Master's Thesis – Master Sustainable Business and Innovation

Towards a circular infrastructure in the Netherlands

A Mission-oriented Innovation System analysis

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Abstract

The *Introduction* discusses the formulation of the mission to transition towards a circular economy by 2050 set by the Dutch government to address pressing societal challenges. Here, the infrastructure sector is an important sector to become circular as it uses a vast amount of materials, energy, and water. This research aims to aid the transition by analyzing how governance actions target the systemic barriers in the innovation system, thereby taking into account the implementation and coordination of the mission at regional and local governmental levels.

The *Theory* section discusses the change of innovations policy towards the formulation of missions and the importance of mapping out innovation dynamics to aid the implementation and monitoring. It argues that a new innovation system perspective is needed since existing approaches are inadequate to capture the 'wicked' nature of societal-challenge based missions. Therefore, the 'Mission-oriented Innovation System' perspective was proposed, followed by an approach consisting of five stages to analyze a MIS, including a problem-solution diagnosis, structural analysis, system function analysis, systemic barrier analysis, and reflection on governance actions.

The *Methodology* describes the data collection methods used to analyze the case study, consisting of a policy document, event analysis, two workshops with a total of 39 participants, and 23 interviews with four sets of experts stemming from varying organizations. Through a thematic analysis, each stage of the MIS analysis was analyzed.

The *Results* section presents the findings of each stage of the MIS analysis. To summarize, it reveals three systemic barriers by connecting weakly fulfilled system functions with underlying structural components. The first barrier concerns the lack of development, diffusion, and adoption of knowledge. The second barrier concerns the lack of market formation, preventing innovations from scaling up. The last barrier concerns the lack of guidance and coordination. The last stage indicates that planned governance actions only partially address the barriers and provides recommendations for additional ones.

The *Discussion* advocates the MIS as a useful framework and provides insights for further development, including the importance of incorporating the effect of a multi-level governance structure and increased need for (policy) coordination on a mission's progress.

The *Conclusion* states additional governance actions might be required to target the root causes of the systemic barriers in order to aid the transition. Where there seems to be a need for more coordination, partially because decentralized governmental organizations struggle to implement and pursue national ambitions which hampers the mission's progress.

Preface

In the Netherlands, the mission has been formulated to transition to a circular economy by 2050. To monitor and evaluate the progress of this transition and to provide the government with the knowledge needed to design or adjust policies, a “Work Programme Monitoring and Steering Circular Economy 2019-2023” [Werkprogramma Monitoring en Sturing Circulaire Economie 2019-2023[1]] was established. As part of this work program, Utrecht University, commissioned by the PBL [Planbureau voor de Leefomgeving], conducts several MIS analyses of different sectors in the Netherlands. A MIS analysis was also carried out on the transition to a circular infrastructure sector in the Netherlands. The results of this research will be part of the Integrated Circular Economy Reporting 2023 [Integrale Circulaire Economie Rapportage (ICER)].

The MIS analysis of the infrastructure sector was conducted by Sanne Bours MSc under the supervision of Prof. Dr. Marko Hekkert. As part of my internship, I participated in this research. Part of the data collection, analysis, and results presented within this Master's thesis result from the MIS analysis conducted by Utrecht University. However, this study will focus more on the translation and implementation of national ambitions by regional and local governmental authorities, thereby providing an additional dimension to the analysis.

[1] https://www.pbl.nl/monitoring-circulaire-economie.

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1. Introduction

Pressing societal problems, including tackling climate change and improving public health, are changing innovation policy objectives (Mazzucato, 2016; Wanzenböck et al., 2020). These 'grand social challenges' (Mazzucato, 2018), are 'wicked' as they are complex, emergent, interconnected, urgent, and uncertain (Wanzenböck et al., 2020). To address them, the concept of 'missions' was introduced by Mazzucato (2016), where a societal challenge-based mission is defined as *"an urgent strategic goal that requires transformative systems change directed towards overcoming a wicked societal problem"* (Hekkert et al., 2020, p. 76). A mission sets a measurable, ambitious, and time-bound goal which requires an active role of policymakers to ensure coordinated action and legitimacy of both the problems and the diverse technological and non-technological innovative solutions which are required to complete a mission (Mazzucato, 2018; Hekkert et al., 2020; Wänzenbock et al., 2020). Mission-oriented Innovation Policy (MIP) has been regarded as a promising mean to formulate and implement such a goal-oriented strategy and direct innovation in pursuit of a mission (Mazzucato, 2016; Mazzucato, 2018; Hekkert et al, 2020).

Despite growing interest, scholars and policymakers struggle to successfully implement and monitor MIP in practice (Hekkert et al., 2020; Janssen et al., 2021; Larrue, 2021). Various innovation system concepts with different geographical and topical lenses have been developed to capture and describe innovation dynamics using a system perspective (Edquist, 1997; Malerba, 2002; Hekkert et al., 2007; Lundvall, 2007). Nevertheless, several scholars argue none of the existing innovation system perspectives suffice for studying the complexity and dynamics that arise in the presence of a mission (Hekkert et al., 2020; Wesseling & Meijerhof, 2020; Elzinga et al., 2021). Hekkert et al. (2020) argue a new analytical innovation system perspective is needed that takes into account the directionality provided by the formulation of a mission and the increased need for coordination. They proposed a new innovation system framework coined the Mission-oriented Innovation System (MIS). A 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). Analyzing a MIS can identify the strengths and weaknesses of the innovation system surrounding a mission. Understanding the underlying barriers or root causes of the weaknesses can in turn help to develop targeted governance actions to tackle a grand societal challenge (Wesseling & Meijerhof, 2020).

The Circular Economy (CE) has been proposed as a promising mean to contribute to several, interrelated, pressing grand societal challenges, including climate change and resource depletion (Murray et al., 2017; Geissdoerfer et al., 2017). Circularity has been receiving increased attention from academics and policymakers, influencing governmental and intergovernmental agencies (Blomsma & Brennan, 2017; Kern, Sharp & Hachmann, 2020). Within the European Union (EU), "An EU action plan for the Circular Economy" was presented in 2015, and a new edition in 2020 (EC, 2015 & 2020). Following the CE Action Plan, several member states developed CE initiatives, including The Netherlands. In 2016, the Dutch government set the clear mission for a 100% circular economy by 2050 (Rijksoverheid, 2016) which was reinforced by drawing up the "Raw Materials Agreement" [Grondstoffenakkoord] in 2017 (Rijksoverheid, 2017).

The Raw Materials Agreement has been signed by governmental organizations, businesses, and civil society organizations and contains measures to accelerate the transition to a circular economy (Rijksoverheid, 2017). To realize this envisioned transition, five Transition Agendas [Transitie Agenda's] were established which cover the most influential and impactful sectors, including the manufacturing, plastic, biomass and food, consumer goods, and construction sector (Transitieteam Bouw, 2018). The construction sector is an important sector to become circular (Joensuu et al., 2020) since it consumes an estimated 50% of all raw materials (EC, 2020), is responsible for a large part of all waste, and approximately 35% of CO_2 emissions in the Netherlands (Transitieteam Bouw, 2018). Part of the construction sector is the infrastructure sector. This study specifically considers traffic infrastructure, including roads, civil engineering structures, and waterways, further referred to as the infrastructure sector. The overall mission of the infrastructure sector is to be fully circular in 2050, with intermediate goals for 2030, including procuring 100% circular, reducing virgin resource consumption by 50%, and reducing CO_2 emissions by 50% (Transitieteam Bouw, 2018; Ministerie IenW, 2020).

The MIS concept is regarded as a promising framework to support policymakers when implementing a mission such as the mission towards a circular infrastructure sector. However, the first studies that rely on MIS thinking appeared only recently and three gaps within the literature have been identified. First, Wesseling and Meijerhof (2020) and Elzinga et al. (2021) both developed a theoretical understanding of typical MIS dynamics and proposed analytical steps for a MIS assessment framework, but emphasize that more empirical studies are necessary to identify the applicability of the MIS framework to different types of missions, especially considering that each mission is unique (Mazzucato, 2018; Janssen et al., 2021; Larrue, 2021). Therefore, this research adds to the literature by applying the MIS framework to the case of the transition to a circular infrastructure in The Netherlands. The MIS framework has been applied by Coenen, Volker, and Visscher (2021) to uncover micro dynamics in the transition process towards a circular infrastructure by studying a single trajectory of a circular infrastructure innovation in-depth, namely the Circular Viaduct. In contrast, this research represents a MIS analysis of the infrastructure sector as a whole allowing for reflection on MIS dynamics by taking into account the complexity that arises with different sets of interrelated technological and non-technological solutions.

Second, Elzinga et al. (2021) highlighted that it is questionable on which level a MIS should be assessed, suggesting it can be done at the aggregate system level, per type or cluster of complementary solutions, or per individual solution. Both Wesseling and Meijerhof (2020) and Elzinga et al. (2021) analyzed a MIS at the aggregate level. In contrast, this research analyzes the performance of the innovation system at the level of clusters of solutions.

Thirdly, there is insufficient knowledge on how different governance structures affect the implementation and pursuit of a mission. Within recent MIS literature, the prominent role for governance structures and coordination has been highlighted (Wesseling & Meijerhof, 2020; Janssen et al., 2021; Elzinga et al., 2021). Wesseling and Meijerhof (2020) portray the *mission arena* as the core of the MIS, which is defined as: "*the actors that are engaged in the highly political and often heavily contested process of mission governance*" (Wesseling & Meijerhof, 2020, p. 7). *Mission governance* is described as the process which aims to mobilize, direct and align existing system components, to legitimize, develop, diffuse and adopt innovative solutions towards achieving the mission (Wesseling & Meijerhof, 2020). All the measures contributing to mobilizing and aligning the MIS components are referred to as the *mission governance actions.* However, there is a lack of knowledge on how different compositions of mission arenas and their corresponding governance actions affect the mission's progress. Since the infrastructure sector is a public sector, where assets are generally purchased, owned, and financed by governmental organizations (Dominguez et al., 2009), this case represents an opportunity to uncover innovation dynamics when the mission arena is largely dominated by public actors.

To address the above-mentioned literature gaps, this research applied the MIS framework to map the innovation system, identify systemic barriers and the governance actions targeting those barriers within the MIS surrounding the transition towards a 100% circular infrastructure by 2050, thereby answering the research question:

“How do the ongoing and planned mission arena’s governance actions target the systemic barriers within the mission-oriented innovation system of the infrastructure sector?”

The mission to transition to a circular infrastructure sector has been formulated on a national level but must be pursued and implemented by national governmental authorities as well as regional and local governmental authorities (Wittman et al., 2021), which represents a multi-level governance structure (Marks et al, 1996; Stephenson, 2013). Within the literature, a lack of policy coordination across and between governmental levels has been marked as a failure that may hamper transition processes (Weber & Rohracher, 2012; Wanzenböck et al., 2020; Janssen et al., 2021), and possibly the successful completion of a mission. The influence of a multi-level governance structure on the implementation and progress of a mission has not yet been reviewed within existing MIS literature. Therefore, the following sub-question has been formulated:

"How is the mission to a 100% circular infrastructure sector implemented and coordinated at the regional and local level and how does that influence the mission's progress?"

By building upon the work of Elzinga et al. (2021) and largely following the MIS framework as set out by Wesseling and Meijerhof (2020) to answer the research question and sub-question, this research adds to the body of MIS literature. First, it applies the MIS framework to a new case study in which a large public actor is present. Within this respect, it reviews the effect of a multi-level governance structure on the implementation and coordination of a mission which helps to deepen the concept of the mission arena and the influence of its composition on the progress of the mission. Second, it provides a new dimension to the MIS framework by analyzing the performance of the innovation system at the level of clusters of solutions.

Besides the aforementioned theoretical contributions, this research bears societal relevance since it supports the identification of barriers that currently hinder the development and diffusion of innovations in pursuit of a circular infrastructure sector. The identified barriers can be used as starting point for MIS actors to design governance actions and policy interventions to address the root causes which can aid the transition. Furthermore, this research assesses the (planned) governance actions and articulates recommendations for complementary governance actions.

The remainder of this research is structured as follows: Section 2 introduces the theoretical framework by giving a short background of the literature on MIP and innovations systems. Additionally, the MIS is elaborated, building upon the foundations of Wesseling and Meijerhof (2020) and Elzinga et al., (2021). Section 3 introduces the CE and the case study. Thereafter, the methodology is outlined in Section 4. Section 5 presents the results of the analysis. The findings in relation to existing literature, directions for further research, and the limitations of this research will be discussed in Section 6. Finally, Section 7 provides a conclusion.

2. Theory

The theoretical framework used in this research is concentrated around the ‘Mission-oriented Innovation System’ (MIS). It will build on the work of Wesseling and Meijerhof (2020) and Elzinga et al. (2021) whom both studied innovation system dynamics in the presence of a mission and proposed a framework to assess the MIS. To understand the origins and dynamics of the MIS, background information regarding Mission-oriented Innovation Policy (MIP) and (Technological) Innovation Systems, is provided. Thereafter, the structural-functional approach to study a MIS as set out by Wesseling and Meijerhof (2020) is presented. Lastly, the concept of multi-level governance will be elaborated upon.

2.1. Mission-Oriented Innovation Policy (MIP)

Combatting the negative externalities arising from market failures with generic technology-neutral policies has been the core aim of innovation policy for many decades (Boekholt, 2010; Mazzucato 2016). From the nineties onwards, a second generation focused on national systems of innovation and strived to strengthen national innovation networks and competitiveness (Boekholt, 2010). Recently, a third generation of innovation policy arrived, aimed at overcoming so-called 'grand societal challenges' (Haddad et al., 2019), including climate change, aging, and security (Mazzucato, 2018; Wanzenböck et al., 2020). Some scholars describe this third-generation innovation policy as 'transformative innovation policy' (Diercks et al., 2019; Haddad et al., 2019), amongst other scholars and politicians it resulted in a renewed interest in 'Mission-oriented Innovation Policy' (MIP) (Mazzucato, 2016, 2018; Wanzenböck et al., 2020). Both are notions of societal challenge-led innovation policy and require transformative innovation policy, but the MIP distinguishes itself by providing directionality through ambitious, actionable, measurable, and time-bound goals, or ‘missions’ (Haddad et al., 2019; Wanzenböck et al., 2020). A MIP can be defined as:

> *A directional policy that starts from the perspective of a societal problem, and focuses on the formulation and implementation of a goal-oriented strategy by acknowledging the degree of wickedness of the underlying challenge, and the active role of policy in ensuring coordinated action and legitimacy of both problems and innovative solutions across multiple actors.* (Wanzenböck et al., 2020, p. 476)

2.2. (Technological) Innovation Systems

A MIP is considered instrumental in directing innovation to overcome societal challenges (Mazzucato, 2018; Wanzenböck et al., 2020). To evaluate a MIP, it is crucial to understand the factors contributing to the development and diffusion of innovations. To capture and describe these innovation dynamics, the concept of innovation systems was introduced by Freeman (1987) who defined it as "*the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies*" (p. 1). Understanding and assessing the make-up of an innovation system is critical for the success of innovations since it aids the development and implementation of interventions and policy designs that support the successful development and diffusion of innovations (Bergek et al., 2008; Hekkert et al., 2020). Over the years, the concept of innovation systems developed, and several different perspectives have been introduced. Some scholars adopted a geographical lens, considering the innovation system from a national or regional perspective (Edquist, 1997; Lundvall, 2007). Others developed a topical perspective, including the sectoral (Malerba, 2002) or technological perspective (Hekkert et al., 2007; Hekkert & Negro, 2009).

The Technological Innovation System (TIS) was introduced to understand and map the dynamics and processes of an innovation system dominated by a specific technology (Hekkert et al., 2007; Bergek et al., 2008). The TIS framework analyses the structural dimensions that make up the innovation system whilst evaluating the processes that support or hamper the development of innovation (Hekkert et al., 2007). The most important processes in a TIS are labelled 'functions of innovation systems' (Hekkert et al., 2007; Hekkert & Negro, 2009; Bergek et al., 2008). When system functions are sufficiently present and aligned, it results in a well-functioning system that aids the diffusion and embedding of a technology (Hekkert & Negro, 2009; Jacobsson & Bergek, 2011). Functions can be studied over time to provide insight into the dynamics of the innovation system (Hekkert et al., 2007; Suurs & Hekkert, 2009). Subsequently, these insights can inform policymakers to design policies and interventions to stimulate weak functions or remove blocking mechanisms (Hekkert et al., 2007).

Although the TIS is a good framework to evaluate and influence the speed and direction of technological innovation, it has several shortcomings when aiming to understand the dynamics that arise when missions are formulated (Wesseling & Meijerhof, 2020; Elzinga et al., 2021). For example, societal missions aim to address a wicked problem that requires the development of technological as well as non-technological innovations (Hekkert et al., 2020) where various solutions can diverge and conflict, resulting in high contestation within the innovation system (Wanzenböck et al., 2020). Relatedly, increased coordination by actors in the innovation system is required to deal with the strong problem directionality generated by the mission and the presence of multiple solution directions (Hekkert et al., 2020; Wesseling & Meijerhof, 2020). The TIS framework is less suitable to deal with a large variety of competing solutions and does not capture the important role of coordination (Elzinga et al., 2021). Therefore, Hekkert et al. (2020) proposed the Mission-oriented Innovation System (MIS).

2.3. Mission-Oriented Innovation Systems

The MIS perspective has emerged as a promising framework to understand and intervene in the innovation dynamics related to prioritizing and solving a societal challenge-led mission, but the first studies relying upon MIS thinking appeared only recently. By building upon the TIS, Elzinga et al. (2021) compared three case studies related to the Dutch circular economy, they identified various MIS dynamics and proposed three central steps to capture and assess these dynamics. Simultaneously, Wesseling and Meijerhof (2020) identified several challenges that arise when analyzing a mission that needs to be taken into account when reviewing a MIS. Building upon the existing structural-functional approach for studying a TIS (Hekkert et al., 2007; Bergek et al., 2008), Wesseling and Meijerhof (2020) developed a framework for analyzing a MIS, consisting of five analytical steps, where the first three steps correspond to the steps proposed by Elzinga et al. (2021). The five analytical steps are as follows:

2.3.1. Problem-solution diagnosis

The first step is mapping out the full scope and complexity of the mission, including the problem(s) a mission aims to tackle and the solutions that are deemed viable, necessary, and legitimate to do so (Wesseling & Meijerhof, 2020; Elzinga et al., 2021). A key characteristic of a mission is that it provides directionality, therefore, assessing both the 'problem directionality' and 'solution directionality' is important (Wesseling & Meijerhof, 2020). Different societal problems can 'compete' over legitimacy and resources (Alford & Head, 2017; Wanzenböck et al., 2020). Problem directionality refers to the way different societal problems are included and prioritized in the mission formulation (Wesseling & Meijerhof, 2020) which is important since the legitimacy of the societal challenge itself can accelerate the achievement of the mission (Wänzenbock et al., 2020).

The directionality affects what solutions are deemed relevant for the mission which is referred to as 'solution directionality' (Wesseling & Meijerhof, 2020; Elzinga et al., 2021). Different solution directions are legitimized through different rationales and logics; understanding and mapping these can explain contestation and competition between solution directions (Elzinga et al., 2021). The interaction between solutions can be characterized by a symbiotic, neutral, or competitive relationship which has been defined by Sandén and Hillman (2011) as elaborated in Table 1.

Table 1. Interactions between two different (sets) of solutions based on Sandén & Hillman (2011)

Mode of interaction	Solution 1	Solution 2	General nature of the interaction
Competition	-	-	Solutions compete over common markets and resources, and/or about attention, support and legitimacy
Symbiosis	+	+	Interaction favourable to both; solutions may be depended on each other or complement each other
Neutralism	0	0	Neither solution affects the other; when two solutions deliver different services and use different resources (no overlap)

2.3.2. Structural analysis

Analyzing and understanding the structural components of the MIS, including the number, and type of actors, institutions, and networks, which are thought to influence the formation, structuration, and completion of a mission, either as supporters or as opponents is crucial (Elzinga et al., 2021). The definitions and subcategories of the structural components are elaborated in Table 2. The important role of the governance structure and the coordination processes actors use to influence and direct a mission has been highlighted in recent works where Janssen et al. (2021) introduced the term *programming level* and Wesseling and Meijerhof (2020) portrayed the *mission arena* as the core of the MIS. This research will use the term mission arena, as defined in the Introduction (Section 1). Wesseling and Meijerhof (2020) argue that the arena actors have four tasks: "*(1) involving stakeholders in the arena, (2) formulating a mission goal, (3) committing to mission governance actions to mobilize the overall MIS, and (4) engaging in reflexive governance*." (p. 20). Overall, the actors and networks present in the mission arena have the ability to guide the directionality and influence the speed of the transition.

