addition, the lack of resource mobilization of energy infrastructure hampers implementation of ZE-NRMM. Therefore, PPI instruments should enable the long-term investment perspective for contractors by guaranteeing take up in platform approach contracts, clearly signal long-term needs as public clients, and embed energy infrastructure identification and facilitation in tender procedures.

Fourth, the PPI barriers affect primarily the overall MIS and thus the majority of platoon actors. Yet, as shown in Figure 10, the MIS is almost completely moving into the take-off phase and moving to the next stage requires rapid increase in adoption of ZE-NRMM. Therefore, the overall MIS and its platoon actors have to actively transform. As the PPI barriers affect primarily the overall MIS and platoon actors, lifting these PPI barriers becomes even more essential to generate wider adoption and enable the development of the system towards the acceleration phase.

Fifth, the systemic barriers on resource mobilization of ZE-NRMM from international OEMs, and the lacking regime change of heavy NRMM. Due to the global context in which international OEMs strategically operate, country specific PPI practices hardly impact them. Therefore, policy instruments at the EU-level could induce change in international OEMs. For example, a lobby for policy instruments at the EU-level that put a deadline to fossil fuel NRMM could increase ZE-NRMM supply. Furthermore, due to the nature of the weaknesses that cause heavy-NRMM to lack regime change, no PPI barriers were identified reinforcing this systemic barrier. It is expected that heavy NRMM will develop in a similar path as light & medium-heavy NRMM, however, monitoring of the adoption of heavy NRMM is essential to ensure that this is the case.

5.2. Practical implications

Knowledge diffusion in the GWW-construction sector on ZE-NRMM can be improved by the following practical implications and suggestions for specific actors:

1. Embracing innovation-friendly procedures: Public clients should persist in utilizing procedures such as build-teams, innovation partnerships, two-phase contracts, and alliance contracts. These procedures foster collaboration, reducing the competitive aspect of tendering, and facilitate knowledge sharing on ZE-NRMM.
2. Collective learning in standard tenders: Public clients that do not have the capacity or capabilities to introduce innovation-friendly procedures, and thus use standardized tender procedures and contracts, should incorporate requirements on knowledge sharing for collective themes, such as safety, monitoring, and infrastructural ZE-NRMM challenges.
3. Programmatic approach: Knowledge diffusion can be increased by moving from project-based towards programmatic-based construction work. Programmatic work can be provided, for example, through a multi-year platform approach, where consortia of contractors gain experience, and learn-by-doing building-up knowledge and sharing it in consecutive projects.

Market formation in the GWW-sector for ZE-NRMM could be improved by the following practical implications are formulated:

4. Good practice networks for the frontrunners work sufficiently, but do not reach the overall MIS. Therefore, umbrella organizations (VNG, IPO, UvW) could widen the span of reach by first of all putting ZE-NRMM on the agenda, so that more water authorities, provinces, and especially municipalities in the platoon embed high level procurement strategies on ZE-NRMM. In addition, the best practices from the Buyer Group ZEB should be communicated through these umbrella organizations to potentially increase the capabilities.
5. However, not all platoon actors possess the capacity or capability to learn from these good practice networks and umbrella organizations. Hence, increasingly strict standards in the RAW tender methods should be created by CROW and released for the phase-out of harmful NRMM and progressive introduction of ZE-NRMM making it standard practice in GWW-construction.

Resource mobilization in the GWW-sector for ZE-NRMM could be improved by the following practical implications:

6. Public clients that currently have the ambition to implement ZE-NRMM should start with local market consultation to see what contractors are capable of in terms of innovative capacity, and adjust their tenders accordingly to this innovation capacity. However, when standards following points 5 and ZE-NRMM criteria are implemented this is less essential.
7. Public clients should first of all sign the SEB covenant to state their ambition, but also proactively signal to the market their long-term ambitions regarding ZE-NRMM implementation in GWW-construction projects following the SEB covenant.
8. The platform approach on local projects is a valid approach to create guaranteed long-term uptake of ZE-NRMM and thereby reduce the risk of take up for contractors. In addition, on system level, the coordination of intergovernmental tender agendas for GWW-projects following a similar approach as the 'Regional Energy Strategy' could create alignment in demand in the tender market and eliminate risk of uptake for contractors.
9. Coordinating the identification and facilitation of energy infrastructure at ZE GWW-projects by public clients could be improved by making a decision-tree for public clients to follow-up on before putting a ZE-tender on the market. In addition, it is necessary to clarify the responsibilities in tender descriptions on what is arranged by the public client (e.g., grid connection) and what by the contractor (e.g., charging infra).

5.3. Theoretical implications

This study combined the Mission-oriented Innovation System framework and Public Procurement of Innovation literature. This provided a novel approach of the MIS application with PPI as Mission-oriented Innovation Policy (MOIP). As a result, three theoretical implications follow from this study, elaborating on the MIS and PPI combination, adapting the regime change function to 'strategic regime change', and the critique of Kirchher et al. (2023) on MOIP is discussed.

First, the combined use of the MIS framework and PPI as MOIP is deemed valuable as it enabled identification of relations between PPI barriers that reinforced systemic barriers of the MIS. However, the sole application of PPI as MOIP does not suffice to address all systemic barriers in the system and in this study has to be complemented with policy instruments on EU-level. Extant literature recognizes the influence of PPI instruments on demand and supply in innovation systems through the functions of market formation (SF5) and resource mobilization (SF6) (Wesseling and Edquist, 2018; Bergek et al., 2015). This study corroborates their results, as PPI barriers strongly influenced market formation and resource mobilization in the Dutch ZE-NRMM mission. However, this study adds to the literature with the suggestion that PPI barriers also have a major influence on the knowledge diffusion. Through observations it became evident that PPI barriers related to the framework conditions hampered knowledge diffusion in the MIS. The lack of knowledge diffusion is caused by ZE-NRMM sustainability criteria in tenders, which similarly like price creates competition.

Whilst Wesseling and Edquist (2018) mention that PPI contributes to knowledge diffusion between supplier-buyer and supplier-supplier relations, in the context of this study the buyer-buyer knowledge diffusion as important as well to stimulate knowledge diffusion to the platoon on good practices when implementing ZE-NRMM. Paradoxically, the implementation of criteria for the procurement of innovation can therefore reduce knowledge diffusion on the procured innovations between buyers (contractors) that develop knowledge. As buyers want to gain a competitive advantage in future tenders, counteracting overall MIS development. Ultimately, it can be questioned whether this can be generalized to other competitive publicly driven markets, which future research should corroborate.

Second, the application of the MIS framework required additional system functions, which were introduced by Reike et al. (2023): directionality (SF4A/B), coordination (SF8), and regime change (SF9). The added system functions provided valuable insights to increase understanding of the system dynamics of the Dutch mission for ZE-NRMM. However, challenges arise in the conceptualization of regime change by country specific missions, whilst they are affected by actors that operate strategically in a global context. Hence, Reike et al. (2023) propose to adapt the system function regime change into 'strategic regime change' to account for the strategic influences of actors in the MIS.