Table 2. The structural components of an MIS are based upon the definitions of Suurs (2009) and Musiolik et al., (2012), and the subcategories of Wieczorek and Hekkert (2012).

Structural dimension	Definition	Subcategory
Actors	Any organizations contributing (with its knowledge and competencies) to the formulation of the problem(s) and mission, and/or the development, diffusion and use of technical- and social innovations that contribute to the completion of the mission, either directly as developer or adopter, or indirectly as a regulator, financer, etc.	• Civil society • Companies: start-ups, SMEs, large firms, multinational companies • Knowledge institutes: universities, technology institutes, research centers, schools • Government • NGOs • Other parties: legal organizations, financial organizations, intermediaries, consultants
Institutions	The humanly devised constraints or 'rules of the game' that structure political, economic and social interaction.	• Hard: rules, laws, regulations, instructions, technology standards • Soft: customs, common habits, routines, established practices, traditions, ways of conduct, norms, expectations
Networks	The structures that facilitate the exchange of information, knowledge and other resources between actors or between and within organizational structure(s)	• Informal: between actors • Formal: organizational structure(s) with clearly identifiable members

Successful completion of a mission depends on a larger number of actors that are not necessarily present in the mission arena but who are developing and adopting innovative solutions and transforming existing practices; these actors are active in the *overall MIS* (Wesseling & Meijerhof, 2020), also called *MIS' performance level* (Elzinga et al., 2021). Although there are no clear heuristics regarding the most preferable composition of the mission arena and overall MIS, mapping the structural components of the MIS can reveal the role and influence of the mission arena in relation to the overall MIS and how this affects the overall functioning of the MIS (Wesseling & Meijerhof, 2020; Elzinga et al., 2021).

2.3.3. System functions analysis

System functions were introduced by Hekkert et al. (2007) and Bergek et al. (2008) to study 'key innovation activities' in the TIS. They help to identify bottlenecks in an innovation system as they represent the processes and activities that contribute to the development, diffusion, and use of innovations, thereby influencing the build-up of an innovation system (Hekkert et al., 2007; Elzinga et al., 2021). Functions may be fulfilled in a variety of ways, where activities can positively or negatively contribute to the development of an innovation system (Suurs & Hekkert, 2009). For proper development of the MIS, all functions should be positively fulfilled and aligned.

The system functions were modified by Wesseling and Meijerhof (2020) and Elzinga et al. (2021) to reflect system dynamics that arise in the presence of a mission. Since the mission and actors in the mission arena aim to influence both the problem directionality (SF4a) as well as the solution directionality (SF4b) these functions replace the original function of 'guidance of the search' (Wesseling & Meijerhof, 2020; Elzinga et al., 2021). In addition, the function 'reflexive governance' (SF4c) was added by Wesseling and Meijerhof (2020) and Elzinga et al. (2021). Reflexive governance represents the necessity to anticipate, assess, and react to (sometimes unintended) mission dynamics, and to respond to them by reformulating the mission or redirecting the solution directionality or policies needed to accomplish the mission (Wesseling & Meijerhof, 2020; Elzinga et al., 2021). However, within this research, the function 'reflexive governance' (SF4c) is replaced with the function 'coordination' (SF8). Coordination includes reflexive governance but is more broadly defined to also encompass the configuration needed between the actors and networks in pursuit of a mission (Weber & Rohracher, 2012). Moreover, 'reflexive governance' does not reflect the coordination across policy domains and levels, also referred to as *policy coordination* (see Section 2.4.), which is required for the successful implementation of a MIP (Weber & Rohracher, 2012; Wanzenböck et al., 2020; Janssen et al., 2021). Since this research will examine the effect of the multi-level governance structure on the implementation and governance of the mission, as will be elaborated upon in Section 2.4., this study will assess the addition of a system function more prominently considering coordination dynamics.

Besides new functions, destabilization and phasing out of 'old' activities are key in the functioning of the MIS (Wesseling & Meijerhof, 2020). Destabilization can be described as the process of weakening the reproduction of core regime elements which gives room for innovations and new processes and can aid sustainable transitions (Turnheim & Geels, 2012). Destabilizing activities have been added as a counterpart to existing functions of the TIS (Wesseling & Meijerhof, 2020; Elzinga et al., 2021). An overview of the functions adapted to the MIS is represented in Table 3.

Table 3. Description of system functions, tailored to the MIS-analysis. Based on the work of Wesseling and Meijerhof (2020) and Elzinga et al. (2021).

System Function	MIS interpretation
SF1: Entrepreneurial experimentation, upscaling and business model phase-out	Experiments to develop technological and non-technological solutions; enable learning, experimenting with business model innovations, building production capacity, and upscaling new business models to foster the

	diffusion of solutions. Including, the phase-out of existing business models that obstruct mission completion
SF2: Knowledge development and unlearning	Learning by searching and by 'doing', resulting in the development and a better understanding of new technical and social knowledge on problems and to develop solutions, through R&D, social research and behavioral science research, while phasing out knowledge development projects, research centers and networks that are obstructing mission completion
SF3: (Withholding) Knowledge diffusion	Actions aimed at disseminating technical and social knowledge on mission solutions between (groups of) actors like stakeholder meetings, conferences, public consultations and mission progress reports, while phasing out knowledge exchange processes that are obstructing mission completion
SF4a: Problem directionality	Actions aimed at creating consensus regarding the conception of the societal problem, the urgency of the focal mission and the level of prioritization over other societal problems
SF4b: Solution directionality	Actions aimed at providing direction to the search for new and further development of existing technological and social solutions, as well as the coordination efforts needed to identify, select and exploit synergetic sets of solutions to the mission with the goal to ultimately converge around solution directions
SF5: Market formation and destabilization	The creation of (niche) markets and upscaling support for technical and social solutions, while diminishing support and destabilizing markets for existing practices that obstruct mission completion
SF6: Resources (re)allocation	Mobilizing financial, human, material, and infrastructural resources to support the development and diffusion of solutions to the mission and enable all other system functions while withdrawing resources allocated to practices that obstruct mission completion.
SF7: Creation and withdrawal of legitimacy	Creation of legitimacy for prioritizing the problem and a supportive socio-institutional environment to develop solutions that contribute to mission completion lobbying for resources and supportive policies in line with the mission and by lobbying for the reduction of support and phase-out of practices that obstruct mission completion.
SF8: Coordination	Coordination efforts to steer and align the various initiatives and actors over the different solution pathways as well as (policy) coordination within and across different levels of government. In addition, monitoring and reflexive governance to redirect the system are included.

2.3.4. Systemic barriers analysis

The fourth stage of the framework analyses the weakly or negatively fulfilled functions of a MIS which can hamper the functioning of the overall system. Within the literature, different terms have been used to indicate problems in innovations systems, including blocking mechanisms (Jacobsson & Johnson, 2000; Bergek et al., 2008; Kieft et al., 2017), system failures (Weber & Rohracher, 2012), and systemic problems (Wieczorek & Hekkert, 2012). Kieft et al. (2017), use the term 'blocking mechanism' to indicate that systemic problems interact with each other resulting in a collective blocking mechanism instead of treating the concept of a 'blocking mechanism' as a separate factor as has been done by Bergek et al. (2008) and Jacobsson and Johnson (2000). Although there are differences in interpretation, all terms stipulate that system functions interact with each other and that the root cause for the absence or weak fulfillment of a function can often be traced back to the structure of the innovation system (Bergek et al., 2008; Weber & Rohracher, 2012; Wieczorek & Hekkert, 2012).

To identify the interplay between weakly fulfilled system functions and structural elements, the term ‘systemic barrier’ will be used within this research, in line with Wesseling and Meijerhof (2020). Thereby taken into account that systemic barriers are part of a complex interconnected network consisting of feedback loops and potential lock-ins, representing the notion of ‘blocking mechanisms’ as defined by Kieft et al. (2017).

2.3.5. Reflection on (planned) governance actions on the overall functioning of the MIS

The final stage of the MIS analysis consists of identifying governance actions that are or can be used to address the systemic barriers as identified in the previous phase. Since systemic barriers consist of a network of systemic problems, it may be more fruitful to design policy interventions that target the underlying problems instead of all problems separately (Kieft et al., 2017). Hence, *mission governance actions* undertaken by the actors in the mission arena should target the root causes of systemic barriers (Wesseling & van der Vooren, 2017) to effectively enhance the functioning of the entire MIS. Wesseling and Meijerhof (2020) start the reflection on planned governance actions from the perspective that a MIS is already engaged in various innovation activities and additional actions should focus on resolving the remaining MIS barriers. Consequently, MIS barriers should be compared to existing or planned governance actions to assess whether all barriers are adequately targeted (Wesseling & Meijerhof, 2020). Recommendations for (additional) governance actions follow for the MIS barriers that are currently not addressed or that may unintentionally be reinforced.

2.4. Multi-level governance

The mission to reach a circular economy, including a circular infrastructure sector, by 2050 has been formulated on a national level, but must be implemented and pursued at all governmental levels. According to Wittman et al. (2021), mission goals should be translated into a specific set of policies where this translation process is usually located at a lower level of government. Within the Netherlands, decision-making responsibilities are shared between national, provincial, and local authorities, including water authorities and municipalities, representing a multi-level governance structure. The term ‘multi-level governance’ was first developed as a conceptual framework to recognize the different roles played by various actors in the European policy context (Marks et al, 1996; Stephenson, 2013). Multi-level governance implies dispersion of policy-making activity and geographical separation but, simultaneously, interdependencies and connections between the different levels (Stephenson, 2013).

As stipulated in section 2.3.3., within the literature related to MIP, a lack of *policy coordination* across and between governmental levels has been marked as a failure that may hamper transition processes, and thereby possibly the successful implementation of a MIP (Weber & Rohracher, 2012; Wanzenböck et al., 2020; Janssen et al., 2021). Challis et al. (1988), broadly portray policy coordination as “*a pursuit of coherence, consistency, comprehensiveness and of harmonious compatible outcomes”* (p. 172). Policy coordination may be difficult due to shared decision-making competencies which result in a variety of policies, instruments, actors, and arenas (Kaiser & Prange, 2007). Moreover, it may be complicated due to variations among regions in terms of budgetary power, capacity, and competencies (Kaiser & Prange, 2007). Nevertheless, policy coordination is required to safeguard the consistency and coherence of the mix of policy instruments (Rogge & Reichardt, 2016; Howlett & Rayner, 2008). Bridging organizations, or the networks within an innovation system, are important according to various authors (e.g. Aranguren, Larrea, & Wilson, 2010; Johannessen & Hahn, 2013; Reed et al., 2014) to facilitate and mediate between different governance levels in order to support networking and cooperation.

This research will review the impact of the multi-level governance structure of governmental organizations within the Netherlands on the progress of the mission and the resulting need for coordination for effective translation and implementation of the mission to reach a circular infrastructure in 2050.

3. Background

This section provides background information of the case study, starting with an introduction of the CE, followed by an introduction to the infrastructure sector, including the scope of the research

3.1. The circular economy

The CE has been proposed as a promising mean to mitigate the negative effects of societies' current linear take-make-dispose practices by closing the loop or 'replacing the end-of-life' (EMF, 2013; Geissdoerfer et al., 2017). A CE can contribute to reducing several, interrelated, environmental and socio-economic effects. Within the Netherlands, the "Planbureau voor de leefomgeving" (PBL) [Environmental Assessment Agency] stipulates that a CE could contribute to four societal problems: 1) Combating climate change; 2) Reducing biodiversity loss; 3) Combating pollution of air, water and soil; 4) Reducing supply risk of raw materials (Hanemaaijer et al., 2021).

The concept of a CE has been gaining momentum since the late 1970s and it incorporates different features from a variety of concepts that share the idea of closed loops, including regenerative designs, performance economy, Cradle-to-Cradle, industrial ecology, and biomimicry (EMF, 2013; Geissdoerfer et al., 2017). CE has been considered an umbrella term (Blomsma & Brennan, 2017) since it is a broad concept encompassing multiple phenomena. After reviewing 114 definitions of a CE, Kirchherr, Reike, and Hekkert (2017) concluded that the definition remains ambiguous[2]. Nevertheless, the CE is frequently depicted as a way to replace the 'end-of-life' by keeping values in the loop for longer (EMF, 2013), through a combination of reduce, reuse and recycle activities, the so-called R strategies as depicted in Table 4 (Kirchherr et al., 2017; Reike et al., 2018). In general, the R strategies at the top require more systemic change, while strategies at the bottom are primarily technologically oriented (Elzinga et al., 2021). Explicating the hierarchy in R strategies is crucial to provide guidance and to ensure not only the easier strategies, like recycling, are adopted by firms and governments which could result in the continuation of unsustainable business-as-usual practices (Kirchherr et al., 2017; Reike et al., 2018).

Table 4. R-strategies from Kirccherr et al. (2017) combined with the R-strategies defined by PBL (Hanemaaijer, et al., 2021)

Strategies		**Strategies by PBL**
R0 Refuse	Make products redundant by abandoning their function or by offering the same function with a radically different product	**Narrow the loop**
R1 Rethink	Make product use more intensive (e.g., sharing a product)	
R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials	

[2] After analyzing 114 definitions, Kirchherr et al. (2017) defined a CE as "*an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers.*" (p.229)

R3 Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function	Slow the loop
R4 Repair	Repair and maintenance of defective product so it can be used with its original function	
R5 Refurbish	Restore an old product and bring it up to date	
R6 Remanufacture	Use parts of discarded products in a new product with the same function	
R7 Repurpose	Use discarded products or parts in a new product with a different function	
R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality	Close the loop
R9 Recover	Incinerations of material with energy recovery	

Within the Netherlands, PBL [Planbureau voor de Leefomgeving] has formulated four solution directions that can contribute to a circular economy (Hanemaaijer et al., 2021). Three out of four solution directions correspond to the R-strategies, as exemplified in Table 4. Moreover, PBL added a fourth solution direction, named substitution. The four solution directions will be used to guide this analysis, and the definitions are as follows (Hanemaaijer et al., 2021):

1. **Narrow the loop**: using fewer materials by forgoing products (Refuse), sharing products (Rethink), or manufacturing them more efficiently (Reduce)
2. **Slow the loop**: longer and more intensive use of products and parts through reuse (including Reuse, Remanufacturing, and Repurpose) and repair (including Repair and Refurbish); this slows down the demand for new raw materials
3. **Close the loop**: by recycling materials (Recycle), so less waste is incinerated or landfilled and fewer new raw materials are needed.
4. **Substitution** of finite raw materials by renewable raw materials (such as bio-based raw materials) or alternative primary raw materials with less environmental impact

Circularity has been receiving increased attention from academics and policymakers, where the conceptual development of the CE within the EU has been largely influenced by the Ellen MacArthur Foundation (Geissdoerfer et al., 2017; Kirchherr et al, 2017; Kern et al., 2020). In 2012, the CE became the central label in policy (Kern et al., 2020) after which the EU action plan for a CE followed in 2015 and in 2020 (EC, 2015 & 2020). The Netherlands responded to the call for action of the EU by setting the mission to reach a 100% circular economy by 2050 (Rijksoverheid, 2016) which has been reinforced with the “Raw Materials Agreement" [Grondstoffenakkoord] in 2017. The Raw Materials Agreement contains measures to accelerate to the transition to a CE, including the drafting of the five Transition Agendas (Rijksoverheid, 2017). In 2018, the Transition Agendas were established for the most influential and impactful sectors, including the construction sector (Transitieteam Bouw, 2018).

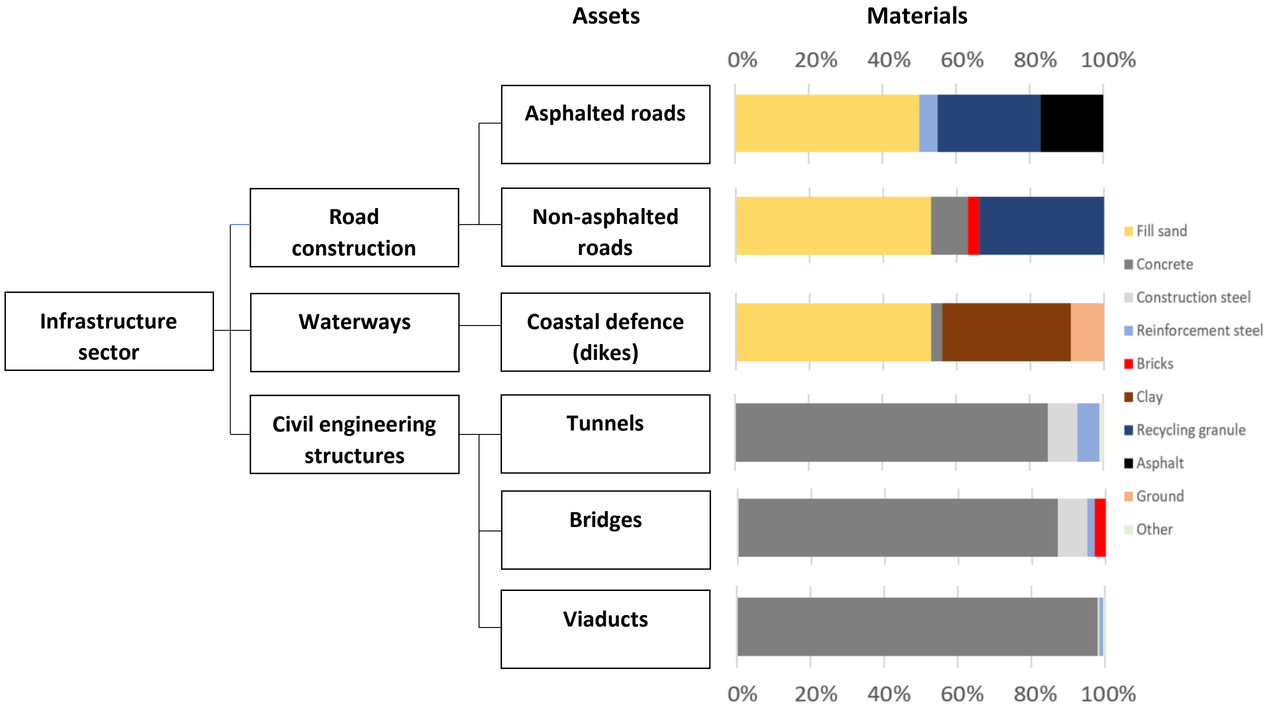
3.2. The infrastructure sector

The construction sector is an important sector to become circular given the intensive consumption of 50% of all raw materials (EC, 2020), 40% of the total energy consumption, and 30% of the total water consumption per year in the Netherlands (Transitieteam Bouw, 2018; Joensuu et al., 2020). Within the Netherlands, the construction sector is subdivided into civil & non-residential construction [Bouw & Utiliteitsbouw], and the infrastructure sector [Grond-, Weg-, en Waterbouw]. This research focuses on circularity within the infrastructure sector.

Within the literature, infrastructure is a terminology used for facilities in the field of transport and communication, including roads, bridges, tunnels, railway lines, airports, electricity and power, and telecommunication. This study specifically considers traffic infrastructure, including roads, civil engineering structures, and waterways, further referred to as the infrastructure sector. The railway sector is out of scope since the scope of this research was determined by taking into consideration 1) the types of work with the greatest impact (considering CO2 emissions and material use) and 2) work types that are comparable to each other in terms of actors and institutions. Regarding the former, the railway sector causes less CO2 emissions compared to the infrastructure sector; the greatest number of emissions is caused during the production of materials for road pavement and civil engineering works and by the transport required in shoreline care and channel maintenance (KCI, 2020; EIB & Metabolic, 2022). Moreover, most primary materials are used in sand and soil movement in coastal defense and for road construction and maintenance (EIB & Metabolic, 2022). Regarding the latter, railways are produced with other materials by different actors, including ProRail. Since ProRail is the only public commissioner for railways, the dynamics in the railway sector are different, making a comparison with the infrastructure sector difficult. Concluding, this study places the boundaries of the infrastructure sector at road construction, civil engineering structures, and waterways.

Within the infrastructure sector, various types of assets are realized, including dikes, bridges, canals, tunnels, bridges, viaducts, and asphalted and non-asphalted roads, as demonstrated in Figure 1. An overview of the acreage within the infrastructure sector at the different governmental levels can be found in Appendix I. For realizing the various types of assets, different materials are used; an overview of the material flows and stock can be found in Appendix II. The most common materials used in terms of mass are soil, sand and clay, concrete, asphalt, and steel (EIB & Metabolic, 2022; Rijkswaterstaat, 2022). In addition, wood is considered to be an important material for the transition towards circularity (Rijkswaterstaat, 2022). Therefore, soil, sand and clay, concrete, asphalt, steel, and wood were the main materials considered in this research.

Figure 1. Scope of the infrastructure sector, including the assets and materials used.



4. Method

This Section outlines the research design and the data collection methods used, followed by the data analysis and operationalization. Lastly, the reliability and validity of the research are discussed.

4.1. Research design

A qualitative case study approach is taken, applying the MIS framework by largely following the structural-functional approach of Wesseling and Meijerhof (2020), as set out in Section 2, to answer the main research question of how the ongoing and planned mission governance actions target the systemic barriers within the mission to transition to a 'circular infrastructure in 2050' in The Netherlands (Transitieteam Bouw, 2018). Thereby taking into account the implementation and coordination between and across the multi-levels of governmental organizations, including provinces, municipalities, and water authorities, to answer the sub-question. The stages of the MIS analysis were slightly adapted. The problem-solution diagnosis and structural analysis were performed rather simultaneously. However, the results of the structural analysis were broken down first, followed by the problem-solution diagnosis, since the outcomes of the structural diagnosis contribute to, and are necessary to understand, the results of the problem-solution diagnosis.

To guide the analysis, diagnostic questions for each stage were formulated, based on Wesseling and Meijerhof (2020). An overview of the main research question, sub-question, and diagnostic questions can be found in Table 5.

Table 5. Research question and sub-questions per stage of the MIS-analysis, based on the structural-functional approach and diagnostic question of Wesseling and Meijerhof (2020)

Main research question	1.	How do the ongoing and planned mission arena's governance actions target the systemic barriers within the mission-oriented innovation system of the infrastructure sector?
Sub-question	2.	How is the mission to a 100% circular infrastructure sector implemented and coordinated at the regional and local level and how does that influence the missions progress?
Stage of MIS-analysis	**Diagnostic questions**	
Structural analysis	a)	What actors, networks, institutions and materiality shape and influence the mission innovation system?
	b)	What actors, networks, institutions and materiality are part of the mission arena thereby contributing to the mission formulation, mobilizing other MIS components and (reflexive) governance of the mission?
Problem-solution diagnosis	c)	How do different societal problems and 'wants' relate to the mission of a circular infrastructure?
	d)	What (technical and behavioral) solutions are being developed to contribute to the mission?
System function analysis	e)	How are the systemic functions fulfilled?
Systemic barriers analysis	f)	What are the underlying root causes of the weakly fulfilled system functions?
Reflection on (planned) governance actions	g)	What are the ongoing and planned governance actions (of the mission arena) and how do they target the (root causes) of the systemic barriers?
	h)	What complementary governance actions are necessary in pursuit of the mission?

To answer the aforementioned questions, several research methods were used. First, desktop research, consisting of a policy document analysis and an event analysis, was conducted. This served as the starting point of the MIS analysis. To verify, deepen and supplement the results of the desktop research, two workshops were organized, and in total 23 interviews were conducted consisting of four sets of experts on different topics and from varying organizations. In total 52 different people participated in the workshops or have been interviewed, of whom some have been consulted on multiple occasions. An overview of the research methods used and to which stage they (mainly) contributed can be found in Table 6. Moreover, Table 6 provides an overview of the participants of the workshops and the interviewees which are described in more detail in Appendix III. Part of the data collection and analysis has been done in collaboration with Sanne Bours MSc and also served for the MIS-analysis of the infrastructure sector carried out by Utrecht University, of which I was part.

Table 6. Summary of the research methods and participants of the workshops and interviewees

Category	Code	Number	Contributed (mainly) to question
Desktop analysis			
Policy document analysis			1, 2, a, b, c, g
Event analysis			1, 2, a, b, d, e, g
Workshop 1: Problem-solution diagnosis			a, b
- Governmental organization	G	13	
- Industry association	I	3	
- Engineering and consultancy firm	E	2	
- Contractor	C	1	
- Knowledge institute	K	1	
Workshop 2: Circular design, reuse and recycling			1, 2, d, e, f, g, h
- Governmental organization	G	8	
- Industry association	I	2	
- Engineering and consultancy firm	E	3	
- Contractor	C	6	
Interviews experts reuse			1, 2, d, e, f, g, h
- Governmental organization	G	2	
Interview expert recycling			
- Industry association recycling	I	1	1, d, e, f
Interviews experts' substitution			1, 2, d, e, f, g, h
- Governmental organization	G	2	
- Engineering and consultancy firm	E	2	
- Knowledge institute	K	1	
- Entrepreneur	O	3	
Interviews decentralized governmental organizations			1, 2, b, c, e, f, g, h
- Advisor municipalities and provinces	A	5	
- Municipality	M	4	
- Province	P	2	
- Water authorities	W	1	

4.2. Data collection

4.2.1. Desktop research

The desktop research served as a point of departure for the MIS analysis. First, policy documents regarding the transition towards a circular infrastructure were gathered. The Transition Agenda (TA) of the construction industry (Transitieteam Bouw, 2018) served as a starting point. Thereafter, other agendas, agreements, and roadmaps, formulated on different governmental levels, were collected if they related to the infrastructure sector and a circular economy. An overview of these documents can be found in Appendix IV. In total 29 policy documents, agendas and agreements were collected.

In addition, an 'history event analysis' has been constructed in Excel using multiple sources consisting of events related to the transition to a circular infrastructure sector. A history event analysis was proposed as a method to systematically map processes taking place in innovation systems (Hekkert et al., 2007; Suurs & Hekkert, 2009) where events are defined "*as an instance of change with respect to* *actors, institutions and/or technology which is the work of one or more actors and which carries some public importance with respect to the TIS under investigation"* (Suurs & Hekkert, 2009, p. 1006). Events can stem from multiple sources and can relate to amongst others, pilot projects, research projects, a publication, expressions of expectations about technologies or discourses, announcements of resources made available, or changes in regulations (Hekkert et al., 2007). This research applied the method of a history event analysis to map processes within the MIS surrounding the infrastructure sector but it did not review the order of the events as the mission was only set recently. Three databases, made available by RVO and Rijkswaterstaat, served as the starting point for the event analysis:

1. RVO database consisting of 57 circular (pilot)projects that received a grand between 2014 and 2021.
2. RWS database 1 in which 200 Circular Economy initiatives between 2016 and 2021 were broken down per region in the Netherlands. Examples are projects in which circular solutions were implemented, tenders using circular criteria, or research reports.
3. RWS database 2 consisting of events collected by a group of experts from Rijkswaterstaat. Consisting amongst others of policy documents, agreements, (pilot)projects, websites of branch organizations and networks (such as Bouwcirculair, Platform CB'23, Cirkelstad, and Platform WOW), manuals, legislation, agreements, and (news)articles related to the infrastructure sector (from websites such as Cobouw, PIANOo, and CROW).

These databases served as input for the rest of the event analysis, thereby framing the selection of events for this research. In the end, the event analysis resulted in a selection of over 800 events between 2014 and March 2022.

4.2.2. Workshops

To complement the desktop research, two workshops were organized, in collaboration with Prof. Dr. Marko Hekkert and Sanne Bours MSc, both serving different purposes. Workshops can be used as research methodology specifically designed to fulfill a research purpose to produce reliable and valid data (Ørngreen & Levinsen, 2017). Within this research, Workshop 1 was organized to contribute to the problem-solution diagnosis. Results from the desktop research were used to design the structure and questions of the workshop, which can be found in Appendix V. The workshop was structured alongside three components: 1) the problems to which a circular infrastructure sector can contribute; 2) the mission/ambitions/goals that have been formulated; 3) the solution (directions) in pursuit of the mission. The problem and solution directions articulated by PBL as explained in Section 3, were taken as starting point. For each component, respondents were asked several open- and closed questions that they could answer via Mentimeter. After each question followed a discussion which provided more in-depth information regarding the underlying reasoning for the answers provided.

Workshop 1 was organized online on the 8th of February 2022 and lasted for 1.5 hours. In total, 20 people participated stemming from various organizations, including governmental organizations, branch organizations, engineers, and consultancy firms. Although it was important that the respondents provided a good reflection of the various actor groups in the sector, the vast majority of participants stemmed from a governmental organization, and mainly from Rijkswaterstaat. This bias was overcome by conducting interviews with actors from decentral governmental organizations which will be elaborated upon in Section 3.3.3. The workshop was recorded after informed consent and notes were taken during the workshop.

Besides workshop 1, workshop 2 was organized. Workshop 2 was a live workshop, organized on the 5th of April 2022 and lasted for 4 hours. In total, 19 people participated as summarized in Table 5. The scope of Workshop 2 was, due to time constraints, reduced to two solution directions: narrow the loop and close the loop. The workshop was structured alongside the systemic functions, as described in Section 2.3.3. First, the fulfillment and the barriers experienced for each function were discussed for the solution directionality close the loop. Next, governance actions that can contribute to overcoming the barriers were discussed. Thereafter, participants were asked what the main differences were between close and slow the loop regarding the fulfillment of the functions and barriers experienced. The workshop was recorded after informed consent and notes were taken during the workshop.

After workshop 2, the participants received an email with a form in which they were asked to indicate on a Likert-scale to what extent the (possible) lack of a function was regarded as a barrier where 1 was not problematic and 5 was very problematic, for close and narrow the loop separately. The form can be found in Appendix VI (Appendix VII for the English translation). In total, 12 out of the 19 respondents filled in the form.

4.2.3. Interviews

In addition to workshop 2, two interviews were conducted by Sanne Bours with experts regarding reuse, and one interview was conducted by myself with an expert regarding recycling. Moreover, since workshop 1 mainly covered the problem-solution diagnosis and workshop 2 focused on two out of four solution directions, interviews with experts on substitution have been conducted. A purposively selected group of actors (Campbell et al., 2020), with varying experiences and perspectives on the transition but all with expertise in substitution was interviewed. In total eight interviews were conducted in April 2022 (Table 5). Sanne Bours conducted five interviews and I conducted the remaining three. The interviews followed a semi-structured format (Bryman, 2012). An overview of the Dutch interview guide can be found in Appendix VIII which indicates for each question to which part of the MIS analysis it contributed (Appendix IX for the English translation). Interviewees were asked to indicate how problematic the (possible) lack of each system function is according to a 1 to 5 Likert-scale for the solution directionality substitution (1 was not problematic and 5 is very problematic). The rationale behind the score was discussed as well as the barriers encountered to gain more in-depth information. Lastly, governance actions that could contribute to overcoming these barriers were discussed.

Besides the interviews with experts regarding substitution, interviews were conducted with advisors of and people working for different decentralized governmental organizations stemming from various regions within the Netherlands. The sample was again selected using purposive sampling (Campbell et al., 2020), ensuring a good reflection of both the different decentral governmental levels (provinces, municipalities, water authorities) as well as a geographical spread within the Netherlands. An overview of the interviewees can be found in Table 5 and is elaborated upon in Appendix III. In total, 12 semi-structured interviews (Bryman, 2012) have been conducted in May 2022 by myself. See Appendix X for an overview of the Dutch interview guide (Appendix XI for the English translation). Questions related to the ambitions formulated on a decentral level, the priority circular ambitions receive, the main barriers experienced when implementing circular ambitions, and the governance actions necessary to overcome these barriers. Specific attention was paid to the coordination between the different levels of government. Conducting these interviews and taking into account the different levels of government added an expansion and deepening to the research in comparison to the MIS analysis conducted in cooperation with Sanne Bours for Utrecht University.

All interviews were conducted online via Teams in Dutch, as this is the native language of both the interviewees and the interviewer. This enabled cultural expression and avoided errors of misinterpretation (Becker & Geer, 1957). The interviews had an average length of 55 minutes. The audio was recorded after informed consent and transcribed afterward, using Amberscript, resulting in over 400 pages of interview transcriptions. By complete transcription of the recorded audio, the most accurate data was produced for further analysis (Heritage, 1984

4.3. Data analysis

Here a brief description of the analysis of the event analysis and data from the workshops and interviews will be provided, before discussing how each MIS-stage was operationalized.

4.3.1. Event analysis

Utilizing Excel, for each event, a short description was provided whereafter they were coded under which discipline (general, road, water, civil engineering constructions) it belonged, which actors and networks were involved, what materials were used and to what solution direction it contributed. Furthermore, since system functions can be understood as (interpretative) categories of events, the events could be allocated to a corresponding system function, as a result of which they served as an indication of the fulfillment of a particular system function (Hekkert et al., 2007; Suurs & Hekkert, 2009). An adapted version of the mapping scheme from Suurs and Hekkert (2009) was used to map each event to a corresponding function which can be found in Appendix XII. It has been taken into account that events can address multiple functions depending on the framing of the event. For example, if the *form* was a report, it was considered to be a knowledge sharing event (SF3), whilst the *content* of the report could lobby (SF7) for a specific solution directionality.

4.3.2. Analysis workshops and interviews

The notes of both workshops and the transcripts of the interviews were analyzed using the different MIS stages and the system functions as key themes, comparable to thematic analysis (Bryman, 2012). The answers were analyzed per theme and similar answers were pooled together (Bryman, 2012). By going back and forth between the results from the event analysis, workshop, and interviews, reoccurring themes and barriers experienced were identified, resembling a constant comparative method (Corbin & Strauss, 1990). The results were summarized, and comments of participants of the workshops and interviewees were added as quotations to supplement and support the results. Within the Results presented in Section 4, references to the policy documents/agendas (Appendix IV) and respondents (Appendix III) are presented in abbreviations. In addition, the abbreviation 'W1' will be used for the anonymous answers provided by participants of workshop 1 via Mentimeter. All data was obtained in Dutch but direct quotations are translated to English in the remainder of the research for readability reasons.

4.4. Operationalization

This section clarifies how each stage of the MIS analysis was operationalized by highlighting how each data source contributed to it. Lastly, the operationalization of the interviews with decentralized governmental experts will be discussed.

4.4.1. Structural analysis

As a first step, the policy documents were analyzed to identify which actors and networks have the ability to steer the transition by reviewing who drew up the agendas and agreements. Thereafter, it was analyzed which actors and networks contributed to each event in the event analysis. Since the events also included (policy) documents, regulations, and standards, the institutions within the infrastructure sector shaping the MIS could be identified. Thereby focusing on "*the formal policies that are in place that are likely to affect the development*" (Hekkert et al., 2011, p. 5) of the transition. The results of the policy- and event analysis were supplemented with interview quotations from workshop 1 and 2 and the interviews.

4.4.2. Problem-solution diagnosis

Reviewing the policy documents and roadmaps also contributed to the problem-solution diagnosis by noting the ambitions formulated for a CE, the reasons for formulating them, and which societal problems they should tackle. Thereafter, the events in the event analysis were filtered on the functions SF4a (problem directionality) and SF4b (solution directionality) to identify the different societal problems and 'wants' that relate to the mission, thereby taking into account how these compete over attention or interact with each other. Moreover, the database was filtered on the functions SF1 (entrepreneurial activities) and SF2 (knowledge development) to identify specific (technological) solutions per solution direction. Different projects using similar solutions were merged per solution direction to provide an overview.

The results from the policy documents and event analysis were supplemented and complemented by the data collected during workshop 1. The answers to the closed questions were averaged which gave an indication of the importance of the four different (social) problems to which circularity can contribute and the degree of attention devoted to the four solution directions. The answers received to the open questions and the discussions were taken into account to identify the degree of convergence amongst the participants. Ultimately, this resulted in an overview of the most important (social) problems to which circularity can contribute, an overview of the agreements and goals that are leading, and the essential solution(direction)s as experienced by the respondents. These results were complemented by quotations from workshop 2 and the interviews.

4.4.3. System functions and barriers analysis

For the system function analysis, the number of times an event was coded under a system function served as a quantitative indicator of the fulfillment of the function. In other words, the degree of attention devoted to a particular function. Moreover, the scores provided by the respondents for close the loop, slow the loop, and substitution were averaged to provide a quantitative indication of the performance of the system functions per solution direction. The scores were plotted in a figure to serve as a quick and strong visual (Hekkert et al., 2007).

The descriptions of the events in the event analysis were analyzed per solution direction and per system function. By reviewing and comparing the events and their description for each direction (Corbin & Strauss, 1990), a first indication of the fulfillment of each function and related barriers could be established. The main observations for each solution direction were written down per system function. The data obtained within workshop 2 and the interviews with substitution experts were compared to these results. The comments of the respondents were added as quotations to supplement and support the results. This resulted in a comprehensive overview of the working of the system functions for the solution directions close the loop, slow the loop, and substitution. The solution direction prevention proved more difficult to operationalize since little data was gathered about this direction; it did not recur often within the event analysis and little attention was paid to it within the workshops and interviews. The lack of attention to prevention will also be discussed in the limitations in Section 6.

4.4.4. Systemic barriers analysis

To determine the systemic barriers within the innovation system surrounding the infrastructure sector, six sessions followed with myself and Sanne Bours. By discussing and reviewing the results of the system functions, a pattern emerged (Suurs, 2009), where hampering system functions could be linked to another weakness or a structural component of the infrastructure sector. By connecting the weak system functions through root causes, an interconnected network was created. Due to the numerous amounts of interconnections, some weaknesses were combined into overarching weaknesses.

4.4.5. Reflection on (planned) governance actions

The reflection on (planned) governance actions started from the perspective of a MIS that is already engaged in various innovation activities and additional actions should focus on resolving the remaining MIS barriers (Wesseling & Meijerhof, 2020). The event analysis was consulted to identify the existing or planned governance actions described within mainly policy documents and agendas. These governance actions were linked to the overarching systemic barriers to assess whether each barrier and its root cause is addressed.

To assess which (additional) governance actions could speed up the transition, the data from workshop 2 and the interviews was consulted. Statements of respondents regarding governance actions that could aid the transition were linked to the remaining systemic barriers which allowed to provide recommendations for (complementary) governance actions.

4.4.6. Interviews decentralized governmental organizations

The interviews with advisors of and people working for decentralized governmental organizations stemming from various regions within the Netherlands served mostly for answering the overarching sub-question. Reoccurring themes were identified by linking interview quotations to the different stages of the MIS and pooling similar answers together. The results were compared to the results already retrieved from the previous steps (Corbin & Strauss, 1990).

Attention was paid to whether the ambitions formulated at the national level were recognized by interviewees and translated into policy frameworks at decentralized governmental organizations, what barriers might inhibit the translation and implementation, and how these might be overcome. In addition, extra attention was paid to the existing coordination and cooperation between and across the different governmental layers, how a (lack of) coordination affects the implementation of the mission, and how coordination could be improved. Overall, this provided insight into the effect of the multi-level governance structure on the mission's progress, and the results were used to support previously obtained results, to make nuances, or indicate differences between the different levels of government.

4.5. Reliability and validity

Reliability and validity are important criteria to assess and establish the quality of a research (Bryman, 2012). According to Bryman (2012), reliability consists of two components. First, *internal reliability* concerns whether "*when there is more than one observer, members of the research team agree about what they see and hear"* (Bryman, 2012, p. 390). Internal reliability was assured on multiple occasions. First, after coding the first 50 events of the event analysis, a second researcher (Sanne Bours), who is experienced in MIS analysis, reviewed the coding using her expertise. After this, the variations in coding were discussed in two sessions. The variations were due to different interpretations of both the system functions and events, but an agreement was reached after the discussions which contributed to the internal validity. Second, internal reliability was assured by intensively discussing the results obtained from the desktop analysis, the workshops, and interviews together with Sanne Bours. Next to internal reliability, *external reliability* concerns the degree to which a study can be replicated (Bryman, 2012). Meeting this criterion is challenging since an innovation system is dynamic and the setting of the case study is changing over time (Bryman, 2012). To ensure some degree of external reliability, the steps taken during the data collection and analysis were rigorously recorded, which makes the analysis replicable in a fashion comparable to the original research (LeCompte & Goetz, 1982).