This study corroborates the need to account for the influences of globally operating actors, and agrees the function 'strategic regime change' would be beneficial. However, Reike et al. (2023) do not define how this function should be operationalized in the MIS framework. Therefore, based on the results of this study a first proposal for its operationalization is provided as theoretical implication. Based on the observations, international NRMM OEMs have a major influence, without any direct reason to go along in the Dutch ZE-NRMM mission. Hence, it can be seen as a strategic power vs. interest problem, which has been defined in research from Ackermann & Eden (2011). Their research uses a matrix with a power and interest axis (scoring low to high) to operationalize actors' strategic behavior into four quadrants. In the MIS the strategic regime change function can be operationalized by mapping all actors into the framework, which helps identify how actors should be involved or managed. For example, in this study the international OEMs would have high power, but little interest and becoming a barrier as their strategic efforts do not align with the mission. The success of missions would require that these actors are 'managed closely'. In contrast, actors that hypothetically would have high interest and power should be part of the MIS arena to actively steer the mission. This operationalization has been applied to societal challenges by Ginige et al. (2018), but the value of this approach for the MIS framework has to be corroborated in future research.

Third, Kirchherr et al. (2023) review and reflect critically upon missions and MOIP for sustainability, emphasizing the normativity bias, focus on top-down governance, stakeholder monotony, the government picking winners, and unintended effects. Hekkert (2023) responds to the critique, refuting the arguments of Kirchherr et al. (2023). Whilst based on this study results most arguments from Hekkert (2023) can be agreed upon, a nuance is made to the normativity bias and unintended effects of MOIP.

Kirchherr et al. (2023) emphasize that scholars underestimate the wickedness of the sustainability challenges at hand, which creates normativity bias. Yet, as emphasized by Hekkert (2023), this is tackled by including the concepts of directionality as a system function and wickedness in the problem-solution analysis. However, this study argues that it is questionable whether sufficient depth of wickedness and directionality is explored in the analysis. Especially, the problem-solution diagnosis, the relation to other missions, and impact on the broader energy transition lack depth to adequately assess the wickedness of the mission and its influence on other missions in same industry or broad transition its part of. Hence, the second point that is nuanced are the unintended effect of MOIP, which is a valid point from Kirchherr et al. (2023) as it is still a novel field of innovation policy. In this study it was observed that whilst the mission can provide directionality to actors, it is important that this does not turn into a tunnel-vision for actors. When the mission is clearly defined, it may be that actors lose sight of the broader context to which the mission is part of. Hence, the scope of the mission should be closely monitored, and synergies should be considered part of MOIP to enhance the success of broader transitions. Ultimately, policy mix literature (Cunningham et al., 2013) can be valuable to frame multiple missions as part of a broader transition (e.g., energy transition).

5.4. Limitations and future research

First, the research is qualitative, based on 27 interviews that provided a wide range of stakeholder perspectives in the MIS, and led to a relatively high saturation of data. However, some stakeholders like retrofitters, subcontractors, and provincial governments were not interviewed. Besides, six prime contractors were interviewed in contrast to only two SME contractors, which resulted in an imbalance in stakeholder representation. Furthermore, the interviewees were knowledgeable, thereby qualifying as experts, but as a result almost no stakeholders part of the platoon were included in the interviews. Ultimately, future research into the ZE-NRMM MIS should incorporate the excluded stakeholders, and incorporate stakeholders part of the platoon.

Second, the research is limited to the Netherlands and its mission-oriented innovation system, making it difficult to generalize findings to other European countries. Yet, the research highlights the challenge of mobilizing ZE-NRMM which relies on international OEMs, and thus the Netherlands becomes dependent on their mission progress. Therefore, future research should widen the scope to an EU-level, and focus on the creation of demand via PPI as MOIP in other EU countries. For example, Shin et al. (2020) provide a framework where PPI is placed into a systemic perspective, which can increase the understanding of PPI and its impact to the EU innovation system.

Third, as this study is qualitative and rather explorative in nature it was able to identify the systemic barriers and PPI barriers that hamper mission progression. However, due to the qualitative nature it is hard to assign weights to the barriers that hamper the system more or less, except based on the times mentioned in separate interviews. Moreover, the quantification of PPI barriers and especially the effectiveness of the PPI instruments would be a valuable avenue for future research to improve effectiveness of innovation-friendly PPI practices implemented by the government. For example, Montalban-Domingo et al. (2021) applied content analysis, descriptive statistics, and logistic regression to construction tenders to analyze sustainability in procurement. A similar approach can be used for Dutch tenders obtained through TenderNed, enabling the researcher to track tenders with certain sustainability requirements focused on ZE-NRMM, and to what extent ZE-NRMM was implemented with different tender methods.

Fourth, two weaknesses of the MIS are not extensively included in the PPI analysis, because they are not hampering the ZE-NRMM MIS directly, but lack synergies with other missions. Interviewees have emphasized concerns with the narrow focus on ZE-NRMM, whilst synergies with the energy transition and circular construction of the KCI strategy can be incorporated. Yet, it is unclear how to incorporate this wider system or mission focus in tenders. Therefore, future research could explore through policy mix analysis the synergies between other Dutch missions in the energy transition and construction industry for ZE-NRMM, and explore possibilities to incorporate synergy thinking in tenders. A potential research question could be: *''What mission synergies are present in the Dutch ZE-NRMM transition in contrast to the energy transition, and how can these synergies be coordinated via tenders in public procurement?''*

Fifth, the initial focus of the research was ZE-NRMM, however, during the problem-solution analysis it became evident that the ZE-NRMM solutions are interrelated with energy infrastructure solutions. Yet, the variety of energy infrastructure solutions have not been mapped in-depth. However, as the resource mobilization of energy infrastructure is one of the main general barriers for the implementation of ZE-NRMM it would be a valuable future research avenue to provide an in-depth solution analysis on the most effective energy infrastructure solutions.

Reference list

Ackermann, F., & Eden, C. (2011). Making strategy: Mapping out strategic success. Sage, 2011.

Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (2005). Competition and innovation: An inverted-U relationship. The quarterly journal of economics, 120(2), 701-728.

Alford, J., & Brian, W. Head. 2017."Wicked and less wicked problems: a typology and a contingency framework.". *Policy and Society*, *36*(3), 397-413.

Arthur, W. Brian. 1989. "Competing Technologies, Increasing Returns, and Lock-In by Historical Events," 97 Economic Journal 642-65.

Baarends, K. (2022). Analysis of the Dutch Mission-oriented Innovation System (MIS) for a natural gas-free built environment (Master's thesis).

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., & Truffer, B. (2015). Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. Environmental innovation and societal transitions, 16, 51-64.

Boon, W., & Edler, J. (2018). Demand, challenges, and innovation. Making sense of new trends in innovation policy. Science and Public Policy, 45(4), 435-447.

BouwendNederland. (2022). Duurzaamheid in openbare aanbestedingen – Analays 2022. Retrieved at 20-02-2023, from: https://www.pianoo.nl/sites/default/files/media/documents/2022-11/analyse-duurzaamheid-in-openbare-aanbestedingen-2021-november2022.pdf

Bryman, A. (2016). Social research methods. Oxford university press.

Cabral, L., Cozzi, G., Denicolo, V., Spagnolo, G., & Zanza, M. (2006). Procuring innovation.

Cheng, W., Appolloni, A., D'Amato, A., & Zhu, Q. (2018). Green Public Procurement, missing concepts and future trends–A critical review. Journal of cleaner production, 176, 770-784.