Validity also consists of two components. First, *internal validity* concerns the integrity of conclusions drawn from the data (Bryman, 2012). Internal validity was ensured using respondent validation by submitting research findings to respondents of this research to confirm that interpretations have been correctly understood (Bryman, 2012), after which any comments were incorporated. Furthermore, triangulation, using multiple research methods and various sources, was used to improve the validity and integration of the results thereby providing more confidence in the conclusions drawn from the study (Bryman, 2012; McKim, 2016). Second, *external validity* refers to "*the degree to which findings can be generalized across social setting"* (p. 390). According to Lecompte and Goetz (1982), external validity represents a problem for qualitative research since findings tend to be oriented to a unique context. This also holds for this study since it applies the MIS framework to analyze the case study of the infrastructure sector. As each mission is unique, generalizing findings from a MIS study is complex (Wesseling & Meijerhof, 2020). Therefore, this study used detailed descriptions, or thick descriptions (Geertz, 1973), to allow others to make judgments regarding possible transferability. Moreover, within the Discussion (Section 6), attention will be paid to the relation between theoretical constructs of the MIS and the case study.

5. Results

This section presents the results of the MIS-analysis of the mission in pursuit of a 100% circular infrastructure sector within the Netherlands by 2050. It will largely follow the structural-functional approach as set out in Section 2 but will start with the structural analysis.

5.1. Structural analysis

There are numerous actors, networks, and institutions within the innovation system surrounding the infrastructure section that influence the formation, structuration, and completion of the mission. First, the characteristics of the infrastructure sector, including formal and informal institutions, will be discussed. Thereafter, the different actors and networks are outlined utilizing the concepts of the mission arena and overall MIS.

5.1.1. Characteristics and institutions

The infrastructure sector has several characteristics and institutions which shape the sector and are thought to influence the transition towards circularity. Table 7 represents an overview of keywords describing the characteristics and institutions and they will be elaborated on in the following paragraphs.

Table 7. Keywords of the characteristics and institutions shaping the infrastructure sector

	Keywords
General characteristics	Public sector; public procurement; public-private dependence; lack of capacity
Project-oriented	Long planning and execution phase; separation planning, design, and execution phase; on-site production; in temporary coalitions; tight budget and time constraints
Assets	Diverse; unique; customer-led location-specific design; complex, long lifespan, strict structural safety requirements
Public procurement	Often awarded on lowest price; can include quality aspects; free to choose weight of quality aspects; can include (minimum) requirements; subject to public procurement laws
Demand side	Governmental organizations, risk-averse, conservative
Market	Dependent on requirements of governmental organizations, no economies of scale, low profit margins, low innovative/learning capacity

The infrastructure sector is a *public sector* where assets are generally owned and purchased by governmental organizations via *public procurement*, making contractors highly dependent on several large public clients and funds (Dominguez et al., 2009). At the same time, governmental organizations depend on numerous market parties, including contractors, architects, consulting and engineering companies, for the realization of the projects (Rijkswaterstaat, 2019). Therefore, the sector is characterized by mutual *public-private dependence*. At the moment, all actor groups within the infrastructure sector are facing a *lack of capacity*, especially a lack of skilled and qualified personnel (Rijkswaterstaat, 2019; A1; A2; A3; A4; C2; M1; M4; P1; P2).

A distinctive feature of the infrastructure sector is that it is *project-oriented*, with projects being extensive, complex and of great social and monetary value, making them prone to risks and uncertainties (Harty, 2005; Rijkswaterstaat, 2019). Projects have a very long *planning and execution phase*. Traditionally, a project is initiated by a public client, after which a preferred solution is developed, with or without an external party such as a consulting or engineering firm. Thereafter, a contractor is procured, to construct the project *onsite*, often based on detailed specifications (Larsson et al., 2013), where the level of detail can vary. Hence, traditionally there is a *separation between the planning, design, and execution phases.* The projects are often realized by a *temporary coalition* with varying combinations of specialists from different companies (Koskela, 2000). Moreover, projects are subjected to *tight budget and time constraints* (Harty, 2005), with many infrastructure projects suffering from cost and schedule overruns (Flyvbjerg et al., 2004; Cantarelli et al., 2012). Whereby infrastructure investments have come under pressure in recent years, mainly at the municipal level (EIB, 2021).

The *assets* realized in the infrastructure sector are *diverse* and *unique* partly due to *customer-led location-specific* design, resulting in little or no repetition (Larsson et al., 2013). Moreover, they are characterized by their *complexity* and *long lifespan* (between 10 years for roads and 100 years for bridges). Although a long lifespan is important to governmental organizations, many assets are demolished before the end of their lifespan due to changing circumstances (G2; I1). For example, as vehicles become heavier and traffic increases, a bridge must be replaced with a stronger one. Assets within the infrastructure sector are subjected to *strict structural safety requirements* and have to comply with different guidelines (G2; G17). Rijkswaterstaat has drawn up guidelines and requirements, which are often adopted by decentral governmental organizations and are therefore dominant within the infrastructure sector. Within the guidelines, several standards are described to which assets and materials must adhere. In addition, local zoning plans and environmental permits influence the building process (EIB, 2021).

The outsourcing of projects via *public procurement* by governmental organizations can be done in different ways. Currently, tenders are often awarded based on the *lowest price*, but *quality aspects* can also be included within the award criteria (Copper8, 2020; Bouwend Nederland, 2021). The range of award criteria that can be included is diverse; quality aspects can relate to sustainability aspects, including the Environmental Cost Indicator (ECI)[3] [MKI] or other circularity aspects, but can also include as little traffic disruption as possible or good cooperation. In addition to the numerous quality aspects, governmental organizations are free to choose the *weight* that is attached to them in relation to the price. Besides award criteria, *(minimum) requirements* may also be set, such as a minimum required percentage of recycled content in a material or an ECI below a specified value for a material or an entire project (Copper8, 2020). The procurement of a contracted service is subjected to *procurement laws* that put strict rules on contracting in order to promote competition and impartiality (Volker, 2010).

The *governmental organizations* on the demand side of the market are often *risk-averse* and *conservative*, i.e. reluctant to use new options, as proven solutions decrease the risks of failure (Larsson et al., 2013; Maghsoudi et al., 2016; D6; C5; C6). However, the market parties on the supply side are *dependent on the requirements* as set out by governmental organizations within procurement. The uniqueness of the projects makes it difficult for market parties to realize *economies of scale* and innovations cannot easily be carried over to the next project. Moreover, investments can often not be recouped within one project since *profit margins are low* (EIB, 2021). Overall, the on-site production of unique assets in temporary coalitions has been marked as a feature resulting in a *low-innovative capacity* and *learning capacity* within the infrastructure sector (Koskela, 2000; Maghsoudi et al., 2016; Rijkswaterstaat, 2019).

5.1.2. Actors and networks

The previous section highlighted that on the demand side there are mainly governmental organizations and on the supply side there are numerous market parties. Additionally, there are numerous networks and platforms consisting of actors from only the supply or demand side or a combination of them. A

[3] ECI [MKI]: The ECI is calculated based on a life cycle analysis and takes into account 11 different indicators to provide insight into the environmental impact of a material or project.

visual representation of the actors and networks within the innovation system surrounding the infrastructure sector is presented in Figure 2. The following paragraphs will elaborate upon the role and influence of the different actors and networks within the mission arena and the overall MIS.

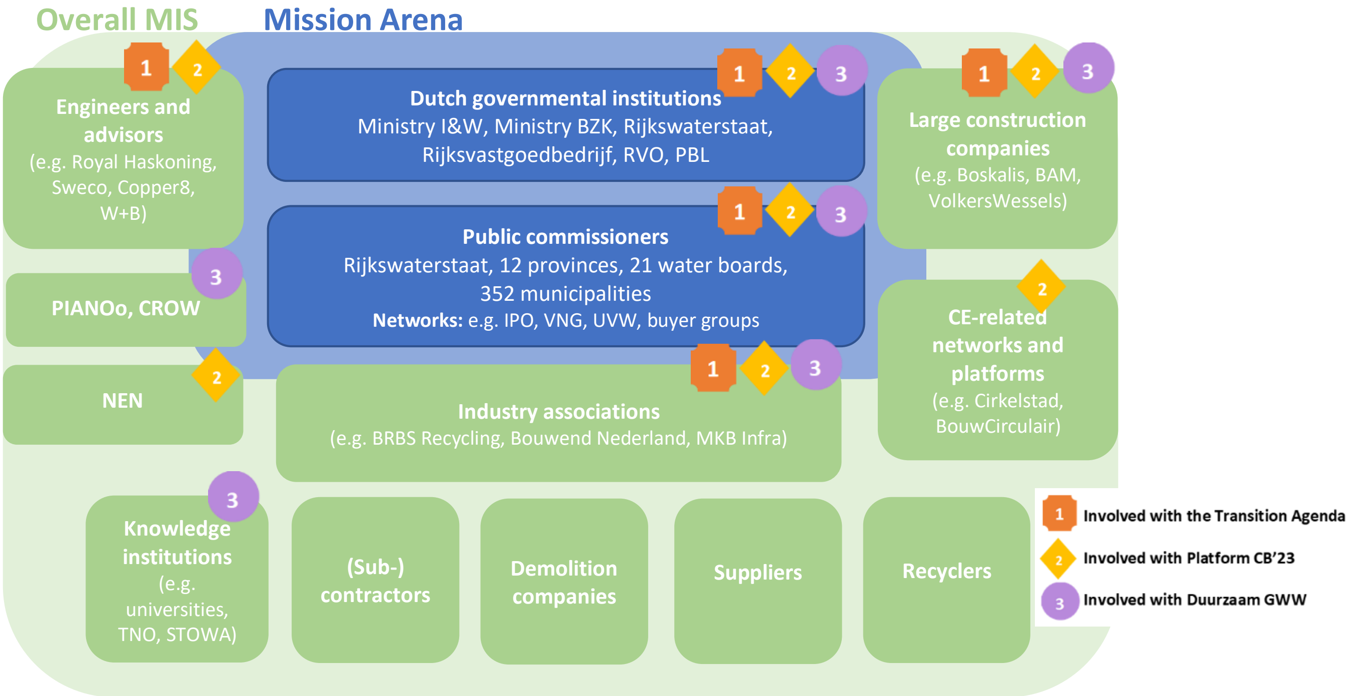


Figure 2. Overview of actors and networks in the innovation system surrounding the infrastructure sector

Mission Arena

In the Netherlands are the governmental organizations, as the public commissioners, responsible for the construction, maintenance, and replacement of the infrastructure to keep the Netherlands passable and accessible (Rijkswaterstaat, 2019). Being the owners of the assets within the infrastructure sector puts governmental organizations in a powerful position to steer the transition. *"To get circular construction off the ground, demand must emerge. Governments, as prominent clients in the infrastructure …, can play an important role in this through their purchasing power as 'launching customer"* (UP, 2021, p 8). Therefore, governmental organizations are considered to be part of the mission arena.

The public clients are at different government levels, including Rijkswaterstaat as the executive body of the Ministry of Infrastructure and Water Management (IenW), 12 provinces, 352 municipalities, and 21 water authorities (EIB, 2021). These central and decentral governmental organizations are all administrative organizations with some form of decision-making power, each with its own way of working, representing a multi-level governance structure (Stephenson, 2013). Currently, the ability to influence and direct the mission is not equally distributed or utilized at each governmental level. The central government generally has more capacity, knowledge, and resources than decentralized governmental organizations, which puts them in a better position to influence the direction and speed of the transition. Hence, Rijkswaterstaat, as the client of large, complex, and high-profile projects, holds a prominent position within the innovation system and they can set an example for other governmental organizations.

However, Rijkswaterstaat manages only about 12% of the material stock in the Dutch infrastructure sector, as represented in Figure 3 (EIB & Metabolic, 2022). Municipalities control by far the largest share of the material stock (73%) and are collectively the largest public client in the infrastructure sector (EIB & Metabolic, 2022). Provinces and water authorities manage respectively 6% and 4% of the material stock in the Dutch infrastructure sector (EIB, 2022). By formulating agendas and ambitions and soliciting for circularity within projects through tenders, decentralized governments are in a position to influence the mission towards a circular infrastructure sector which puts them in the mission arena.

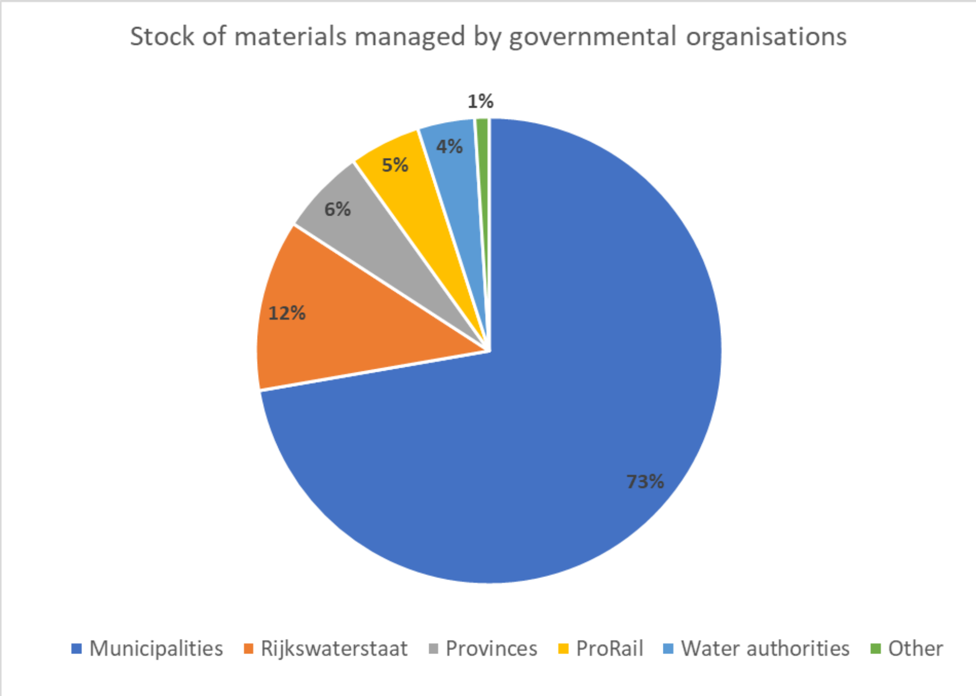


Figure 3. The stock of materials managed by the various public clients

Although there is a dispersion of policy-making activity, spatial distinctions, and geographical separation, at the same time, there are interdependencies and linkages between and within the different governmental levels (Stephenson, 2013). Within each governmental level (provinces, water authorities, municipalities), there is a network in which the parties are represented (respectively Interprovinciaal Overleg (IPO), Union of Water Authorities (UVW), Vereniging van Nederlandse Gemeente (VNG)). Additionally, there are networks in which representatives from the different layers of government work together, for example in buyer groups. Moreover, there are various regional networks in which provinces work together with municipalities or several municipalities cooperate (e.g. 18 municipalities in the region of Arnhem and Nijmegen).

Next to governmental organizations, there are several networks and platforms that take a prominent position in the system surrounding the infrastructure sector consisting of actors stemming from diverse groups, as demonstrated in Figure 2. First, the Transition Team takes a leading role since they were responsible for drawing up the Transition Agenda Circular Construction (TA, 2018), and they have drawn up an implementation program [Uitvoeringsprogramma (UP)] every year thereafter. Since the Transition Team formulated the mission and is committed to governance actions, they are considered part of the mission arena (Wesseling & Meijerhof, 2020). Second, Platform CB'23 was established with the aim of shaping and adjusting the mission for circular construction in line with the Transition Agenda, thereby mobilizing, directing, and aligning existing system components and initiatives. The goal of Platform CB'23 is to draw up national, construction sector-wide agreements regarding circular construction before 2023, including the infrastructure sector, by drafting and publishing guiding principles on different themes. Hence, Platform CB’23 is considered to be part of the mission arena.

Other networks positioned in the mission arena are centered around several agreements. First, the Manifesto Sustainable infrastructure 2030 [Manifest Duurzaam GWW 2030 (DGWW2030)] has been drawn up by actors stemming from various parties with the support of CROW. DGWW2040 is not only focused on circularity but sustainability in its entirety. By means of the Sustainable Infrastructure Approach [Aanpak Duurzaam GWW], they try to implement sustainability throughout the procurement process. Since "the *DGWW approach is a generally accepted tool*" (A4) and is widely used by governmental organizations, this network influences the infrastructure sector in general, including the transition to circularity. Second, several agreements related to materials have been drawn up which are not reflected in Figure 2 but do exert some influence on the transition to some extent. Each agreement has set ambitions that might impact the direction of the mission. The level of acknowledgment of each agreement varies where the concrete agreement [Betonakkoord] has the longest history and was mentioned several times by respondents (W1; A2; G14; P1). The Wood Chain Trajectory [Houtketentraject] and the Asphalt-Impulse [Asfalt-Impuls] were hardly mentioned by participants of the workshops and the interviewees which indicates they are less established. The Construction Agreement Steel [Bouwakkoord Staal] has only been signed in March 2022, hence, its influence still has to be determined.

Overall MIS

Actors in the overall MIS consist of over 2,100 market parties, including contractors, consisting of large companies and SMEs, sub-contractors, engineering and architect firms, advisors, suppliers, demolition companies, and recycling companies (Rijkswaterstaat, 2019). Governmental organizations are dependent on contractors and construction companies for the realization of their projects. Moreover, (technical) design knowledge has been phased out in recent years within governmental organizations (Rijkswaterstaat, 2019). Consequently, they often outsource specialist knowledge, making them reliant on contractors, engineering firms, and architects for the design of projects. In addition, governmental organizations frequently approach advisors to guide them through the process and organizational changes associated with the implementation of circular ambitions in both business processes and within projects. Hence, contractors, engineers, architects, and advisors are vital for developing and adopting innovative solutions and transforming existing practices. However, independently they seem to have little ability to steer the transition. Nevertheless, since they join together in branch organizations and are represented in influential networks and platforms, they can still exert some influence, placing them on the edge of the mission arena.

Knowledge and training institutions are important for developing and sharing knowledge, since "*the circular transition requires new knowledge … For this, existing training courses at all levels - from wo to vmbo - need to be adapted, new training modules need to be developed and refresher courses need to be offered*" (TA, 2018 p. 22). In addition to the role of training institutes, other knowledge institutions - including EIB, CBS, PBL, BTIC, TNO, STOWA, CROW, and PIANOo - are of great importance in developing technical, process, and policy knowledge. Overall, knowledge and training institutions are essential for the transition, but individually have little power to influence it.

A chain approach is essential to realize a circular infrastructure sector (TA, 2018). For example, suppliers need to offer innovative materials, recyclers need to improve existing recycling mechanisms and innovate so new materials or mixtures can be recycled, and demolishers need to change their practices to enable the reuse of components or improve recycling possibilities. Hence, suppliers, demolishers, and recyclers are vital for developing and adopting innovative solutions and transforming existing practices in pursuit of the mission but enjoy little to no power to steer the mission.

5.2. Problem-solution diagnosis

The problem-solution diagnosis maps out the full scope and complexity of the mission to a circular infrastructure sector, including the problem(s) it aims to tackle and the solutions that are deemed viable, necessary, and legitimate to do so (Wesseling & Meijerhof, 2020; Elzinga et al., 2021). To understand what problems are addressed by the mission and how these are prioritized, the formulation of the mission and corresponding ambitions will be explained first. Special attention will be paid to the translation of the mission into ambitions at the different governmental levels. Thereafter, the problem directionality (SF4a) is explicated. Lastly, the different technological- and social solutions (SF4b) that might contribute to the mission will be discussed.

5.2.1. Formulation of the mission and ambitions

The mission to achieve a 100% circular infrastructure sector is sparked by ambitions on a European level, followed by the national level, whereafter it should be translated and implemented at the level of decentralized governmental organizations, including provinces, municipalities, and water authorities. An overview of the various agendas that have been drawn up at different governmental levels can be found in Appendix IV.

National ambitions

On a national level, ambitions have been formulated within the TA (2018) and UPs that have been published every year thereafter, with the “Establishment of the base camp – Implementation program 2021-2023” [Inrichting van het basiskamp – Uitvoeringsprogramma 2021-2023] (UP, 2021) as the most recent one. In addition, the Ministry of IenW, Rijkswaterstaat and ProRail drafted the Strategy "Towards Climate Neutral and Circular Infrastructure" [Naar Klimaatneutrale en Circulaire Infrastructuur] (KCI, 2020). The goals articulated in the TA (2018), the UP (2021), and the KCI (2020) are presented in Table 8.