Chiappinelli, O., Giuffrida, L. M., & Spagnolo, G. (2023). Public procurement as an innovation policy: Where do we stand? (No. 23-002). ZEW Discussion Papers.

Creswell, J. W., & Miller, D. L. (2000). Determining validity in qualitative inquiry. Theory into practice, 39(3), 124-130.

Creswell, J. W., & Poth, C. N. (2016). Qualitative inquiry and research design: Choosing among five approaches. Sage publications.

CROW, (2023). Aanpak Duurzaam GWW. Retrieved at 04-05-2023, from: https://www.duurzaamgww.nl/documenten/67-aanpak-duurzaam-gww

Cunningham, P. N. (2009). Demand-side innovation policies. Policy Brief No 1 (2009). European Trend Chart on Innovation Policy

Cunningham, P., Edler, J., Flanagan, K., & Laredo, P. (2013). Innovation policy mix and instrument interaction: a review. Manchester: University of Manchester.

Dalpé, R., DeBresson, C., & Xiaoping, H. (1992). The public sector as first user of innovations. Research policy, 21(3), 251-263.

Desouza CD, Marsh DJ, Beevers SD, Molden N, Green DC (2020) Real-world emissions from non-road mobile machinery in London. Atmos Environ 223:117301

Devers, K.J., Frankel, R.M. (2000). Study design in qualitative research: sampling and data collection strategies. Education for health; Mumbai Vol. 13. Iss 2:263. DOI: 10.1080/13576280050074543

DNV GL. (2019). Perspectives on zero emission construction sites: status 2019. Climate Agency, City of Oslo. (Report No.:2019-0535, Rev. 1)

Doloreux, D. (2002). What we should know about regional systems of innovation. Technology in society, 24(3), 243-263.

Dominguez, D., Worch, H., Markard, J., Truffer, B., & Gujer, W. (2009). Closing the Capability Gap: Strategic Planning for the Infrastructure Sector. California Management Review, 51(2), 30–50. https://doi.org/10.2307/41166479

EC (2023). European Commission: Public Procurement of Innovative solutions. Retrieved at 01-03-2023, from: https://digital-strategy.ec.europa.eu/en/policies/ppi.

Edler, J., & Georghiou, L. (2007). Public procurement and innovation—Resurrecting the demand side. Research policy, 36(7), 949-963.

Edler, J. (2013). Review of policy measures to stimulate private demand for innovation. Concepts and effects. Compendium of Evidence on the Effectiveness of Innovation Policy Intervention, 13, 44.

Edler, J., Georghiou, L., Blind, K., Uyarra, E., 2012. Evaluating the demand side: new challenges for evaluation. Research Evaluation, 21 (1): 33-47.

Edquist, C., & Hommen, L. (2000). Public technology procurement and innovation theory (pp. 5-70). Springer US.

Edquist, C., & Zabala-Iturriagagoitia, J. M. (2012). Public Procurement for Innovation as mission-oriented innovation policy. Research policy, 41(10), 1757-1769

Edquist, C., & Zabala-Iturriagagoitia, J. M. (2015). Pre-commercial procurement: a demand or supply policy instrument in relation to innovation?. R&D Management, 45(2), 147-160.

ElaadNL. 2023. ElaadNL: over ons. Retrieved at 04-05-2023, from: https://elaad.nl/over-ons/.

ENI. (2022). Real World Insights into the emerging discipline of Zero Emission Constructions. Emissieloos Netwerk Infra, December 2022.

ENI (2023a). Rapport: geleerde lessen uit ENI volgprojecten anno 2022. Emissieloos Netwerk Infra, 09-02-2023. Retrieved at 03-05-2023, from: https://www.emissieloosnetwerkinfra.nl/publicaties/42/rapport---geleerde-lessen-uit-eni-volgprojecten-anno-2022

ENI. (2023b). Emissieloos Netwerk Infra: Doelen. Retrieved at 04-05-2023, from: https://www.emissieloosnetwerkinfra.nl/organisatie/doelen

Erridge, A., & Greer, J. (2002). Partnerships and public procurement: building social capital through supply relations. Public Administration, 80(3), 503-522.

European Commission (2016) Buying green! A handbook on green public procurement, 3rd edn. European Union, Belgium. https://ec.europa.eu/environment/gpp/buying_handbook_en.htm.

European Commission, (CE), 2011. Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. COM/2011/144 final. Available at: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:EN:PDF

European Commission, Directorate-General for Regional and Urban Policy. Stock-Taking of Administrative Capacity, Systems and Practices across the EU to Ensure the Compliance and Quality of Public Procurement Involving European Structural and Investment (ESI) Funds: Final Report; Publications Office: Luxembourg, 2016.

EVConsult, 2023. In transitie naar een emissievrije bouwplaats: stand van zaken, barrières en kansen. 27-03-2023, EVConsult, Amsterdam.

Gann DM, Salter AJ (2000) Innovation in project-based, service-enhanced firms: the construction of complex products and systems. Res Policy 29(7–8):955–972.

Geels, F. W. (2005). Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. Technological forecasting and social change, 72(6), 681-696.

Georghiou, L., Edler, J., Uyarra, E., & Yeow, J. (2014). Policy instruments for public procurement of innovation: Choice, design and assessment. Technological forecasting and social change, 86, 1-12.

Georghiou, L., Li, Y., Uyarra, E., & Edler, J. (2010). Public procurement for innovation in small European countries. A Report from the ERA-PRISM:(Policies for Research and Innovation in Small Member States to Advance the European Research Area) OMC-Net Project, Brussels.

Geroski, P. A. (1990). Procurement policy as a tool of industrial policy. International review of applied economics, 4(2), 182-198.

Ginige, K., Amaratunga, D., & Haigh, R. (2018). Mapping stakeholders associated with societal challenges: A Methodological Framework. Procedia engineering, 212, 1195-1202.

Glover, A., Anderson, R., Byles, T., Georghiou, L., Gillies, C., Ippolito, J., ... & Warrington, J. (2008). Accelerating the SME Economic Engine.

Golafshani, N. (2003). Understanding reliability and validity in qualitative research. The qualitative report, 8(4), 597-607.

Haddad, C., Nakić, V., Bergek, A., Hellsmark, H., 2019. The design and organization of innovation policy The policymaking process of transformative innovation policy: a systematic review. 4th Int. Conf. Public Policy 1–45.

Harrell, M. C., & Bradley, M. A. (2009). Data collection methods. Semi-structured interviews and focus groups. Rand National Defense Research Inst santa monica ca.

Hekkert, M. P., Janssen, M. J., Wesseling, J. H., & Negro, S. O. (2020). Mission-oriented innovation systems. Environmental innovation and societal transitions, 34, 76-79.

Hekkert, M. P., Suurs, R. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. (2007). Functions of innovation systems: A new approach for analysing technological change. Technological forecasting and social change, 74(4), 413-432.

Hekkert, M., Negro, S., Heimeriks, G., & Harmsen, R. (2011). Technological innovation system analysis. Technological innovation system analysis,(November), 16.

Holton, J. A. (2007). The coding process and its challenges. The Sage handbook of grounded theory, 3, 265-289.

https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf

Huang, L., Krigsvoll, G., Johansen, F., Liu, Y., & Zhang, X. (2018). Carbon emission of global construction sector. Renewable and Sustainable Energy Reviews, 81, 1906-1916.

I&W (2021). Strategie KCI Rijksinfrastructuurprojecten. Ministerie van Infrastructuur en Waterstaat (IenW). Retrieved at 14-03-2023, from: (https://magazines.rijksoverheid.nl/ienw/duurzaamheidsverslag/2022/01/strategie-naar-klimaatneutrale-en-circulaire-rijksinfrastructuurprojecten

I&W (2022). Roadmap transitiepad Weg-, Dijk- en Spoortmaterieel (WDSM). Ministerie van Infrastructuur en Waterstaat. Retrieved at 14-03-2023, from: https://www.duurzame-infra.nl/Portals/0/adam/Content/M74VTn6OH0ijWf0f6bZHMQ/Text/Roadmap%20Weg,-Dijk-en%20Spoormaterieel.pdf

Ihonen, J., Aronsson, B., Skúlason, J. B., Korneliúsdóttir, A. M., Jensen, T. L., Fenne, E., ... & Eriksen, J. (2021). Next Nordic Green Transport Wave–Large Vehicles: Prospectus of using hydrogen in heavy-duty equipment, including non-road mobile machinery.

IPCC Working Group III. (2022). Climate Change 2022-Mitigation of Climate Change: Summary for Policymakers. Intergovernmental Panel on Climate Change.

J. F. Reinganum. Innovation and Industry Evolution. The Quarterly Journal of Economics, 100(1):81–99, 1985.

JCB, 2023. Altijd op zoek naar een betere manier. Retrieved at 08-05-2023, from: https://www.jcb.com/nl-nl/campaigns/hydrogen.

K. Arrow. Economic Welfare and the Allocation of Resources for Invention. In The Rate and Direction of Inventive Activity: Economic and Social Factors, pages 609–626. Princeton University Press, 1962.

KCI, 2021. Strategie KCI Duurzaamheidsverslag: strategie KCI Rijksinfrastructuurprojecten. Ministerie van Infrastructuur en Waterstaat 2021. Retrieved at 03-05-2023, from: https://magazines.rijksoverheid.nl/ienw/duurzaamheidsverslag/2022/01/strategie-naar-klimaatneutrale-en-circulaire-rijksinfrastructuurprojecten

KCI, 2023a. Update Programma KCI en transitiepaden. Retrieved at 04-05-2023, from: https://www.duurzame-infra.nl/actueel/details/update-programma-kci-en-transitiepaden

KCI, 2023b. Transitiepad Weg-, Dijk- en Spoormaterieel. Retrieved at 04-05-2023, from: https://www.duurzame-infra.nl/roadmaps/transitiepad-weg-dijk-en-spoormaterieel

Kirchherr, J., Hartley, K., & Tukker, A. (2023). Missions and mission-oriented innovation policy for sustainability: A review and critical reflection. Environmental Innovation and Societal Transitions, 100721.

Lajunen, A., Sainio, P., Laurila, L., Pippuri-Mäkeläinen, J., & Tammi, K. (2018). Overview of powertrain electrification and future scenarios for non-road mobile machinery. Energies, 11(5), 1184.

Lajunen, A., Suomela, J., Pippuri, J., Tammi, K., Lehmuspelto, T., & Sainio, P. (2016). Electric and hybrid electric non-road mobile machinery–present situation and future trends. World Electric Vehicle Journal, 8(1), 172-183.

Ledna, C., Muratori, M., Yip, A., Jadun, P., & Hoehne, C. (2022). Decarbonizing Medium-& Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis (No. NREL/TP-5400-82081). National Renewable Energy Lab.(NREL), Golden, CO (United States).

Liander. (2022). Levertijden en energienet onder druk. Retrieved at 17-02-2022, from: https://www.liander.nl/consument/aansluitingen/mogelijk-langere-levertijden

Lincoln, Y. S., & Guba, E. G. (1985). Naturalistic inquiry. sage.

Lundvall, B. A., Dosi, G., & Freeman, C. (1988). Innovation as an interactive process: from user-producer interaction to the national system of innovation. 1988, 349, 369.

Malerba, F. (2002). Sectoral systems of innovation and production. Research policy, 31(2), 247-264.

Martland, C.D. (2011). Toward More Sustainable Infrastructure: Project Evaluation for Planners and Engineers. Wiley; 1st edition (February 22, 2011). ISBN-10: 0470448768.

Mazzucato, M. (2017). Mission-oriented innovation policy. UCL Institute for innovation and public purpose working paper, 1.

Mazzucato, M. (2018). Mission-oriented innovation policies: challenges and opportunities. Industrial and corporate change, 27(5), 803-815.

Meijerhof, N. (2020). The Mission-oriented Innovation System around the Green Deal in the Short Sea Shipping Sector (Master's thesis).

Ministry of Interior and Kingdom Relations, 2023. Regio-indeling: bestuurlijk. Retrieved at 03-05-2023, from: https://www.regioatlas.nl/regioindelingen.

Mowery, D., & Rosenberg, N. (1979). The influence of market demand upon innovation: a critical review of some recent empirical studies. Research policy, 8(2), 102-153.

NEA, 2023. Marktmechanisme en HBE's. Nederlandse Emissieautoritiet. Retrieved at 09-05-2023, from: https://www.emissieautoriteit.nl/onderwerpen/algemeen-hernieuwbare-energie-voor-vervoer/marktmechanisme.

Nokka, J. (2018). Energy efficiency analyses of hybrid non-road mobile machinery by real-time virtual prototyping.

Otten, M., van de Lande, P., Tol, E. & Vendrik, J. (2022). ZE-bouwplaats: Inrichting ZE-bouwplaats en meerkosten. Delft, CE Delft, 2022.

Packendorff, J. (1995). Inquiring into the temporary organization: new directions for project management research. Scandinavian journal of management, 11(4), 319-333.

PIANOO (2022). Dutch Public Procurement Expertise Centre. Developments. Retrieved at 17-02-2022, from: https://www.pianoo.nl/en/sustainable-public-procurement/developments

PIANOo, 2023a. About PIANOo. Retrieved at 04-05-2023, from: https://www.pianoo.nl/en/about-pianoo-0.

PIANOo. 2023b. Buyer Group zero emissie bouwaterieel. Retrieved at 04-05-2023, from: https://www.pianoo.nl/nl/themas/maatschappelijk-verantwoord-inkopen/buyer-groups/gww/buyer-group-zero-emissie-bouwmaterieel

PIANOo, (2023c). GWW contractvormen. PIANOo expertise centre for tendering. Retrieved at 22-05-2023, from:https://www.pianoo.nl/nl/sectoren/gww/gww-contractvormen

PIANOo, (2023d). Inkopen met de milieukostenindicator. PIANOo expertise centre for tendering. Retrieved at 22-05-2023, from: https://www.pianoo.nl/nl/document/17703/inkopen-met-de-milieukostenindicator#:~:text=Door%20MKI%20als%20eis%20of,juiste%20manier%20toe%20te%20passen.