Table 8. Formulated goals per year and agenda for the infrastructure sector

Year	Goal	Agenda
2023	100% circular procurement unless this is not (entirely) possible	TA
2030	50% reduction of CO2 emissions	TA
	100% circular procurement	UP
	100% reduction of CO2 emissions	KCI
	100% working circular	
	50% reduction of primary raw materials	
2050	100% circular infrastructure sector	TA
	All assets an ECI of 0	UP

The goals set at the national level were acknowledged by interviewees and participants of the workshops. However, they are regarded as “*vague goals in the future*” (M3) and there is an “*absence of concrete goals”* (W1). Also illustrated by: *“In 2050 100% circular: what does it mean? What does 50% mean?”* (C3). Moreover, a discussion arose in workshop 1 about the ambition aimed at an ECI of 0 and whether it is feasible (G2; D1), illustrated by: “*ECI = 0 depends on the scope. … It is a nice goal, but I wonder if they already thought about how to achieve it*” (D1). Overall, the goals are viewed as a ‘point on the horizon’, but must be made concrete and operationalizable (A1; A5; C2; C3; C4; M1; M3).

Efforts to operationalize the objectives and stipulate the route towards a 100% circular infrastructure sector by 2050 are increasingly underway, illustrated by “*Objectives are not yet SMART-enough, but it is work in progress”* (P1). Currently, the Ministry of IenW and Rijkswaterstaat have taken the lead to create roadmaps within the "goal trajectory" [Doelentraject] for high-impact product groups, including civil engineering structures and asphalted roads, in which specific circularity, performance, and effect goals will be formulated. Moreover, following the KCI, roadmaps for the different disciplines within the infrastructure sector are produced by Rijkswaterstaat. In addition, the various material agreements have formulated more specific goals for materials, as exemplified in Table 9. However, the agreements are not equally specific regarding the goals. For example, the Construction Agreement Steel (2022) does not (yet) contain any measurable goals and the Asphalt-Impulse does not specify a time frame.

Table 9. Goals set within material agreements

Agreement	**Goal**
Concrete agreement (2018)	"by 2030, 100% high-quality reuse of released concrete and immediately replace at least 5% of the total volume of aggregates with concrete residual flows"
Asphalt Impulse (2019)	"Doubling the average lifetime of asphalt roads, halving dispersion in lifetime, halving CO2 production, at equal or lower cost"
Construction agreement steel (2022)	Promote the highest possible use of freed-up steel [...] smart design for material savings, [...] less use of steel per unit of product

Ambitions decentral governmental organizations

At the level of decentral governmental organizations, there are large differences in the extent to which circular ambitions have been formulated. First, considering the water authorities, several have formulated their own goals and ambitions in the field of circularity and translated them into policy. "*But most of the water authorities have not yet to the point where the circular way of working has become a normal part of their regular work*" (UVW, 2021, p. 2). Therefore, the UVW seems to have taken a leading role in formulating a strategy through the 'Story of Circular Water Authorities' (UVW, 2021) which sets out different key development lines towards circularity and provides examples. Work is currently underway to make these key development lines more concrete, set intermediate targets and milestones, and define the activities and necessities needed to achieve them (UVW, 2021; U1). With this, the water authorities seem to have given more substance to the ambitions formulated on a national level.

Second, all provinces have adopted the national targets and established a strategy or agenda regarding the transition to circularity in general, where the infrastructure sector is labeled as an important sector to become circular. However, the level of ambition varies, and some frontrunners can be distinguished (A2; A4; P1). For example, the Province of North-Brabant has been named the public client that awards the highest number of tenders on sustainability, including circularity, for three years in a row (Bouwend Nederland, 2021). Furthermore, the Province of Overijssel has drawn up a special Regional Transition Agenda (RTA) for infrastructure. Overall, "*provinces have formulated objectives, but it is difficult to make them concrete*" (A1).

The difference in the level of ambition and policy formulation becomes greater when considering municipalities: "*The larger municipalities are generally more engaged with it than others*. ... *Several municipalities are ahead, others are behind*" (P2). Where "*The big cities, the G40, do put in the most efforts. I think that's because they have more civil service capacity. It really is people work; civil servants can really make a difference*" (A5). For smaller municipalities, four different reports (Sulkers & Koops, 2020; Schik & Kuijper, 2020; Wienk, 2020, 2022) paint the picture that they are mostly aware of the circular ambitions on a national level but struggle to translate national ambitions within their own policies. This was also highlighted by several interviewees (A3; M1; M3; M4), exemplified by: "*What I notice is that, although something is said about years and percentages, no concrete policy is formulated to actually get to work*" (M4). On the other hand, there seems to be an increasing awareness of the need to "*do something with circularity*" (A3) within municipalities, fueled by the national ambitions.

5.2.2. Problem directionality

Problem directionality refers to the way different societal problems are included and prioritized in the mission formulation (Wesseling & Meijerhof, 2020). According to PBL (Hanemaaijer et al., 2021), the CE can contribute to four, interrelated social challenges, as described in Section 3. Participants of workshop 1 ranked the degree of importance of the problems articulated by PBL as shown in Table 10. Combating climate change by reducing CO2 emissions seems to be the main reason for pursuing circularity (A5; K1; G6; M3; P2; W1). Circular and CO2 emission reduction ambitions are closely linked, as evidenced by the ambition of the Ministry of IenW, Rijkswaterstaat, and ProRail "*to be fully climate neutral and to work in a circular manner by 2030 at the latest*" (KCI, 2020). Thereby stating "*We use CO2 reduction as a quantitative measure because a large part of the circularity measures also contributes to the reduction of CO2*" (KCI, 2020 p.8). Since CO2 is more tangible than circularity, it is easier to pursue, as also confirmed by market parties, including contractors (C3; C4), illustrated by: "*CO2 emissions are easy to measure and easier to get there*" (C4).

Table 10. Ranking of the importance of problems to which a circular infrastructure contributes

	Climate change	**Pollution**	**Biodiversity loss**	**Supply risk**
Average score	1,3	2,6	2,6	3,3

Moreover, targets for CO2 reductions have been laid down in the Paris Climate Agreement, which was mentioned as a guiding agreement by 6 of the 15 participants of workshop one: *"[a circular infrastructure is] essential for achieving the climate goals"* (W1). Due to the legal obligation to reduce CO2 and the measurability of CO2, it appears as if reducing CO2 emissions receives priority over circularity (A1; A5; A3; P2). Even though circularity can contribute to reducing CO2 emissions, there are critical questions about whether the short-term goals of reducing CO2 emissions may inhibit circularity in the long term (Schut, 2019; A3; G17). For example, a more circular solution, like a robust asset that lasts longer, might have a higher environmental burden now but not over the long run (Schut, 2019).

The importance of reducing the use of raw materials was frequently mentioned as one of the reasons for transitioning to a circular infrastructure sector by interviewees (A4; A5; G6; P1), and also within agendas: "*Given the large amount of (primary) raw materials used in construction and infrastructure, there is a major task to make the sectors more circular*" (RTA, 2020, p. 8*).* According to the definitions of PBL, the large consumption of raw materials is part of the societal problem of supply risk (Hanemaaijer et al., 2021). Although supply risk was not ranked as the main reason to strive for circularity by participants of workshop 1, the discussion that followed revealed that reducing material use is perceived as important. Despite that, an interviewee mentioned: "*Why circularity? People don't even have a good idea yet. The scarcity of materials is not yet very clear, but it is now being felt a bit more; there was no such urgency before that"* (A3). The need for a circular economy has become clearer over the past year due to increasing scarcity and rising raw material prices: "*This year you notice that raw materials and products are becoming increasingly scarce*" (M4). Scarcity of materials is especially problematic for some specific materials such as bitumen (G7), a crucial component in asphalt, and zinc (G4) which is used for crash barriers.

Biodiversity and pollution are regarded as equally important by participants of workshop 1. However, pollution does not receive much attention in agendas and agreements nor within the interviews. Biodiversity seems more relevant and is also mentioned within agendas (KCI, 2020; UP, 2021; UVW, 2021) and in the goals drawn up by Platform CB'23. However, there are no specific goals formulated and biodiversity remains a broad problem that receives little specific attention from the various solution directions.

Besides the problems articulated by PBL, participants of workshop 1, several interviewees (M1; P1; P2), and within various agendas, a reason for the infrastructure sector to become circular is also: *"Infrastructures sector is government-driven, so circular infrastructure is an opportunity for a flywheel for broader circular transition"* (W1). Since the infrastructure sector is a public sector, governments are in a powerful position to implement circular ambitions: *"The infrastructures sector is actually low hanging fruit for us and easy to fill in"* (W1). Governmental organizations feel they must lead by example using the infrastructure sector (M1; P1).

Priority of circularity

A CE was introduced as a way to contribute to sustainability challenges (EC, 2015 & 2020; TA, 2018), but sustainability is a more holistic concept, encompassing more aspects, including a social aspect (Geissdoerfer et al., 2017). It was emphasized by participants of workshop 1 that circularity can contribute to sustainability goals, provided certain preconditions are met. This resonates with the criticism circularity receives by scholars who state the relationship between sustainability and a CE is questionable (Geissdoerfer et al., 2017; Blomsma & Brennan, 2017; Murray et al., 2017).

Sustainability is more broadly defined than circularity (Schik, 2020) which is well reflected in the "Sustainable Infrastructure Approach" [Aanpak Duurzaam GWW]. The approach offers a tool that governmental organizations can use to prioritize their sustainable ambitions for a certain project or tender based on 12 themes; only one theme refers specifically to material use and circularity. Other ambitions focus for example on energy and CO2, investment costs, but also social relevance and welfare. The importance of reducing traffic nuisance and involving residents was also regarded as important by respondents (G17; M4). Hence, a much broader spectrum of ambitions is taken into consideration when using the approach which could cause circularity ambitions to fall by the wayside, illustrated by: "*Circular use of materials is underemphasized in sustainability efforts; most attention is paid to limiting CO2-emissions*" (A5). Moreover, sustainability is more widely known and better embedded within companies (C3; C4): "*Everyone is convinced about sustainability, circularity still needs to grow. Sustainability is much clearer. … Already had to explain circularity a few times; what is it exactly*" (C3). Overall, it seems that the term circularity is fighting over attention with sustainability (A1; A5; C3; Diepeveen, 2020).

In addition, within governmental organizations, especially municipalities, the energy transition (Schik, 2020; Wienk, 2020; A1; M1; M4) seems to be prioritized over circularity.

> *If you look at sustainability in its full breadth, you see that there is a lot of focus on energy and climate. But there is growing attention to the circular economy now, but targets are very far away. ... On the theme of energy there are a lot of obligations: it has to happen. This helps municipalities to free up time and money for it and to take steps*. (M1)

Overall, there does not yet seem to be a clear picture of the importance to transition to a circular infrastructure and circularity seems to be fighting over attention with numerous other societal problems and 'wants', which results in a low problem directionality (SF4a). Problem directionality is important since the legitimacy of the societal challenge itself can accelerate the achievement of the mission (Wänzenbock et al., 2020).

5.2.3. Solution directionality

The transition towards a circular infrastructure requires the development of technological as well as non-technological innovations. The various solutions have been divided based on the circular solution directions: narrow the loop, slow the loop, close the loop, and substitution (Hanemaaijer et al., 2021), as elaborated in Section 3. An overview of specific technological and non-technical innovations can be found in Appendix XIII. The number of events related to each solution direction is outlined in Table 11.

Within this section, only the total number of events per strategy will be elaborated upon, and the system functions will be addressed in Section 5.3.

Table 11. Heat map of the events

Strategy	SF1	SF2	SF3	SF4a	SF4b	SF5	SF6	SF7	SF8	Total per strategy
Circular	3	26	43	30	9	46	9	38	48	**252**
Narrow the loop	16	1	0	1	3	5	0	4	0	**30**
Substitution	66	24	12	7	20	13	7	31	10	**190**
Slow the loop	35	16	13	9	21	21	6	29	13	**163**
Close the loop	36	11	5	17	31	25	4	25	12	**166**
Total per function	**167**	**83**	**91**	**84**	**103**	**144**	**33**	**150**	**113**	

The heat map of the event analysis shows that for the majority of events (31%) no solution direction is specified. During interviews and workshops, it was noted that there is a lack of solution-directionality (SF4b), as illustrated by: "*There is no steering in terms of prioritizing directions for solutions. Everyone does what he/she thinks is best from his/her perspective*" (A4). However, in workshop 2 it was emphasized that *"it is very important to look at the impact. Where can the most impact be made? It still needs to be figured out what the impact/ECI is of all the innovations"* (D6). Currently, there is no overview of impactful solutions per asset type, which can result in putting a lot of effort but realizing little impact. Not specifying how a project or asset should become circular can lead to confusion, causing solution directions to diverge (Wanzenböck et al., 2020). On the other hand, by not specifying a solution, there is a lot of room for market parties to fill in the details utilizing their expertise (A2; C4; C5; I1). Opinions regarding whether or not to prescribe solution(s) in projects and tenders seem to be divided and depends on the specific project, the objectives of the project, and the level of knowledge of both the public commissioner and the contractors (A2; P1; M4).

Considering the four solution directions, participants of workshop 1 indicated which direction is receiving the most attention within the infrastructure as of this moment, as can be found in Table 12. The main developments within each solution direction, following the degree of attention devoted to them, are described in the following paragraphs whereafter the interaction between them will be discussed.

Table 12. Ranking of the degree of attention paid to each solution direction

	Narrow the loop	Slow the loop	Close the loop	Substitution
Average score	2,9	2,2	1,5	3,2

Close the loop

Close the loop concerns the recycling of materials and occurs in about 20% of the events in the event analysis, mainly (more than 50%) within the discipline of road pavement. The main materials recycled are asphalt and concrete which is considered to be business as usual in the infrastructure sector (A4; D7; G3; I2): *"Recycling is common practice in this sector for decades, such as in foundations but also PR [partial recycling] in asphalt*" (G3). Pulverizing concrete after which it serves mainly as a foundation material in roads (downcycling) is the most common form of recycling at the moment (I2), but higher recycling strategies are currently being developed (C7; D6; G3; I1), including separating concrete at the component level which allows it to be applied in new concrete again.

Slow the loop

Slow the loop comes down to the longer and more intensive use of products and components, through reuse or repair (Hanemaaijer et al., 2021). Product reuse takes place at different levels according to Cirkelstad (2021a) and Platform CB'23 (2022c). Extending the lifetime of a structure is considered the highest form (lifetime extension), followed by reuse at the object or component level, where entire structures or parts of them are reused in another location, such as entire bridges, and girders or beams (Cirkelstad, 2021a). Slow the loop takes place in about one-fifth of the events from the event analysis. Reuse often (±50% of the events) takes place within civil engineering structures, where mostly concrete elements (beams) and wood (sheet piling, bridges) are reused. There are also increasing advancements towards the reuse of entire bridges. On the other hand, lifetime extension is primarily used in road surfacing (85%), mainly related to asphalt (67%).

Narrow the loop

The solution direction narrow the loop concerns refraining from the construction of an asset or manufacturing it more efficiently. Narrow the loop was only found in about 4% of the events from the event analysis where they mostly concerned more efficient production of assets in both civil engineering constructions and road surfacing. An explanation for narrow the loop coming back little in the event analysis might be that 'doing nothing' usually does not make it to the front page (A2).

Even though narrow the loop did not recur often in the event analysis, governmental organizations stipulate that critical thought is being given to whether new constructions are necessary (G15). This is also represented by the circular design principles of Rijkswaterstaat (2020) where the first step is: "*Prevention: Avoid building anything"* (p. 2). Narrow the loop also includes maintaining assets properly and in a timely manner; closely linked to lifetime extension. Maintenance seems to take place more often, especially from a financial point of view.

Substitution

Various solutions fall under substitution. Substitution within asphalt concerns in particular the replacement of bitumen with a bio-based alternative. For concrete, several developments fit under substitution, including cementless concrete (geopolymer concrete) and biobased concrete, where sand and gravel are replaced by elephant grass or other plant fibers. Furthermore, wood is a renewable material that can be used as a construction material (G3; K2). In addition to replacing components in existing commonly used materials, civil engineering constructions can also be built of wood. Overall, substitution appears in a quarter of the events from the event analysis, mainly within road pavement (50%), and a quarter of the events related to civil engineering structures.

Interaction solution directions

Close the loop is currently receiving the most attention according to participants of workshop 1 (8 out of 13), which was acknowledged by participants of workshop 2 (C2; C3; G12). Since recycling is already common practice in the infrastructure sector, there is a "*perception that recycling [and the GWW sector] is already circular*" (A4). The current focus on recycling can get in the way of the attention and crucial resources needed to develop other solutions, thereby representing a competitive relationship (Sandén & Hillman, 2011). However, participants of workshop 1 and interviewees also emphasized that circularity is more than recycling and that we need to "*move up the R ladder*" (I1).

Within this respect, high-quality reuse is promoted as a promising solution direction (I1; I2; G2; G17; G18), illustrated by: *"Recycling of raw materials is a nice first step, but for real impact we will (also) have to start reusing whole building products and structures*" (Cirkelstad, 2021a, p.3). Recycling and reuse compete over the same materials that are released when existing assets are demolished, thereby presenting a competitive relationship (Sandén & Hillman, 2011). Since recycling has been practiced for some time, this is easier for contractors, architects, and consultants. In addition, the legitimacy of reuse is still lagging behind that of recycling. On the other hand, market parties do seem to be open to reuse, but it does require commitment and demand from governmental organizations. Since reuse is receiving increasing attention from governmental organizations, this could speed up its development.

In relation to recycling and reuse, substitution is seen as a solution direction that is currently receiving the least attention (Table 12). This also became apparent from the interviews: "*Circularity is translated primarily into reuse and less into the replacement of fossils and minerals with biotic materials*" (G19). Substitution seems to be fighting for the same market and mainly for the attention and resources needed to develop in comparison to recycling and reuse. On the other hand, there is also a symbiotic relationship between substitution and recycling (Sandén & Hillman, 2011). For example, research is currently conducted into the application of bio-based components in asphalt in combination with recycled granule (Junginger et al., 2022), so in this respect, the solutions could complement each other. In addition, it was noted that it is important that materials with a bio-based component can also be recycled in the future (Junginger et al., 2022; E2; I2). Current recycling structures are not equipped for this (E2; I2), but it was indicated that these recycling strategies can be developed, provided that there is enough mass (I2). Moreover, building with wood in combination with reuse can also represent a symbiotic relationship; for example, there are projects where wooden sheet piles or bridges are reused. However, building with wood does compete with more familiar materials that also have a larger lobby behind them, such as asphalt and concrete.

Prevention is the solution direction that is mainly in competition with all other solution directions, because if something is not built then there is no need for recycling, reuse, or substitution. Prevention is attractive for public commissioners from a financial point of view and can significantly contribute to the circular ambitions within the infrastructure sector, but at the moment it appears as if it does not receive that much attention to be getting in the way of the other solution directions (W1; G2; G3). Moreover, the infrastructure is and will remain an essential part of society, and will need to be maintained and replaced, which implies that the need for recycling, reuse, or substitution persists.

5.3. System function analysis

This section outlines the fulfillment of each system function. A visual representation of the scores provided by the participants of workshop 2 and the interviewees with experts on substitution is presented in Figure 4. The scores reflect how prohibitive the lack of a function (if any) is perceived, where 1 is not problematic and 5 is very problematic. In the following paragraphs, the fulfillment of each system function will be discussed and differences in the solution directions close the loop, slow the loop, and substitution will be provided when there are any. The system functions SF4a (problem-directionality) and SF4b (solution-directionality) are not presented in Figure 4 and will not be discussed here, as they have been discussed in Section 5.2. In addition, narrow the loop will not be taken into account in this section since little data has been collected on this direction. However, it will be discussed in Section 5.4. and in the limitations (Section 6).

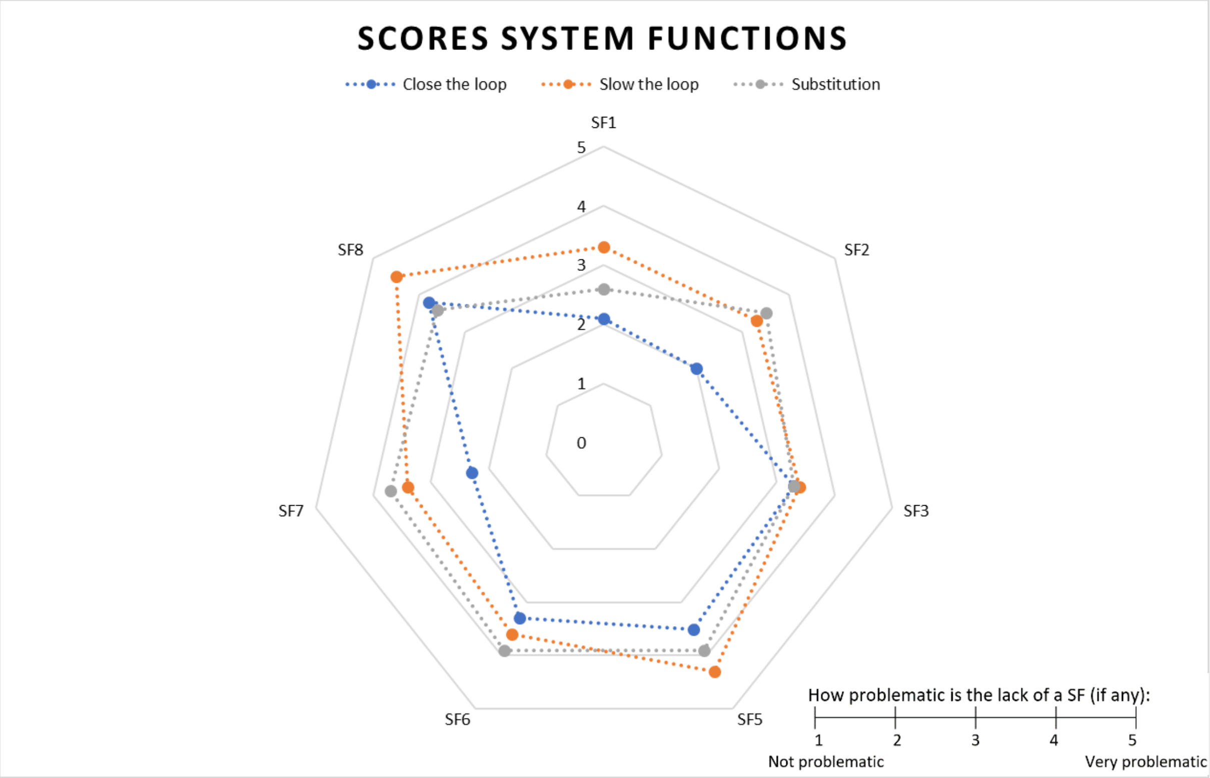


Figure 4. Scores of the system functions

SF1: Entrepreneurial experimentation, upscaling and business model phase-out

Within the infrastructure sector, experiments and pilots on all previously mentioned circular solution directions take place, as can also be seen by the overview of solutions in Appendix XIII and the heatmap as presented in Table 10; the majority of events are related to entrepreneurial activity. "*A lot of experimentation is going on in pilots and the first projects are being carried out. Think of geopolymer concrete, SBIR Circular viaducts*[4]*, the circular road*[5]" (A4). Technological experimentation takes place within pilot and demonstration projects and several so-called 'trial areas' [proeftuinen]. Besides technical experiments, there are several pilots in which new forms of tendering, contracting, and

[4] SBIR Circular Viaducts [Small Business and Innovation Research Circulaire Viaducten]: The SBIR is a procurement method that stimulates innovations by partly financing the research and development process and was put on the market by Rijkswaterstaat to develop innovations for circular viaducts.

[5] The circular road [De Circulaire Weg]: A program in which the opportunities, possibilities, and effects of 'infra-as-a-service' on the circularity of infrastructure assets are examined within 8 pilot projects.

cooperation (SF5) are being tested, including tenders with functional requirements, two-phase tendering, a portfolio approach, working with maintenance contracts, 'as-a-service' contracts or using a construction team. However, both the interviewees and participants of the second workshop state that within each solution direction more (technological) experimental development is required to accelerate the transition (D6; E2; E3; G3): "*Should we do more experiments? that is a sure thing*" (D6). Public commissioners play a major role in initiating and stimulating more pilot projects, as they are the ones who ultimately have to apply the innovations.

Despite the need for more experimentation, upscaling of existing innovations is regarded as more problematic (C3; C5; C6; D6; G3; I1; K2). Pilots take place on a small scale, with a number of iconic projects, after which regular demand from public commissioners often fails to materialize (SF5), illustrated by:

> *The market launch is often the frustrating part. The developer has done a demonstration project with several clients. This has been communicated positively. But unfortunately. With the regular clients, the demand remains lacking. All kinds of innovations have been developed in the Netherlands that are market-ready and have the potential to be applied on a large scale.* (Kolk, 2021, p. 17)

Overall, it appears as if more experimentation is needed, but more importantly, existing innovations should be given the chance to develop further and scale up. In the following paragraphs, the activities and main differences between the solution directions will be discussed.

Close the loop

A lack of entrepreneurial activity was not seen as a major barrier when reviewing the scores provided by respondents (Figure 4). There are various pilot projects in which the properties, behaviors, and quality of materials (asphalt and concrete) with a higher percentage of granule are tested and monitored, including maintenance requirements and the lifespan. More entrepreneurial activity is mainly required to increase the percentage of granule even further and enhance its legitimacy (SF7). Moreover, for upscaling it seems important that also major producers come along (C3; D6). "*In the field of recycling, many entrepreneurs are already active, but also many parties are still lagging behind. These are often the larger players who benefit most from the existing regime"* (G16). In addition, the step from downcycling (low-grade recycling) to upcycling (high-grade recycling) of materials requires more experimental development but is considered possible (SF7; G15; I2), illustrated by: *"It should be possible to make the step to high-grade recycling from the existing practice of [low-grade] recycling. There are experiments, but still to a fairly limited extent and often from smaller parties. So that should certainly get a boost, but we have a lot of ground to build on"* (G15).

Slow the loop

Regarding slow the loop, there are also various pilots. Regarding lifetime extension, there are projects where rejuvenating creams in both asphalt and concrete are tested. For reuse, there are experiments with reusing components of bridges and viaducts or the entire construction, stimulated, amongst others, by the "bridge bank" [Bruggenbank]. However, as can also be seen by the scores provided by respondents in Figure 4, slow the loop is in an earlier phase of development, illustrated by: "*In the field of product reuse we are still very much at the beginning"* (G16). More experimental development (SF1) is required to enhance the legitimacy (SF7) of the innovations and to scale up: *"For reuse, the situation is slightly different. Here, there are experiments with, for example, urban mining and marketplaces, but they are still far behind in comparison with recycling. Much more mass must be created to achieve upscaling"* (G15).

Substitution

There are numerous events related to experimental development with substitution, as shown in Table 10. Most pilots are regarding testing and monitoring the properties, behaviors, and quality of both asphalt and concrete containing a bio-based component, including maintenance requirements and the lifespan. Moreover, the use of wood as a building material, mainly for bicycle and footbridges, is piloted. Interviewees indicated that a lack of experimental activity is not regarded as a major bottleneck, but the main challenge is the upscaling of the use of (biobased) renewable materials (D3; D4; G3; K2).

SF2: Knowledge development and unlearning

Knowledge is being developed at different levels, by different actors, and within different networks through the pilot projects (SF1), as mentioned above, and research projects (SF2). "*I certainly don't have a complete picture, but I suspect that there is a fair amount of research taking place*" (G15). Research projects include, amongst others, studies into the behavior of innovative materials, how circularity can best be included in tenders, new ways of contracting, obstructing legislation and regulations, and raw material flow analyses. Knowledge is developed by governmental organizations, knowledge institutions, entrepreneurs, and also within the networks, for example by Platform CB'23, platform WOW, platform bridges, CROW, and the networks surrounding the material agreements. Additionally, within "*various buyer groups knowledge is developed and gained*" (P2).

Although there is a lot of existing knowledge and knowledge development, in several crucial areas there is a lack of knowledge. First, there is a lack of a uniform understanding of circularity and a measurement method for it, while "*measuring circularity is seen as a prerequisite for the transition to a circular building economy*" (Platform CB'23, 2022a). Moreover, "*valuing circular construction is still in its infancy. ... There is no clear frame of reference, and knowledge about the circularity of materials, products, detachability, and potential reuse is lacking*" (Cirkelstad, 2021b, p. 5).

Secondly, knowledge regarding the acreage, its condition, and the materials used is lacking (G1; G14). A first study regarding the material flows and assets within the infrastructure sector has been published recently, but stated: "*For a number of assets, actual data on inventory and production was not available. ... For a better picture of the task per asset for the future, more and better information about the stock and quality of assets is desirable*" (EIB & Metabolic, 2022, p. 11). On the positive side, several governmental organizations have commissioned a material flow analysis (SF2). Moreover, the developments of the material passport[6] (SF1/SF2) can contribute to the recording of materials used in assets, also at maintenance times (Cirkelstad, 2021c; Platform CB'23, 2022b).

Thirdly, there is a lack of knowledge (SF2) about the existing or perceived risks associated with new circular solutions. A lack of knowledge (SF2) or an accepted method to evaluate the risks, and guarantee the safety, quality, maintenance costs, and lifespan of innovations (D6; G7; E2; P1; P2), hinders market formation (SF5), as illustrated by: "*There is cold feet within the infrastructure sector, therefore the safe option is often chosen due to a lack of knowledge*" (Sulkers & Koops, 2020, p.9).

Lastly, within governmental organizations, there is a lack of knowledge (SF2) regarding how to implement circularity within internal processes and projects (A1; A2; A3; A4; A5; G14; G15; M3; P1; P2). *"There is a great need for knowledge HOW to work circular in construction projects (so also: how to organize that), and what measures have what effect"* (Boukje). Governmental organizations seem

[6] Material passport [Materialenpaspoort]: within a materials passport it can be recorded which materials are used during construction and maintenance. This provides insight into the availability and quality of assets and can facilitate recycling and reuse in the future.

to lack knowledge in order to ask for circular solutions tenders: "*We have to create awareness and learn to ask the right questions*" (M1). In addition, there is a lack of knowledge (SF2) about what can and cannot be done within tenders whilst complying with existing laws and regulations which hinders the solicitation of circular solutions (SF5), illustrated by: "*If you don't know how to ask for it; if you have doubts about whether it's going to hold up legally, then you don't think about it*." (A4). The lack of knowledge within governmental organizations seems to be greater for decentralized organizations; a lack of knowledge was mentioned as a barrier by 7 of the 12 interviewees.

> *[The second largest obstacle is] a lack of knowledge or concrete examples on implementation. How can I incorporate sustainability/circularity into my project? How can I ask for it in a tender? Which concrete materials and examples can I apply? Because of a lack of knowledge it is easy to say: well, then we won't do it. (M3)*

In addition to the aforementioned knowledge gaps which influence each solution direction, there are also several differences between the directions which will be explained in the following paragraphs.

Close the loop

Within workshop 2, participants agreed that there is quite a lot of knowledge about recycling. Hence, a lack of knowledge is not seen as a barrier (G12; G15; I2). However, there is a question regarding what should be used as a foundation material for roads when other sectors (e.g. the civil & non-residential construction sector), from which the currently used recycled granulate partly originates, also become circular (A2; G7; G15; I2). An interview indicated: "*my biggest concern for the future are the materials for foundation. This is still a blind spot*" (A1).

Slow the loop

For slow the loop, knowledge development (SF2) is still at the beginning (C3; G7). Currently, knowledge development takes place in various pilots (SF1) or studies (SF2). For example, within the SBIR Circular Viaducts (SF1/SF2), consortia are working on knowledge development regarding the reuse of components of viaducts and the design of circular viaducts for future reuse. Nevertheless, there seem to be four knowledge gaps, specific for reuse that inhibit upscaling: 1) measuring and securing reusability and quality, 2) knowledge on how to design with used components or objects, 3) the supply and demand of used components, 4) knowledge on designing for future reuse.

First, there are currently no methods to assess and ensure the quality and remaining (technical) lifespan of components or structures (SF5): "t*here is a lack of knowledge: what is still a good part what is not?*" (G7). However, the first methods are currently being developed and tested (SF1) which will likely contribute to the legitimacy (SF7) of reuse. Second, to reuse components, they need to be incorporated into the design of new assets. Designing with used parts requires a different way of thinking, and a change in culture (A4), which requires new knowledge (SF2). Moreover, before parts can be reused, they have to be "harvested" from structures that were not built for that purpose (G2). This requires a different way of thinking and demolition (C6).

Thirdly, to design with components that are freed up, one needs to know what is released where and when (A4; C4; D6; G2). Partly due to the lack of knowledge and data about the current condition of the acreage, the materials used, and what maintenance has been carried out within all governmental layers (SF2), an overview is lacking. In particular, the level of detail of the assets and parts required for reuse is lacking (G14). Moreover, not only the supply is unknown, but also the demand for used components; there is no good overview of upcoming projects within all governmental levels (C4) and communication between the levels of government regarding future projects is poor (SF8).

Lastly, in addition to assets being designed with used components, new assets can be designed in such a way that they can be reused in the future. For future design, modular and detachable construction are crucial (SF7) (Cirkelstad, 2021a; Platform CB'23, 2022c; C5; G1; G2). The first pilots (SF1) using modular design principles have been conducted, but "*on the design side [for reuse] there is still a lot to gain*" (I2). More experimentation (SF1) is required to develop more knowledge (SF2) and standards (SF5) for circular design (G1; G2; G17).

Substitution

For substitution, within the pilots (SF1) knowledge (SF2) is developed on the technical functionalities and properties of (renewable) alternatives in practice. However, as of this moment, a knowledge gap regarding the long-term performance of both applying biobased alternatives in asphalt and concrete and using wood as building material seems to inhibit upscaling (E2; G3; G19; K2). Hence, the lack of knowledge about the risks when applying alternative materials seems to be great. Pilots are currently monitored over a longer period (5-10 years) to develop this knowledge. However, since there is no generally accepted methodology for predicting and certifying (SF5) the long-term behavior of materials, it is difficult to validate and guarantee the quality, which hampers upscaling (E3).

SF3: (Withholding) Knowledge diffusion

Despite the described knowledge gaps (SF2) described above, it seems more problematic than available knowledge is not well diffused (SF3) within and between organizations for all solution directions. There is *"a lot of knowledge (SF2), but the exchange of that knowledge is lacking (SF3)"* (C2). Knowledge exchange within and between organizations fails on several fronts. First, "*academically developed knowledge is hard to come by*" (C7), because people often have to pay for it without knowing what they will get in return. Second, knowledge exchange on technical aspects between market parties is lacking (C2; C4; C7; G16). Despite that, a contractor stipulated that "*developments can be much faster by working together*" (C2). The SBIR was recognized as a good way to stimulate knowledge sharing (SF3) as it 'forces' market parties to work open-source and has been positively received by both market parties (C5, D6) and Rijkswaterstaat (G3).

Not only between organizations there is (too) little knowledge sharing, but also within organizations this can be problematic; circular knowledge is often in the hands of a limited group of people and it is difficult to distribute this internally (A4; C4; I2). In addition, knowledge developed in (pilot)projects (SF1) or studies (SF2) is often left behind (A2; E1; G3; K2; M4), as one interviewee stipulated *"reports just end up on the shelf or get lost. Before one study is completed, the next is already being started. But little seems to happen with the knowledge that is gathered"* (E1). This seems largely due to the lack of a knowledge infrastructure (A2); the structured recording and sharing of knowledge hardly occurs (A1). On the contrary, when knowledge is shared, it is often in the form of voluminous reports that people often do not read, and there is a lack of good examples that can be easily applied in practice (G11; G17).

On the positive side, within the networks, including Platform WoW, Platform CB'23, Cirkelstad, the buyer groups, and the UVW, knowledge diffusion is stimulated (G7; P2). For example, the UVW organizes regular 'circular' sessions where water authorities can discuss problems encountered when implementing circularity and sharing best practices (G12; U1). Additionally, within industry associations, such as for recycling, there is an open culture where knowledge exchange takes place (I2).

SF5: Market formation and destabilization

Applying circular solutions within projects is far from standard practice. As described under SF1, upscaling of innovation is regarded as very problematic, illustrated by: "*you often see a very big, beautiful iconic project, and the other 80% just goes on as business as usual*" (A2). Consequently, the participants of workshop 2 and the interviewees marked market formation and destabilization as one of the weakest fulfilled functions for all solution directions, as can be seen in Figure 4.

Within all levels of government, circularity seems to receive little attention within regular projects and tenders where the problem becomes greater considering lower decentralized governmental organizations (A2; A3; C2; C4; D6 G14). Nevertheless, public procurement offers opportunities to stimulate or even mandate circularity within projects in several ways, such as with minimum requirements, preconditions, technical or functional requirements, and diverse sustainability criteria (Copper8, 2020) as described in Section 5.1. However, sustainability and circularity criteria are only two out of often numerous criteria within tenders (D6). Moreover, standard tenders frequently give too little weight to award criteria related to circularity, as a result of which contractors indicate they cannot distinguish themselves in this respect (C4; C7; D6). An analysis of Bouwend Nederland (2021) shows that in 2020 a large majority of public tenders (60.8%) did not include any sustainable award criteria. Hence, standard tenders are often still awarded at the lowest price (A5).

A specific award criterion that can stimulate circularity and was often mentioned within the workshops and interviews was the ECI. An employee of Rijkswaterstaat indicated that the ECI has been compulsory in tenders since 2020 (G15). In addition, the interviews with decentralized governmental organizations revealed that the ECI is frequently used in tenders (A2; A3; A5; M1; M3; M4; P1; P2). Nevertheless, the ECI is not applied consistently by all government organizations, and when it is applied, the weight attached to it varies (I1; P2). Market players consider the ECI to be a useful tool (C3; C4; C6; C7), but the weight attached to it is often too low (C4; C7; D6). In addition, it seems to be thought that the ECI should not be used as the only criteria for stimulating circularity, but that it can help to make it comprehensible (A2; A3; A4; C5; I1).

A lack of market formation is partially explained by the lack of guidelines or standards (SF5) on how to request circularity within projects. In addition, the existing standards and norms for materials are high and stringent and the lack of validation processes and certification procedures (SF5) for innovative materials or reused components impedes the application of it in common projects (C2; C6; E2; G2; G14 G15; P1).

SF6: Resources (re)allocation

Concerning resources, within the infrastructure sector, a lack of human capital seems the most inhibiting factor. The lack of time and capacity was stressed within workshop 2 and within the interviews concerning decentralized governmental organizations (mentioned as a barrier by 9 out of 12 interviewees). An interviewee stipulated that the main obstacle is "*the lack of capacity, people are so busy. All organizations are so optimized. People want to, but it's just not possible. Must have time; doing things differently takes time*" (A2). As already described in Section 5.1., there is a lack of capacity within all organizations active within the infrastructure sector. In general, smaller decentralized governmental organizations face more capacity shortages, especially considering staff whose main responsibility concerns pursuing circular or sustainable ambitions while this is regarded as important (A1; A2; A3; A4; M1; M2; M4). Accompanied by a lack of capacity is a "*lack of knowledge within governments"* (A1), as elaborated under SF2.

Considering financial resources (SF6), there are several funds and subsidies available for pilots (SF1), but more financial resources are required to further develop and scale up innovations, especially for slow the loop and substitution. Nevertheless, a lack of budget for implementing circularity structurally within projects seems more problematic (A2; A4; M3). Increasing societal ambitions regarding sustainability and circularity have not yet been sufficiently taken into account when infrastructure budgets were determined resulting in tension between project goals and budgets (EIB, 2021).

Lastly, considering the supply of materials, there are not sufficient secondary materials to meet the demand in the infrastructure sector; there is a 'gap' of 35% between theoretical demand and supply (EIB & Metabolic, 2022). This implies it is necessary to focus not only on reuse and recycling but also on prevention and substitution in order to transition to a circular infrastructure sector.

SF7: Creation and withdrawal of legitimacy

There are mixed perspectives regarding the legitimacy of the mission itself. First, the concept of circularity remains vague, and the formulated goals are abstract and distant (A1; A5; C2; C3; C4; M1; M3), resulting in a lack of urgency (SF7). Within decentralized governmental organizations it appears as if "*support is there, but you live in a time when a lot of things seem to be very important*" (M4). As described in Section 5.2.2., circularity is competing over attention with other societal problems as well as day-to-day responsibilities. Although a lack of capacity and time (SF6) results in underprioritizing circularity, the importance and necessity of a circular infrastructure sector seem to be recognized (A3). On the contrary, a contractor stated: "*There are still far too many people in the industry who see any form of sustainability as something that 'must be done' and prefer to stick with ' we've always done it this way'" (*C2). With this, the need for the transition to circularity does not yet seem to be recognized by all actors in the infrastructure sector thereby compromising the legitimacy of the mission itself.