PIANOo, (2023e). Innovatiepartnerschap. PIANOo expertise centre for tendering. Retrieved at 22-05-2023, from: https://www.pianoo.nl/nl/inkoopproces/aanbestedingsprocedures/innovatiepartnerschap

PIANOo, (2023f). bouworganisatievormen GWW. PIANOo expertise centre for tendering. Retrieved at 22-05-2023, from: https://www.pianoo.nl/nl/sectoren/gww/inkopen-gww/bouworganisatievormen-gww

Provinciale staten, (2019). Notulen vergadering van Provinciale Staten van Noord-Holland. Retrieved at 17-02-2022, from:

PSN, 2023. Programma Stikstofreductie en Natuurverbetering 2022-2035. Eerste editie 2022. Retrieved at 03-05-2023, from: https://open.overheid.nl/documenten/ronl-ce9cacdc2f43a287fda6ed95e3d2d2f0a95e277f/pdf

R. R. Nelson. The Simple Economics of Basic Scientific Research. Journal of Political Economy, 67(3):297–306, 1959.

Raiteri, E. (2018). A time to nourish? Evaluating the impact of public procurement on technological generality through patent data. Research Policy, 47(5), 936-952.

Ratzinger, J. M., Buchberger, S., & Eichlseder, H. (2021). Electrified powertrains for wheel-driven non-road mobile machinery. Automotive and Engine Technology, 6, 1-13.

Reike, D., Hekkert, M. P., & Negro, S. O. (2023). Understanding circular economy transitions: The case of circular textiles. Business Strategy and the Environment, 32(3), 1032-1058.

Rijksoverheid (2019). Klimaatakkoord hoofdstuk C2 mobiliteit. Publicatie: 28-06-2019. Retrieved at 09-03-2023, from: https://www.klimaatakkoord.nl/mobiliteit/documenten/publicaties/2019/06/28/klimaatakkoord-hoofdstuk-mobiliteit

Rijksoverheid (2022). Over mobiliteit in de bouw. Retrieved at 17-02-2022, from: https://dashboardklimaatbeleid.nl/viewer/jivereportcontents.ashx?report=mobiliteit_bouw

Rijksoverheid, 2023. Klimaatbeleid. Retrieved at 03-05-2023, from: https://www.rijksoverheid.nl/onderwerpen/klimaatverandering/klimaatbeleid

Rijkswaterstaat (2019). Toekomstige Opgave Rijkswaterstaat: Perspectief op de uitdagingen en verbetermogelijkheden in de GWW-sector, Mei 2019. Rijkswaterstaat - Ministerie van Infrastructuur en Waterstaat.

Rijkswaterstaat, (2023a). Duurzaam inkopen in het inkoopdomein GWW. Retrieved at 11-05-2023, from: https://www.rijkswaterstaat.nl/zakelijk/zakendoen-met-rijkswaterstaat/inkoopbeleid/duurzaam-inkopen

Rijkswaterstaat, (2023b). Best value. Retrieved at 22-05-2023, from: https://www.rijkswaterstaat.nl/zakelijk/zakendoen-met-rijkswaterstaat/werkwijzen/werkwijze-in-gww/aanbesteden-en-contracteren

Rijkswaterstaat, (2023c). Economisch meest voordelige inschrijving. Retrieved at 22-05-2023, from: https://www.rijkswaterstaat.nl/zakelijk/zakendoen-met-rijkswaterstaat/inkoopbeleid/aanbesteden/economische-meest-voordelige-inschrijving

Rittel, H. W., & Webber, M. M. (1974). Wicked problems. Man-made Futures, 26(1), 272-280.

Roller, M. R., & Lavrakas, P. J. (2015). Applied qualitative research design: A total quality framework approach. Guilford Publications.

Rothwell, R., & Zegveld, W. (1981). Government regulations and innovation—industrial Innovation and Public Policy. Industrial Innovation and Public Policy. Frances Pinter, London, 116-147.

Sariola, R. (2018). Utilizing the innovation potential of suppliers in construction projects. Construction innovation.

Schot, J., & Steinmueller, W. E. (2018). Three frames for innovation policy: R&D, systems of innovation and transformative change. Research policy, 47(9), 1554-1567.

Schumpeter, J.A. (1939). Business cycles: A theoretical, historical and satistical analysis of the capitalist process. New York, NY: McGraw-Hill.

SEB 2023. Routekaart Schoon en Emissieloos Bouwen. Versie 10-2-2023. Working document.

Selviaridis, K., Hughes, A., & Spring, M. (2023). Facilitating public procurement of innovation in the UK defence and health sectors: Innovation intermediaries as institutional entrepreneurs. Research Policy, 52(2), 104673.

Shin, K., Yeo, Y., & Lee, J. D. (2020). Revitalizing the concept of public procurement for innovation (PPI) from a systemic perspective: objectives, policy types, and impact mechanisms. Systemic Practice and Action Research, 33, 187-211.

SLA, 2020. Schone Lucht Akkoord: Gezondheidswinst voor iedereen in Nederland. Retrieved at 03-05-2023, from: https://www.infomil.nl/onderwerpen/lucht-water/luchtkwaliteit/thema'/schone-lucht-akkoord/

Smits, R., Kuhlmann, S., 2004. The rise of systemic instruments in innovation policy. Int. J. Foresight Innov. Policy 1, 4. https://doi.org/10.1504/IJFIP.2004.004621

Stokke, R., Qiu, X., Sparrevik, M., Truloff, S., Borge, I., & de Boer, L. (2022). Procurement for zero-emission construction sites: a comparative study of four European cities. Environment Systems and Decisions, 1-15.

Templier, M., & Paré, G. (2015). A framework for guiding and evaluating literature reviews. Communications of the Association for Information Systems, 37(1), 6.

TenderNed. (2022). Sectorrapportage bouw. Retrieved at 20-02-2023, from: https://www.tenderned.nl/cms/nl/aanbesteden-cijfers-sectorrapportages-aanbesteden/sectorrapportage-bouw

Tepeli E, Taillandier F, Breysse D (2021) Multidimensional modelling of complex and strategic construction projects for a more effective risk management. Int J Constr Manag 21(12):1218–1239.

Tsipouri, L., Edler, J., Rolfstam, M., & Uyarra, E. (2010). Risk management in the procurement of innovation: Concepts and empirical evidence in the European Union.

Turner, J. R., & Müller, R. (2003). On the nature of the project as a temporary organization. International journal of project management, 21(1), 1-8.

UN. (2015). Paris Agreement. Retrieved at 03-05-2023, from: https://unfccc.int/sites/default/files/english_paris_agreement.pdf

Unruh, G. C. (2002). Escaping carbon lock-in. Energy policy, 30(4), 317-325.

Uyarra, E., Edler, J., Garcia-Estevez, J., Georghiou, L., & Yeow, J. (2014). Barriers to innovation through public procurement: A supplier perspective. Technovation, 34(10), 631-645.

Uyarra, E., Zabala-Iturriagagoitia, J. M., Flanagan, K., & Magro, E. (2020). Public procurement, innovation and industrial policy: Rationales, roles, capabilities and implementation. Research Policy, 49(1), 103844.

Uyarra, E. (2010). Opportunities for innovation through local government procurement. Report No. PLG/51, NESTA, London.

Uyarra, E., & Flanagan, K. (2010). Understanding the innovation impacts of public procurement. European planning studies, 18(1), 123-143.

Van Arkel, J. N. J. (2021). Analysis of the Dutch Mission-oriented Innovation System for sustainable aviation (Master's thesis).