In addition to the legitimacy of the mission itself, there are differences between the legitimacy of the solution directions. These will be elaborated upon in the following paragraphs.

Close the loop

Close the loop seems to enjoy a higher level of trust and legitimacy (SF7) compared to the other directions since it is already common practice within the infrastructure sector. This is also reflected in the scores provided by the respondents in Figure 4. *"For recycling, there are already many products on the market that are proven and sufficient to meet the standards"* (G16).

Slow the loop

Extending the lifetime of assets or reusing at the construction or component level is regarded as essential to the transition by respondents of the workshops and interviewees. Nevertheless, since knowledge development (SF2) is still at the beginning and there is a lack of certification (SF5), the legitimacy of reuse seems currently low (SF7) (A4; C3; G14; I2), illustrated by: "*With reuse, there is much more distrust about the quality and usability of the product for the years that follow*" (A4). Moreover, there seems to be resistance from asset managers, engineers, and architects to work and design with reused components (G2; G12); there is still work to be done to make designing with used components 'sexy' (G2).

Substitution

The legitimacy of using (biobased) alternative materials within the infrastructure sector appears to be low (SF7). However, this might be enhanced due to insufficient secondary materials (SF6) to meet the demand in the infrastructure sector (Rijkswaterstaat, 2022). When considering wood, building with wood has a long history, but it seems to be forgotten a bit due to the arrival of modern materials (including concrete, asphalt and steel), which often have a stronger lobby (SF7) (G3). Additionally, public commissioners, as well as engineers and contractors, are more familiar with modern materials. Moreover, the large-scale maintenance required on one of the two large wooden bridges in Sneek does not contribute to the image of wood (SF7). Overall, as of this moment, confidence in building with wood is still low (SF7).

For materials with a biobased substitute, the legitimacy varies between specific solutions. Applying a biobased material, such as lignin, as a substitute for bitumen is recognized as an important solution at various levels of government and also by Rijkswaterstaat (G3). On the contrary, the legitimacy of geopolymer concrete as a circular solution is debated. Some parties, including contractors (C2) and the Concrete Agreement, state it is an important solution (SF7), at least to reduce CO2 emissions (SF4a). Other parties, like the Betonhuis, highlight the disadvantages of applying geopolymer concrete, with which they seem to be lobbying against the use of geopolymer concrete (SF7).

SF8: Coordination

According to the participants of workshop 2 and the interviewees, the lack of coordination (SF8), for the mission in general, is seen as one of the biggest barriers, as can also be seen in Figure 4. An interviewee stipulated: *"In my opinion, there is no coordination, and everyone does the best according to their own good judgment*" (A4). Coordination seems to be lacking on several fronts. First, there is a lack of coordination to map existing knowledge and subsequently identify knowledge gaps (SF2). After which there is also little coordination as to who undertakes what pilots (SF1), resulting in similar pilots being undertaken at a different location by a different coalition. Partly because of the lack of coordination (SF8), there is no overview of impactful solutions, which results in a low solution directionality (SF4a), as described in Section 5.2.3. Second, there are many initiatives and networks, as also demonstrated in Section 5.2., but there seems to be no good overview of them. Cooperation and coordination are lacking between them, which can result in divergence and a lack of a clear vision of the transition (SF4). Moreover, it seems that there is overlap between them resulting in scarce resources, such as time and capacity, being used for the same things.

Third, *policy coordination*, as described in Section 2.4., and communication between and across the different governmental levels seems to be lacking. Every autonomous governmental organization draws up its own policies, and an interviewee said that one of the biggest obstacles is that:

> *Everyone does it for themselves: If A does one thing, and B does another. As a market party, you have to switch gears constantly, which makes it complicated. The clocks have to be synchronized. There is a lack of continuity for market parties.* (A1)

The lack of (policy) coordination influences the reflexive governance of the mission. Currently, it appears as if there is no good overview of the progress of the mission, which makes it difficult to realign the mission if needed and to implement policies that aid the transition. Although agendas have been drafted and both market players and governmental organizations seek each other out to make agreements (SF8), there seem to be too many groups that also overlap and there is little convergence at the moment (A2; G7; P1). Overall, there is a prevailing view that "*more clear guidance/coordination is needed"* (G7), but it is not clear who should and can take on this role.

Besides coordination, monitoring within projects seems insufficient (P1) which benefits parties who promise *"golden mountains in the tenders"* (C4). The lack of monitoring seems to become greater when considering smaller decentralized organizations (A2; M4).

5.4. Systemic barriers analysis

After studying the innovation system, the ambitions set, the problem- and solution-directionality, and the fulfillment of each system function, three overarching systemic barriers have been identified that apply to all solution directions. The systemic barriers consist of functional barriers that influence and reinforce each other whereby these are also affected and amplified by structural features of the infrastructure sector. This section will first explicate the three general systemic barriers whereafter specific systemic barriers for each of the four solution directions will be discussed.

5.4.1. Generic systemic barriers

The three general systemic barriers within the infrastructure sector are:

1. The degree of knowledge development, sharing, and adoption is not sufficient
2. A lack of market formation prevents pilots from scaling up
3. There is a lack of guidance and coordination within the multi-level governance structure

The three systemic barriers do not stand alone but are connected and influence each other, resulting in a 'collective' blocking mechanism (Kieft et al., 2017). In the following paragraphs, a visual representation of each systemic barrier, and the link to the other systemic barriers, is presented. Herein, links between the functional barriers, as well as structural components, are merged to provide a comprehensive overview.

Systemic barrier 1: Lack of knowledge development, sharing, and adoption

Systemic barrier 1 concerns the development (SF2), diffusion (SF3), and adoption of circular knowledge as represented in Figure 5.

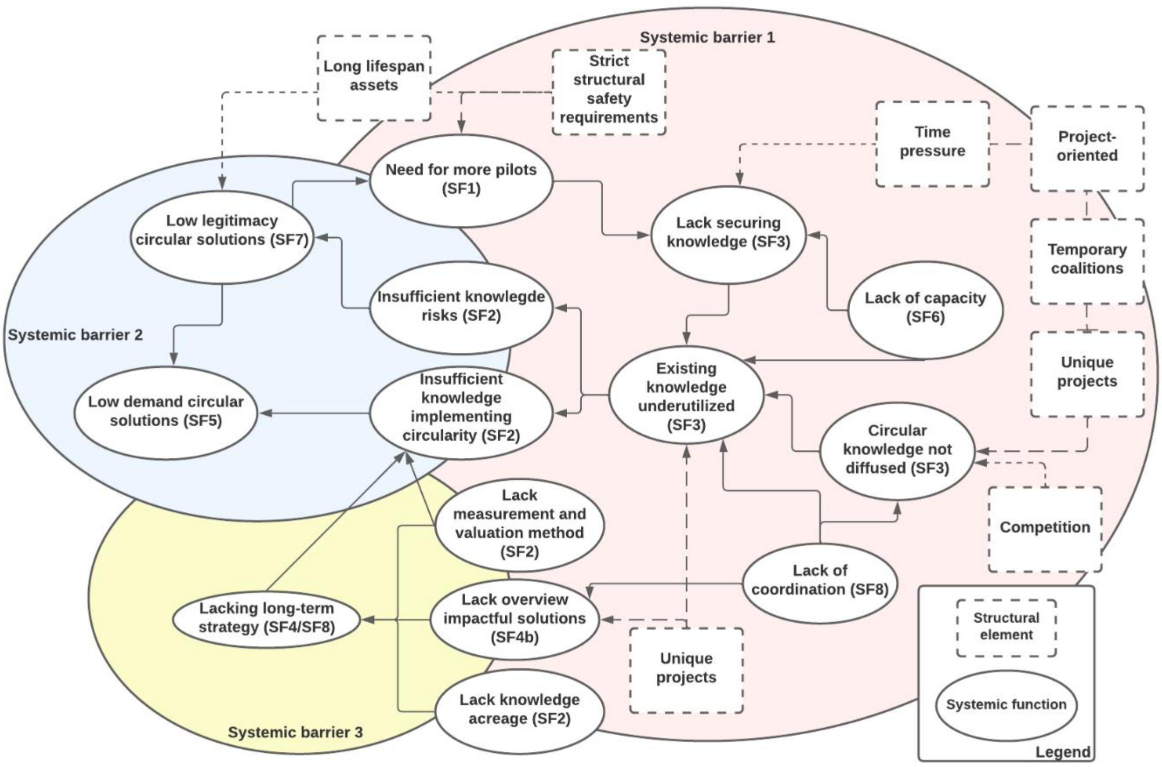


Figure 5. Systemic barrier 1: lack of knowledge development, diffusion, and adoption

The lack of knowledge (SF2) in several areas is currently impeding the transition to circularity. The lack of a clear definition of circularity (SF2/SF4a) in combination with no good overview of impactful solutions per asset type (SF4b) and a lack of knowledge regarding the acreage (SF2), hinders the drafting of a long-term strategy outlining targeted steps towards a circular infrastructure sector (SF4/SF8; Systemic barrier 3). The lack of a strategy in combination with the lack of a measurement and valuation method for circularity (SF2/SF5) fuels the lack of knowledge within governmental organizations on how to implement circularity within internal processes and projects. This in combination with the low legitimacy (SF7) of circular solutions due to a lack of knowledge (SF2) about the risks associated with them, makes governmental organizations hesitant to apply circular solutions in common projects (SF5; Systemic barrier 2). Knowledge about the risks is especially important in the infrastructure sector, given the long life span of assets and the strict structural safety requirements they must meet. More pilots (SF1) seem necessary to gain more confidence in innovations (SF7) and to acquire knowledge (SF2) on how to stimulate and implement them in projects.

On the contrary, existing knowledge is underutilized which can be traced back to several causes. First, contractors are reluctant to share knowledge (SF3) because it is part of their competitive advantage (C3; C4; C5). Second, new knowledge developed in pilots (SF1), or studies (SF2) is not secured, which is partly due to the lack of capacity within organizations and time constraints on projects (SF6) in combination with the project-oriented character of the sector: *"If one project is delivered, then the next project presents itself again. Partly due to lack of time (SF6), there are no project evaluations, and no one is behind it, you don't 'have' to follow it up (SF8)"* (M4). Due to a lack of coordination (SF8) and the absence of responsibilities, lessons learned are not recorded in a structured manner and collected at a central location which hinders the dissemination and use of knowledge (SF3). Complicating diffusing and utilizing knowledge (SF3), is the realization of unique assets by temporary coalitions. A large part of the knowledge developed is project specific and concentrated in the hands of a few (G17); transferring and applying the knowledge elsewhere requires a great deal of effort from both the first project team and the next (G17) while there is already a great lack of capacity (SF6). Overall, it seems like *"we learn, but we never complete the circle properly. And that has to do with different clients different companies that do the project, often in different combinations. So often wheels are reinvented"* (K2).

In addition to not diffusing and securing knowledge (SF3), people do not seem to have time to absorb and internalize existing knowledge (A3; A5; A4; M1; M4; P1; U1). Reviewing circular opportunities within projects or looking for information and examples requires time, but due to the high workload, this time is not available. As a result, available knowledge is not utilized (SF3) and there remains a knowledge gap (SF2) on how to implement circularity and the risks that accompany them (SF2). Consequently, confidence (SF7) in circular innovations remains low which results in testing circular innovations again in some kind of pilot form (SF1), by a different coalition at another location, again making securing and diffusing the knowledge gained difficult. This dynamic prevents the scaling up of innovations (SF5), resulting in a lock-in.

Systemic barrier 2: Lack of market formation preventing pilots from scaling up

Systemic barrier 2 concerns the lack of market formation (SF5) which prevents pilots from scaling up (SF1) as presented in Figure 6.

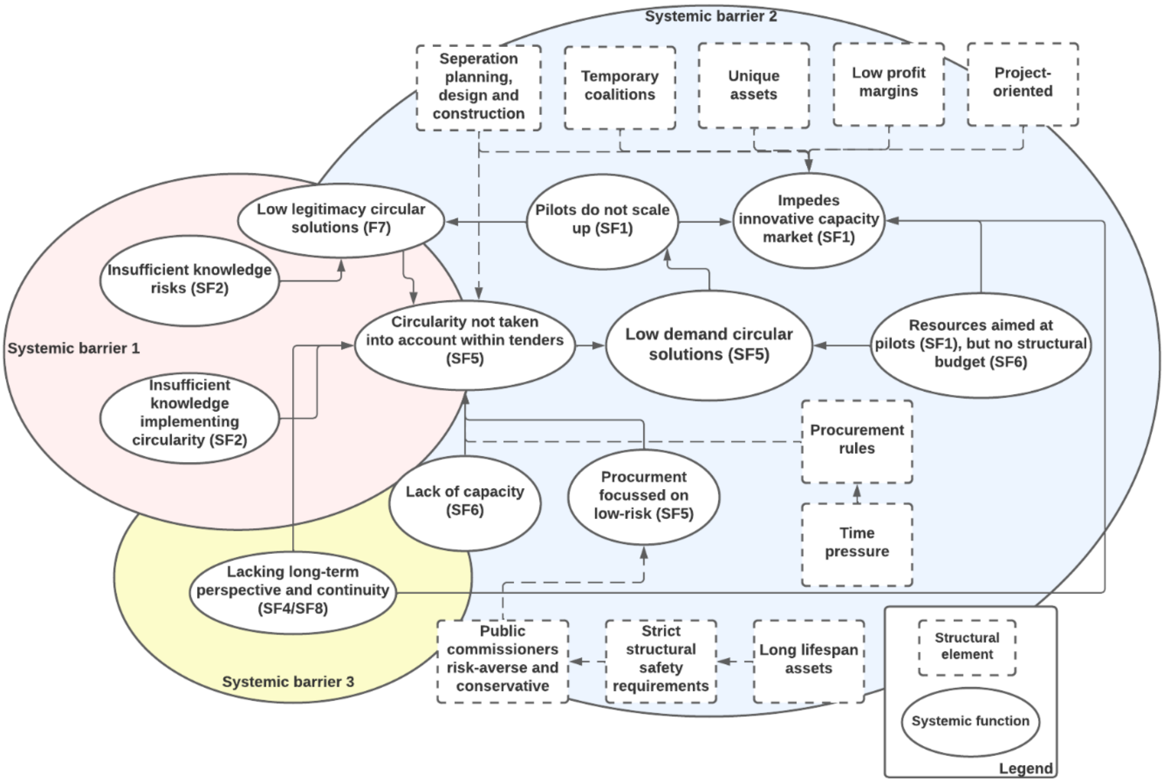


Figure 6. Systemic barrier 2: A lack of market formation prevents pilots from scaling up

A low demand for circular solutions in regular projects (SF5) curbs the innovative capacity of market participants (C3; C5; E1; I1). This is reinforced by the project-oriented character of the sector in combination with the uniqueness of the assets often realized in temporary coalitions; contractors (C3; C5) indicate that it is difficult to develop innovations further because they often cannot be applied in a subsequent project. Moreover, due to the low margins that market parties face in the infrastructure sector (EIB, 2021; C3), recouping investments within one project is difficult (SF6). Market parties seem willing to invest on the condition that there is a business case (C4). However, due to resources being aimed at pilots (SF1) and a lack of structural budget (SF6), there is uncertainty about the payback time of innovations. Additionally, the lack of a long-term perspective and continuity from public commissioners (SF4b/SF8; Systemic barrier 3) causes stagnation in developing and scaling up innovations (SF1) since market parties are dependent on the requirements of public clients.

> *The analysis showed that a predictable long-term pipeline of projects is a prerequisite for innovation. Because of limited certainty to recoup investments across projects, it is important to have a repetitive project. Therefore, in order to stimulate innovation, a long-term perspective should be developed for market players*. (Rijkswaterstaat, 2019, p. 38)

A low demand for circular solutions (SF5) is partly the result of strict structural requirements and an emphasis on the lifespan of assets in combination with governmental organizations that are risk-averse and conservative. As a result, tenders are often focused on low-risk (Cirkelstad, 2019) and circularity aspects are not sufficiently considered (SF5), which is fueled by the dynamics as discussed in Systemic barrier 1. Standard tenders frequently do not apply circular award criteria or give too little weight to them resulting in the majority of tenders still being awarded at the lowest price (Bouwend Nederland, 2020) which is partially explained due to the lack of structural funding (SF6). Furthermore, procurement rules and tender requirements in combination with the lack of knowledge within governmental organizations (SF2) on what is possible within these rules and a lack of time to do research (SF6), make public commissioners hesitant to change current practices and solicit for circular solutions, where this problem seems to be greater for smaller local authorities (A2; A4; M3).

Implementing circularity within projects requires a different way of thinking and working together (A1; A3; A4; A5; I2; C2; C4; D6; M2; P1; P2). The traditional separation between the planning, design, and execution phases and late involvement of market parties reduces opportunities for innovative, circular, approaches in projects since there is little or no room for contractors to propose alternative solutions during the execution phase (Larsson et al., 2013; A5; G2). Circularity should be included as early as possible within the process since "*in the preliminary process, the room must be created so that the circular solution can be made*" (G2) where it seems important to make use of the expertise of market participants. This is especially important given the long planning phase of infrastructure projects.

Overall, the public-private dependency within the infrastructure sector seems to result in a lock-in: governmental organizations are risk-averse and want proven innovations before they implement them widely in common projects (SF5), but market parties depend on the requirements set by governmental organizations and need the certainty of a sales market before they commit to innovations on a large scale as a result of which the legitimacy (SF7) of solutions remains low. Consequently, circular innovations are not applied in standard projects preventing innovations from scaling up (SF1), resulting in a vicious circle.

Systemic barrier 3: A lack of guidance and coordination within the multi-level governance structure

Systemic barriers 1 and 2 are partly the result of systemic barrier 3 which concerns the lack of guidance (SF4) and (policy) coordination (SF8) across and within the multi-level structure of governmental organizations. The dynamics of systemic barrier 3 are represented in Figure 7.

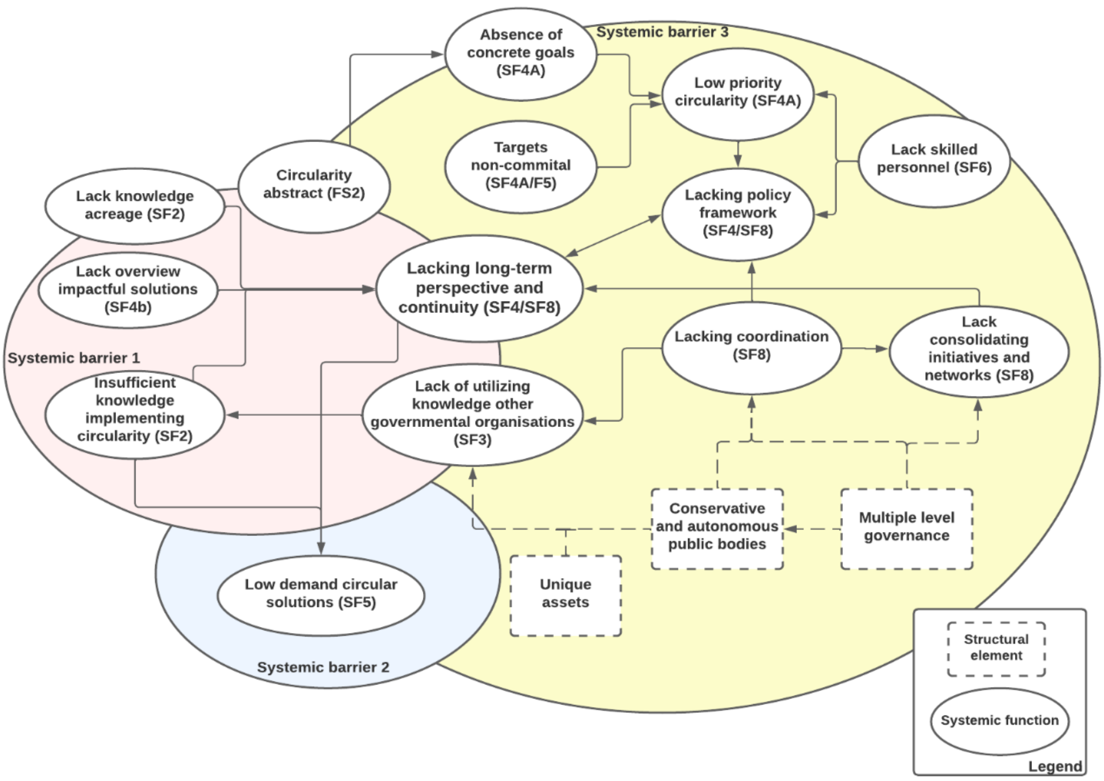


Figure 7. Systemic barrier 3: a lack of guidance and coordination within the multi-level governance structure

Despite the plans and agendas (SF8) drawn up at various levels of government, coordination (SF8) and directionality (SF4) seems insufficient. The concept of circularity remains vague, and the formulated goals are abstract and far away (SF4a) (A1; A5; C3; M1; M2; M4). In addition, there is a prevailing view at the level of decentralized governmental organizations that the national targets set are too non-committal, which makes it difficult, especially for municipalities (M1; M3; M4), to pursue them and results in a low priority for circularity (SF4a). As a result, a policy framework with ambitions and objectives revolving around circularity is often lacking in many decentralized governmental organizations "*which makes translation to the internal process and practice impossible"* (Sulkers & Koops, 2020, p. 9), which seems even more problematic for smaller governmental organizations (Sulkers & Koops, 2020; Schik & Kuijper, 2020; Wienk, 2020, 2022). This is reinforced because in many governmental organizations "*no one is responsible for implementing circularity in projects*" (M4); it is often something that has to be done on the side, which "*causes circular ambitions to fall by the wayside against everyday priorities"* (P2).