Verhelst, S., Turner, J. W., Sileghem, L., & Vancoillie, J. (2019). Methanol as a fuel for internal combustion engines. Progress in Energy and Combustion Science, 70, 43-88.

Wanzenböck, I., Wesseling, J.H., Frenken, K., Hekkert, M.P., Weber, K.M., 2020. A framework for mission-oriented innovation policy: Alternative pathways through the problem–solution space. Sci. Public Policy 1–16. https://doi.org/10.1093/scipol/scaa027

WattHub, 2023. WattHub: sourced sustainably, charged smartly. Retrieved at 03-05-2023, from: https://watthub.nl/.

WDSM, 2022. Roadmap Transitiepad Weg-, Dijk- en Spoormaterieel (WDSM). Ministry of infrastructure and Watermanagement and NewForesight. 7th of June, 2022.

Weber, and Rohracher, H. (2012) ‘Legitimizing Research, Technology and Innovation Policies for Transformative Change: Combining Insights from Innovation Systems and Multi-Level Perspective in a Comprehensive ‘Failures’ Framework’, Research Policy, 41: 1037–47

Wesseling, J.H., Van der Vooren, A., 2017. Lock-in of mature innovation systems: The transformation toward clean concrete in the Netherlands. J. Clean. Prod. 155, 114–124. https://doi.org/10.1016/j.jclepro.2016.08.115

Wesseling, J. H., & Edquist, C. (2018). Public procurement for innovation to help meet societal challenges: a review and case study. Science and Public Policy, 45(4), 493-502.

Wesseling, J., & Meijerhof, N. (2021). Developing and applying the Mission-oriented Innovation Systems (MIS) approach.

WGBC (2019) New report: the building and construction sector can reach net zero carbon emissions by 2050. World Green Building Council, London. Retrieved at 09-03-2023, from: https://www.worldgbc.org/news-media/WorldGBC-embodied-carbon-report-published.

V. Appendix

Appendix A – Diagnostic questions

Guiding diagnostic questions per system function, adapted from Wesseling et al. (2021).

Function	Guiding diagnostic questions
SF1: Entrepreneurial activities	Are experiments to develop existing and new solutions, conducted sufficiently rapidly to complete the mission?
SF2: Knowledge development	Is sufficient knowledge developed to understand the societal problem? Is knowledge to develop existing and new solutions, created sufficiently rapidly to complete the mission?
SF3: Knowledge diffusion	Is knowledge about the societal problem diffused sufficiently to formulate a broadly supported, clear, time-bound and ambitious mission? Is knowledge to develop and use solutions diffused sufficiently rapidly amongst all stakeholders, to complete the mission?
SF4A: Problem directionality	How do stakeholders prioritize the mission's problem and framework conditions in relation to other societal problems?
SF4B: Solution directionality	Which stakeholders support and pursue the development and diffusion of the solutions sufficiently rapidly to complete the mission? What solutions do they prioritize? Do stakeholders sufficiently recognize and exploit the interdependencies between different solutions?
SF5: Market formation	Are formal or informal policies supporting the diffusion of solutions sufficiently rapidly to complete the mission? Are formal or informal policies phasing-out harmful technologies and practices sufficiently rapidly to complete the mission? Are stakeholders sufficiently rapidly adopting the solutions? Are stakeholders sufficiently rapidly abandoning harmful practices and technologies?
SF6: Resource mobilization	Are sufficient human, financial and material resources mobilized to fulfil the other system functions?
SF7: Creation of legitimacy	Do all stakeholders support the mission's problem? Are stakeholders advocating or lobbying to prioritize the mission's problem over other societal problems and wants? Are stakeholders advocating or lobbying for more solution-support and phase-out of harmful practices and technologies? What solutions receive the strongest lobby support or opposition?
SF8: Coordination	Are actors sufficiently coordinating the diversity of solutions that stakeholders explore? Are coordinating roles shared among actors or single actors driving system coordination?
SF9: Regime change	Are actors sufficiently rapidly unlearning practices harmful to the mission?

The researcher's own interpretation of diagnostic questions following (Georghiou et al., 2014).

Policy category	Guiding diagnostic questions
Framework conditions	Are procurement regulations driven by competition or innovation logic? Are public tenders accessible for all or are (dis-)advantages present for a set of contractors? Do contractors perceive tenders as innovation-friendly?
Organization and capabilities	Is a clear innovation strategy present for public procurement within the governmental organization? Are specific functions for procurement of innovation appointed within the organization? Are procurers sufficiently capable of creating and governing innovative procurement tenders?
Identification, specification and signaling of needs	Is there sufficient communication and feedback between contractors and procurers regarding each other's needs? Is there sufficient communication and feedback between suppliers and procurers regarding needs and innovation potential?
Incentivizing innovative solutions	Do contractors perceive lack of take up as a risk for their innovation activities? Are public procurers risk-averse in tender projects?

Appendix B – Interview guide

The following interview guide is the general semi-structured interview protocol that has been used during the interviews.

Interview Guide	
Opening word – 5 min.	
Personal introduction	Thank you for making time for this interview. I am Ewout Timmermans, a student at Eindhoven University of Technology for the Master Innovation Sciences and I am doing my thesis research at EVConsult, a company focused on accelerating the energy transition with its advice to companies. The research is about the mission in the construction industry to promote Zero-Emission construction equipment and how this can be accelerated by means of public tenders in GWW-construction.
Goal of the interview	The purpose of the interview is to hear your perspective and experiences about this mission and learn more about the challenges faced by GWW. The interview will last approximately 1 hour.
Confidentiality and consent	All information you provide to me will be anonymized in this research, so your name will not be mentioned, only your position and the type of company where you work. I would like to record the interview so that it can later be transcribed and analyzed for my research, do I have your permission?
Context	There is a mission in the GWW-construction industry to reduce emissions by 2030 and to phase out all light equipment by 2033 and medium and heavy equipment by 2035. Therefore, in the interview, there are three main topics that we will discuss, namely: problems and solutions for ZE construction, the functions of innovation and public procurement policies and processes. But let's start with an introduction from your end.
Start of the interview – 55min. (Start recording)	
Subject 1: Personal information (2min.)	- Could you briefly introduce how your position/expertise relates to the GWW-construction sector and the number of years working in your field of expertise/GWW-sector?
Subject 2: MIS questions (30min.)	
Problem-Solution diagnosis	- Why is it important that GWW uses ZE construction equipment? - What solutions are present for ZE construction equipment?
Structural analysis	- Which parties are actively involved in formulating and monitoring the mission and mobilizing other stakeholders?
System Functions (score 1-5)	
Barriers	- What do you think is the largest barrier that hampers the mission for ZE construction equipment in 2030 and what is the underlying cause?
SF1	- Are experiments/pilots to develop ZE construction equipment innovations set up within GWW to complete the mission?
SF2	- What knowledge is required to understand the societal problems in the GWW-sector and what knowledge to apply ZE construction equipment solutions, and why?
SF3	- How is knowledge diffused among stakeholders about societal problems (CO_2, NO_x and pm) and ZE construction equipment solutions in the GWW-sector? Is the knowledge spreading fast enough to complete the mission?
SFA	- Do you think it is important to prioritize the social problems in construction in relation to each other and why?
SFB	- Are there solutions that you or the market are paying more attention to and why those solutions?
SF5	- Is ZE construction equipment being implemented sufficiently for the solutions to be scaled up and how does government policy play a role in this?
SF6	- Are sufficient resources being deployed to make ZE construction equipment the standard? (human, financial and material)
SF7	- Are stakeholders advocating or lobbying for more support for ZE innovations and phasing out harmful practices and technologies?

SF8	- Are there initiatives that steer and bring together the diversity of ZE construction equipment projects in the market?	
SF9	- What is being done in the market to limit and phase out harmful technologies and practices?	
Subject 3: Procurement (20min.)	**Public client questions**	**Other stakeholders questions**
Framework conditions	- Are procurement rules within your organization driven by competition or innovation logic and why? - How is space for innovation created within your organization's tenders?	- Are there advantages/disadvantages within public tenders for you as a contractor compared to other contractors? - Do you experience the scope to experiment with innovative solutions within tenders?
Organizational capabilities	- Does your organization have sufficient knowledge and expertise about designing innovation-stimulating public tenders and what are the challenges?	- Does your organization have sufficient knowledge and expertise regarding the purchase of ZE innovations?
Incentivizing innovative solutions	-Do you experience your organization as a daredevil or more risk-averse when issuing tenders and why?	-Do you experience risks related to the use or purchase of ZE construction equipment and how do these manifest?
Identification, specification and signaling of needs	-How does coordination and feedback take place about needs between you as a contracting authority and suppliers or contractors? - Has the role of public principals changed in ZE GWW tenders compared to regular GWW projects?	- Is it desirable to tender ZE GWW projects with a different scope than comparable regular GWW projects?
Recommendations	- How do you think that tender processes can be better implemented to stimulate ZE construction equipment in the market?	
Subject 4: Closing questions (3min.)	- Are there topics that have not been discussed in this interview but are relevant to this topic or from the point of view of your position?	
Thanking interviewee	Thank you very much for the interview and the insights you provided, this is the end of the interview.	
Finishing the interview – 2 min. (Stop recording)		
Next steps	I will transcribe the interview and if you want I can send the transcript for you to check your answers. If there are still things that come to mind that you would like to add, you can always reach me by email. May I still contact you if I have any remaining questions? In addition, I can share the research with you when it is completed.	
	Have a nice day, bye!	

Appendix C – Overview of interviews

Overview of the semi-structured interview with experts

Nr.	Respondent	Company category	Function	Years experience	Date
1	BAN1	Bank	Director Energy Transition and PPP	10	6th of April 2023
2	BRA1	Branche organization	Senior policy advisor	15	3rd of April 2023
3	CON1	Prime contractor	Manager sustainability national GWW projects	10	27th of March 2023
4	CON2	Prime contractor	Business development & tender manager	10	27th of March 2023
5	CON3	Prime contractor	Director of NRMM	30	3rd of April 2023
6	CON4	Prime contractor	Director of NRMM	24	30th of March 2023
7	CON5	Prime contractor	Sustainability coordinator & member internal workgroup NRMM	1	4th of April 2023
8	CON6	Prime contractor	Sustainability manager	25	4th of April 2023
9	CPO1	Charging point operator	Manager business development	10	11th of April 2023
10	ENG1	Engineering company	Manager innovation	10	12th of April 2023
11	ENG2	Engineering company	Consultant sustainability and purchasing GWW	11	31st of March 2023
12	GOV1	Ministry I&W and Rijkswaterstaat	Senior policy maker and Secretary buyer group ZEB	6, 10	28th of March 2023
13	GOV2	Rijkswaterstaat	Senior policy maker	21	29th of March 2023
14	GOV3	High Water Protection Program (HwbP)	Sustainability advisor	15	7th of April 2023
15	INS1	Knowledge institute	Program manager	25	4th of April 2023
16	MUN1	Municipality	Senior project leader	20	29th of March 2023
17	MUN2	Municipality	Strategic purchaser NRMM	15	31st of March 2023
18	NET1	Knowledge network	Program manager	10	28th of March 2023
19	NET2	Knowledge network	Webinar Buyer Group ZEB	-	11th of April 2023
20	NET3	Knowledge network	Consultant market development	13	6th of April 2023
21	OEM1	International NRMM OEM	EAME Sales and Asset manager	12	5th of April 2023
22	OEM2	Dutch NRMM OEM	Technical manager	5	11th of April 2023
23	REN1	NRMM rental	Strategic customer development manager	21	3rd of April 2023
24	SME1	SME contractor	Project leader	7	28th of March 2023
25	SME2	SME contractor	Project leader	4	5th of April 2023
26	WAT1	Water authority	Contract manager	14	28th of March 2023
27	WAT2	Water authority	Sustainability advisor & contract manager	24	29th of March 2023

Appendix D – Solutions overview

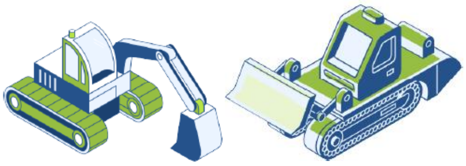
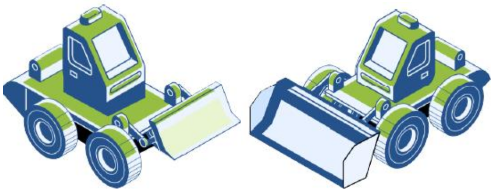
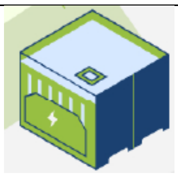
Overview of the problem-solution analysis.

Solutions	TRL	Innovation type	Advantages	Disadvantages
NRMM solutions				
Battery electric	5-9	*Radical*: replacing the drive train and add battery pack.	Zero-emission solution reducing CO_2, NO_x, and PM. Light NRMM available.	Low energy density, limited operation time. Requires charging infrastructure. Heavy NRMM not available, except in pilots.
Hydrogen electric	5-8	*Radical*: when used with a fuel cell, it replaces the entire drive train.	Zero-emission solution reducing CO_2, NO_x, and PM. Offers ZE solution especially for heavy NRMM	More immature than BEV. Limited infrastructure in NL. Used in pilots.
Kinetic energy	9	*Incremental:* optimizes energy efficiency by capturing kinetic energy from movements.	Readily available technology for OEMs. Useful in combination with hydrogen and battery electric.	Is not self-sufficient in providing energy during usage, needs either fossil or non-fossil as main energy source.
HVO	9	*Incremental*: HVO requires no adaptation to the ICE.	CO_2 emissions are reduced during production stage of HVO, compensating CO_2 emissions during combustion of NRMM.	Does not reduce nor eliminate NO_x and PM. Does not count as theoretical reduction of CO_2 due to regulations.
Methanol fuel	3-5	*Incremental*: synthetic fuels requires no or some adaptation to the ICE.	Reduces emissions on CO_2, NO_x and PM	Does not fully eliminate emissions. Expensive and not readily available.
Emission filters	8-9	*Incremental:* used in ICE to reduce emissions	Readily available technology to reduce emissions from fossil fuel NRMM.	No CO_2 reduction, and still emits some NO_x and PM, especially lower stages still polluting.
Energy infrastructure solutions				
Grid-based				
New grid connection & charging point	9	*Incremental: high power connection for ZE-NRMM*	Existing grid connection not always used all the time.	Very expensive, financially not an option for remote projects. Except if it has long-term usefulness in the form as charging station.
Unguaranteed grid connection & charging point	7-9	*Incremental: existing infra used*	Existing grid used, and low investment costs	Can only be used during certain timeslots.
Existing charging points	9	*Incremental: using existing charging infrastructure in rural areas.*	No high investment required. Not always an option due to grid congestion and location dependent.	Mainly suited for light-NRMM. Adapters required, and software protocols need to match NRMM. Not an option on remote GWW projects.
Non-grid based				
Battery swap	7-9	*Radical: requires changing the battery pack in ZE-NRMM*	Energy supply anywhere along GWW construction sites.	Extra investment costs for double batteries. Also increasing resource use. Battery swap services often use diesel trucks.
Mobile battery energy storage	8-9	*Radical: requires large energy storage units to charge ZE-NRMM*	Mobile solution for remote GWW projects.	High investment costs, and extra transport movements.
Mobile hydrozine energy generator	8-9	*Radical: electricity supply via hydrogen energy generator*	Reducing emissions by using hydrogen. Mobile	High investment costs, and extra transport movements.

			solution for remote GWW projects.	
Heavy-duty charging hub	7-8	*Radical: heavy-duty charging-hub based on local green-energy*	Heavy NRMM can be charged, and green energy is used.	Very high investment costs, only suited for larger or multi-year projects.
Energyhub	7	*Radical: hub with hydrogen and/or battery storage as energy supply.*	Both suited for FCEV and BEV applications.	Very high investment costs, only suited for larger or multi-year projects.
Fossil fuel based generators	9	*Incremental: using ZE NRMM, but supplying it with diesel*	Reduces emissions by using ZE NRMM.	Suboptimal transitionary solution to cover in moments of urgent energy need. Still emitting emissions through generator.

Appendix E – ZE-NRMM power categories

NRMM power categories following SEB working document February 2023.

NRMM category	Visual examples
Light (19-56kW)	
Medium-heavy (56-130kW)	
Heavy (130-560kW)	
Special (>560kW and/or lifespan >15 years)	No visual available, examples are pile driving machine or asphalt machine.
Stationary	

Appendix F – SEB Roadmap minimum level

Appendix E provides an overview of the minimum level phase-out path of the SEB Roadmap for ZE-NRMM, do mind this is based on a working document from February 2023 and might not be up to date.

	Periode 1 1 jan. 2023 - 31 dec. 2024	**Periode 2** 1 jan. 2025 - 31 dec. 2027	**Periode 3** 1 jan. 2028 - 31 dec. 2029	**Periode 4** 1 jan. 2030 en verder
Licht ('minimaterieel' <19 kW)	Geen eis	Geen eis	100% ZE**	100% ZE**
Licht (19-37 kW)	Stage IIIa	Stage IIIa	Stage IIIa	100% ZE**
Licht (37-56 kW)	Stage IIIa	Stage IIIb	Stage IIIb	100% ZE**
Middelzwaar (56-130 kW)	Stage IIIa	Stage IV met roetfilter*	Stage IV met roetfilter*	Stage IV met roetfilter* (2030) 100% ZE (2035)
Zwaar (130-560 kW)	Stage IIIa	Stage IV met roetfilter**	Stage IV met roetfilter*	Stage IV met roetfilter* (2030) 100% ZE (2035)
Specialistisch (levensduur >15 jaar) Zeer zwaar (>560 kW)	Geen eis	Geen eis	Katalysator en roetfilter*	Katalysator en roetfilter* 100% ZE (2035-2040)
Stationair (generatoren, pompen, torenkranen)	Stage IIIa (tot 560 kW)	Stage IV met roetfilter*	100% ZE**	100% ZE**

Appendix G – Tender methods used in the GWW-construction sector

Tender method/contract /criteria	Description
RAW	A standardized form of prescribing works is the RAW specification, a system of legal, administrative and technical conditions for compiling contracts. The CROW (knowledge platform for ground, road and hydraulic engineering) updates and manages this. Another traditional form of contract that is regularly used is a RAW framework agreement (formerly Agreement With Open Items). (PIANOo, 2023c)
Platform approach (Raamovereenkomsten)	Many larger clients conclude framework agreements/collaboration agreements with (a group of) engineering firms. Further agreements can be concluded with the framework agreement partners. Agreements with engineering firms occur in the design, engineering and contract management phases. (PIANOo, 2023c)
Two-phase (Twee-phase process)	The action plan Towards a vital infrastructure sector states how Rijkswaterstaat, together with the market, wants to work on, among other things, better risk management and thus better predictability of projects. One of the instruments that Rijkswaterstaat will use for this is the 2-phase process. Rijkswaterstaat only sets a price for the most risky or uncertain parts of the construction phase when the risks can be better estimated. The CROW has drawn up a handbook for Tendering two-phase contracts. (PIANOo, 2023c)
Build team (Bouwteam)	In a construction team, there is more cooperation between the various parties. In addition to a contractor and client, an architect, a consulting engineer, an installation company and/or certain specialized company can also be part of a construction team to further develop a preliminary design. The integrated approach guarantees optimal coordination between the various disciplines. And that can benefit the price, lead time and overall quality. Participants in a construction team enter into a construction team agreement. (PIANOo, 2023c)
Innovation partnership	Innovation partnership is a new procedure in European Directive 2014/24/EU and (from its entry into force) in the amended Public Procurement Act 2012. You can use this procedure to purchase products, works and services that are not yet available on the market (or in at least not with the performance level you want). You define the problem or need and companies propose innovative solutions. After completing the research and development phase, you can purchase the product, work or service in commercial volumes under the terms you agreed upon at the start of the innovation partnership. (PIANOo, 2023e)
Alliance contract	The division of tasks is clear in the traditional and the integrated construction organization form. The client and the market party each have their individual factual and legal responsibility for the tasks they perform separately. In the traditional form, the responsibilities and risks lie more with the client than in the integrated form. In the alliance form, however, the client and the market party jointly perform one or more tasks of the construction process and also share the associated risks. This form is often used in combination with the integrated form and is then often limited to a task for which the risks cannot be sufficiently overseen. It does not benefit either party to bear those risks themselves or to place those risks solely with the other party. (PIANOo, 2023f)
EMVI	EMVI has now become an umbrella term for 3 award criteria (Rijkswaterstaat, 2023c): (1) Best Price Quality Ratio (BPKV), (2) Lowest costs based on cost-effectiveness (lifecycle), (3) Lowest price. What used to be referred to as EMVI has now become BPKV. Rijkswaterstaat uses BPKV to select tenders based on a combination of price and quality. We understand quality to include public focus, sustainability and risk management. In this way, Rijkswaterstaat also wants to contribute to stimulating innovation in the sector.
Best value tender (BPKV)	Best Value is the approach in which we strive for the most value for the best price. In Best Value projects, the contractor takes the lead, so that his expertise can be used optimally. The animation below makes it immediately clear what the approach entails and what the benefits are. (Rijkswaterstaat, 2023b)
MKI	By including MKI as a requirement or award criterion in the tender, suppliers are stimulated to offer the most sustainable solution and they will in turn also demand this in the delivery from the chain. It requires knowledge and preparation to apply the environmental cost indicator correctly. Moreover, not every sector is equally familiar with working with MKI. (PIANOo, 2023d)