The aforementioned dynamics are partly due to the multi-level governance structure of governmental organizations. Partially due to differences in capacity, money, capabilities (SF6), and enthusiasm (P1; M1) within organizations, there are varying levels of ambition within the governmental layers where the size of an organization does not necessarily equal the level of ambition (P1; M1). All governmental organizations are autonomous and free to formulate and implement policies themselves which results in diverse policies and ways to integrate circularity in projects. However, governmental organizations (A1; M1; P1; P2; U1), as well as market parties (C3; C4; D6), emphasize the importance of a common goal and approach: "*Together, governmental organizations should provide a more unified signal, or a way of working together, towards the market*" (P2). Providing continuity and a long-term perspective (SF4/SF8) is essential to market parties, as described in Systemic barrier 2, and requires (policy) coordination (SF8) and communication within and across the different levels which is currently not sufficient. Networks can play a role to facilitate this (A5; M1; M2; P1; P2; U1), such as the UVW, IPO, the buyer groups, the various (materials) agreements, and various regional collaborations. However, at the moment there are too many 'clubs' (P2), which can lead to divergence and can send an ambiguous signal towards market parties. Moreover, an excess of clubs and networks requires a great deal of capacity (SF6), while human capital is already scarce. Coordination (SF8) is again required to consolidate initiatives and networks.

Moreover, partially due to the lack of coordination (SF8) between different governmental levels, the level of internal knowledge within governmental organizations about process related as well as technical aspects remains low (SF2; Systemic barrier 1). This is fueled by the reluctance of governmental organizations to adopt knowledge or best practices from others (A4; M1; P2): when an innovation has been tried and tested elsewhere, governments are reluctant to implement it themselves because they "*do not know it yet"* (P2) or because they think their project is slightly different (M1) which is also often the case due to the uniqueness of each project. Nevertheless, governmental organizations *"can learn a lot from each other, especially smaller municipalities, 'no need to reinvent the wheel*" (M1). The lack of coordination (SF8) to secure and diffuse existing knowledge (SF2/SF3) in combination with the reluctance of governmental organizations to implement tested innovations, fuels systemic barriers 1 and 2.

Overall, implementing circular ambitions requires a change of behavior and culture within organizations (A2; A3; A4; I1; M1; M2; M4). The lack of a clear vision and how to get there (SF2/SF4) in combination with the lack of skilled personnel and finances (SF6) to translate and implement national ambitions seems to currently hinder this transformation which is fueled by the lack of coordination (SF8) and cooperation.

5.4.2. Systemic barriers per solution direction

The three systemic barriers as described above apply to all solution directions but are more prevalent in some solution directions than in others. In addition, there are specific dynamics for each solution direction which are explicated in the following paragraphs.

Close the loop

A lack of market demand, as described in systemic barrier 2, seems the most inhibiting factor for close the loop. This is partially due to the lack of knowledge (SF2) on high-quality recycling and the life cycle of materials with a higher percentage of recycling granule in combination with a lack of diffusion and using existing knowledge (SF3; Systemic barrier 1) which makes governmental organization cautious (Systemic barrier 2). There is increasing attention to experiments and pilots (SF1) aimed at increasing recycling rates or high-grade recycling, but "*there is still too often looked at primary materials and still too little reliance on secondary materials … While granule suppliers are ready for upscaling"* (I2). For large market parties, the certainty of a sales market is important, otherwise, they are reluctant to invest in circular innovations (SF6) since they have set up their entire business case around the standard way of working (SF7) (C3; D6; G16). Hence, the lack of a unified signal towards the market and long-term perspective (SF4/SF8), as described in Systemic barrier 3, seems to inhibit upscaling. Moreover, high-quality recycling is not being promoted by award criteria (SF5). For example, the ECI used in tenders does not differentiate between high- and low-quality recycling (Stichting Bouwkwaliteit, 2019; Bizaro et al., 2020; Fraanje et al., 2021). Additionally, current legislation and regulations (SF5) may impede the application of higher percentages of granule in concrete or road surfacing which hampers the upgrading of recycling rates.

Slow the loop

The problems as discussed under systemic barrier 1 are more prominent for solution directionality slow the loop since it is in an earlier stage of development. Slow the loop is regarded as essential (SF7) for a circular infrastructure sector (Cirkelstad, 2021a; Platform CB'23, 2022c), but it is a complex task (C3; G7; I1) and requires a more radical change (C3). Knowledge development (SF2) is still at the beginning and certification (SF5) for secondary material is lacking which hinders their application because of the high structural safety requirements in the infrastructure sector. A method or system to validate the reusability and quality of parts or whole objects, whereafter this might be recorded via certification (SF5), seems essential to accelerate reuse (C3; D6; G2; G7; G14). Moreover, since the infrastructure sector produces many unique objects, guidelines and standardization (SF5) regarding (modular) circular design can promote reuse (G1). Coordination (SF8) and assistance in disseminating and integrating existing knowledge (SF2/SF3) also appear to be particularly important for reuse since only a few parties currently possess or are developing this knowledge, and reuse requires different competencies.

Knowledge development regarding the condition of the assets and materials (SF2; systemic barrier 1) in combination with coordination (SF8) among the levels of government (Systemic barrier 3) will be required to provide an overview of upcoming projects which is needed to bring supply and demand together. In this respect, marketplaces could play an essential role and should be scaled up and linked together to create enough mass and overcome timing issues (Cirkelstad, 2021a).

Coordination (SF8) and a clear direction set by the government (SF4b) could also help to further develop design know-how (SF2). Some components or structures lend themselves better for reuse than others, when there is a clearer focus (SF4b) on certain components, it is easier for market parties to build a business case around them (SF5). According to contractors, designing with freed-up parts could be stimulated by a functional demand with some kind of 'ingredients list' (SF5) (C5; C6; D6), illustrated by "*these are the objects/parts/materials that are available, and we want them to be applied in the most circular way possible*" (C5).

Overall, due to the lack of knowledge (SF2), experience, and standards (SF5), reuse currently takes much more time (SF6), and *"time is needed to design. Projects are already under such time pressure and reuse just takes much longer*" (C2). Therefore, it seems essential to allow more time (SF6) within the planning, design, and procurement phase (SF5) to enable reuse (A4; C2; C6; D6; G17).

Substitution

Substitution still seems to be fighting over attention compared to recycling and reuse (SF7). Substitution is not given a prominent place within agendas and agreements (SF8) and there is a lack of concrete targets to provide direction (SF4b), while interviewees stressed that this could help to get substitution off the ground (E3; G3).

The low legitimacy (SF7) of building with wood is caused by a lack of knowledge (SF2) which results in prejudices. More experimental development (SF1) is needed to develop knowledge on technical issues (SF2), including the lifespan and maintenance of wood structures, but also process issues such as the guidelines that wood must meet (SF5) (G3). Structural characteristics of the sector, including over-dimensioning, structural safety, and a strong focus on the lifespan of objects stand in the way of the use of wood. The lock-in as described in systemic barrier 1 seems especially problematic for building with wood:

> *Civil engineering structures are now usually made of concrete or steel, but they can also be made of wood. Well, there is also a lot of experience with this (SF2). Very often the word pilot is used, but I can tell you that we already have a lot of experience, but people often don't know that anymore (SF2/SF3). So it becomes a pilot again (SF1).* (K2)

Besides increasing the legitimacy of building with wood, confidence needs to be increased (SF7) in the quality and life span of asphalt and concrete containing (bio-based) substitutes. Certification (SF5) could also help to reduce the (perceived) risks which seems necessary due to the high structural safety standards and risk-averse public clients. This process could be facilitated by a greater commitment to substitution from governments (SF4b).

Narrow the loop

From both workshop 1 and 2 and various interviews, the picture emerged that the greatest impact can be made with prevention since *"step 1 of circularity is not doing it, that is where the biggest benefits lie*" (U1). However, as also described in Section 5.2.3., this strategy seems to receive too little attention (SF4b) partially because "*doing something less or not doing something is not sexy. … New projects are interesting; pilot projects (SF1) are always fun. [Asset] management is boring*" (A2). However, it has been indicated that asset management, from a primarily financial point of view (SF6), is always preferred (G2; G12; M2; M4). But due to a shortage in the budget (SF6), there is a lot of deferred maintenance, especially within municipalities (EIB, 2021). In addition, the of lack data and information regarding the state of the acreage (SF2), makes it difficult to perform timely maintenance.

Prevention requires a different way of thinking and should be considered in the initiation phase of a project. Rijkswaterstaat indicates that the decision to undertake a project or not is taken into account when a decision is made (G15). However, it was also stated that *"this should be done in collaboration with the market*" (I1). Since prevention does not only imply not doing something but also doing something (radically) different, such as extending public transport or reducing the speed limit so that widening of a road is not necessary (A2; C5), it appears as if these major social issues require attention from higher political powers, as different social problems and interests come together here (A2).

5.5. Governance actions

This section elaborates on the (planned) governance actions and how they may contribute to overcoming the systemic barriers as described in the previous section, hereby focusing on the three overarching systemic barriers. Moreover, recommendations for additional governance actions will be presented.

5.5.1. Identified governance actions

Numerous governance actions have been formulated or implemented by the actors within the mission arena that target the systemic barriers. For example, in the UP (2021) the Transition Team identified four focal points that should support the transition towards a circular infrastructure sector: 1) market development; 2) measurement; 3) policy, legislation and regulations; 4) knowledge and awareness. For each focal point, several specific actions have been written out. In total, 18 out of the 35 actions described seem to contribute directly or indirectly to overcoming one or more of the overarching systemic barriers in the infrastructure sector. Moreover, 6 actions contribute to overcoming the systemic barriers for slow the loop, and 3 contribute to overcoming systemic barriers for substitution. In addition to the Transition Team, several other actors have formulated or implemented governance actions, including Platform CB'23, Rijkswaterstaat, the Approach Sustainable infrastructure [Aanpak Duurzaam GWW], the UVW, and decentralized governments. An (incomplete) overview of (planned) governance actions and which systemic barrier(s) they address can be found in Appendix XIV. Within the following paragraphs, a brief overview will be provided of the governance actions in relation to the three overarching systemic barriers.

Concerning the dynamics discussed within systemic barrier 1, several governance actions address the knowledge gaps (SF2) and lack of knowledge diffusion (SF3). First, various parties, including the Transition Team, Rijkswaterstaat, and Platform CB'23, are taking action to improve securing data regarding the assets, including developing and streamlining the Materials Passport (SF2). In addition, governance actions are aimed at designing and improving methods to measure and value circularity (SF2/SF5). Together, these actions can contribute to determining high-impact measures and setting up a long-term perspective (SF4), which in turn stimulates market formation (SF5). To develop more knowledge regarding the risks and how to implement circularity (SF2), Rijkswaterstaat has put a tender on the market to establish a framework contract with (multiple) entrepreneurs to help them develop this knowledge. Moreover, governmental organizations at various levels are committed to carrying out pilots (1) in order to identify and learn about the risks accompanying circular innovations (SF2). These governance actions can help to increase the legitimacy (SF7) of circular solutions and knowledge regarding how to apply them which contributes to market formation (SF5; systemic barrier 2).

There are also several governance actions aimed at improving knowledge sharing (SF3). For example, the UP (2021) states all knowledge needs to be streamlined and bundled in one central place. In addition, several regional initiatives are constructing a website where specific examples of how to include circularity should be easily retrievable, for example by the Province of North-Brabant (Indusa) (P1) and by Circular Friesland (M1). Concrete examples in a central location could contribute to the dissemination of knowledge (SF3) and were regarded as important by several interviewees, especially for lower levels of government with limited resources (SF6) and knowledge (SF2) (A1; A3; A4; A5; M1; M3; P1). Bundling all existing knowledge is also a form of coordination (SF8), thereby addressing the problems as discussed in systemic barrier 3.

Regarding the lack of market formation and insufficient upscaling of innovations, as discussed in systemic barrier 2, various governance actions by the Transition Team were identified since market formation (SF5) is one of their spearheads. The following actions, among others, are considered:

mapping the most effective ways of circular procurement practices, setting up an inventory or toolbox for circular requirements within procurement, investigating how to include circularity as early as possible in the process, and reviewing obstructing regulations. Moreover, Rijkswaterstaat tries to stimulate market formation by a 'leader-pack' [koploper-peleton] approach, in which leaders who score well on the ECI in tenders are rewarded with a contract and the pack is taken along by tightening up (minimum) requirements along the way (KCI, 2020). The various buyer groups are also trying to promote market creation by developing a shared market vision and strategy that can send a clear signal to the market (SF4/SF8) and allow costs and risks to be shared. In this respect, a governance action of the Transition Team is to actively communicate and share knowledge about the buyer groups with municipalities and provinces (SF8). This is important as a market vision should be broadly supported to offer continuity to contractors, allowing them to further develop innovations (SF1/SF5) and make them more willing to invest (SF6). In addition, when provinces and municipalities are actively involved in the buyer groups, this can reduce the coordination problems (SF8) as discussed in systemic barrier 3.

The "Approach sustainable infrastructure" also focuses on market formation (SF5). Their aim is that the approach is used integrally, starting from the formulation of policy to concrete projects, for all projects in the infrastructure sector. By offering tools they contribute to knowledge about the implementation of circularity within projects (SF2; Systemic barrier 1), stimulate circular solutions within tenders (SF5; Systemic barrier 2), and provide guidance and continuity to both governmental organizations (SF4/SF8; Systemic barrier 3) and market players (SF4; Systemic barrier 2). Currently, they are, amongst others, developing a "Climate dashboard" [Klimaatdashboard] for governmental organizations in which various KPIs can be monitored to gain insight into the sustainable performance of infrastructure assets. This will help to measure circularity (SF2; Systemic barrier 1), identify impactful opportunities thereby providing directionality (SF4b; Systemic barrier 3), and improve monitoring (SF8). Moreover, the dashboard enables comparing the performance of governmental authorities, allowing for benchmarking, which can stimulate transferring best practices and learning (Systemic barrier 1 and 3).

Concerning the problems discussed within systemic barrier 3, there are governance actions aimed at creating a better understanding of the end goal and the way to go there. For example, the Transition Team stipulates they want to *"develop a concrete, measurable, widely supported end goal (by 2050) of the circular construction economy and a roadmap or timeline towards it, including a milestone for 2030*" (UP, 2021, p. 14). Moreover, roadmaps including more specific targets are being developed in various places, for example within the "goal trajectory" [doelentraject] and by Rijkswaterstaat within the "Programme CE in the infrastructure sector", but also for the focal areas within the KCI (2020). If the roadmaps paint a clear picture of why it is important to move towards a circular economy (SF4a) and give the targets more substance (SF4b), this could help with creating legitimacy of the mission itself (SF7) and aid the translation of circular ambitions to internal policies and processes for decentralized governmental organizations.

The UVW also formulated several governance actions that contribute to the coordination problems (SF8) and lack of guidance (SF4) as discussed in systemic barrier 3. To begin with, the "circular water authorities' story" (UVW, 2020) stipulates 90 actions that should be undertaken to aid the transition. For example, each water authority was encouraged to draw up their own circular strategy, for which they received assistance from the UVW (U1). Currently, every water authority has established a circular strategy and they are, in collaboration with the UVW, looking at how the strategy can be implemented and what is needed to do so (U1). The coordination (SF8) and assistance from the UVW, in combination with some pressure, seem to make it easier and more urgent for individual water authorities to work on and implement circular ambitions.

5.5.2. Recommendations additional governance actions

The governance actions set by actors in the mission arena address several root causes of the systemic barriers in the innovation system. However, some root causes are only partially addressed, while others seem to be neglected. In the following paragraphs, the unaddressed systemic barriers in combination with recommendations for (complementary) governance actions in order to speed up the transition will be discussed for the three overarching systemic barriers.

Regarding systemic barrier 1, there are several governance actions aimed at developing and sharing knowledge, but there seem to be few governance actions aimed at improving the recording of acquired knowledge and stimulating the utilization of existing knowledge. Within this regard, there seems to be a lack of governance actions on several fronts. First, it seems important that market parties are stimulated to share knowledge (SF3), this could for example be done by starting another SBIR in a field where knowledge is currently lacking (C2; C5; D7; G3). Second, interviewees stipulated that no one is currently responsible for securing knowledge gained in (pilot)projects and that too little time (SF6) is being made for (pilot)project evaluations (A2; M4). It could therefore be beneficial to free up more time for evaluation, to make someone responsible for securing lessons learned, and to transfer these to one central location so that the knowledge gained does not get lost. Coordination (SF8) is also required to ensure (pilot)projects are not undertaken multiple times, by different parties, at different locations and to create one 'central' location as there are currently multiple initiatives trying to construct such a place. Under these conditions, a central location with knowledge, tools, and concrete examples could contribute to securing and diffusing circular knowledge which was a major problem discussed in Systemic barrier 1.

The central location could also contribute to translating abstract ambitions to practice, which addresses the problems of systemic barrier 3 (A4; M1; M3; P1; P2). However, it was stipulated that mere examples are not sufficient to ensure that knowledge is also utilized and internalized within governmental organizations and projects (A4; G17; M1). Pursuing circular ambitions requires the integration of circularity into daily operations and projects which requires an organizational change (A2; A3; A4; G2; I1; M1; M2; M4), this social component seems currently insufficiently addressed by the governance actions. It seems essential that more support is created for circularity (M3); a better division of responsibilities for the implementation of circular ambitions within policies and projects could contribute to this (A2; M4). Moreover, raising internal knowledge (SF2) within governmental organizations by for example offering training (SF3) regarding how to implement and request circularity within projects could increase support for circularity (SF7) and help with the translation and implementation of goals (A4; G14; I2; M1); an example is the circular purchasing academy from Circular Friesland.

Also addressing systemic barrier 3 is the creation of roadmaps. However, coordination (SF8) seems to be required to ensure one clear vision is created, given there are currently multiple initiatives. Moreover, it would be advisable to actively involve decentralized governmental organizations and market players in the process to ensure broad support. Additionally, interviewees (A1; M1; M3) highlighted that removing the non-committal of targets to some extent could increase the priority of circularity (SF4a) and help local authorities to free up both financial and human resources (SF6).

It appears as if the networks within each layer of government (IPO, UVW, VNG) could help with translating ambitions into policy and facilitate implementation, illustrated by: *"It would certainly help if the VNG could also ensure that the administrative ambitions [regarding circularity] receive more* *attention"* (A5). It seems that the UVW has already taken on this coordinating role to a greater extent and could serve as an example. However, the promotion and use of existing networks does not seem to be a focal point of existing governance actions. Moreover, the consolidation and connection of initiatives and networks, does not seem to be sufficiently addressed by (planned) governance actions, although it could free up time and resources (SF6), and can contribute to providing a unified signal to the market (SF4/SF5). The lack of coordination (SF8) seems largely due to the fact that it is unclear who should and could take on this role. Therefore, it would be advisable to do more research into this aspect. As a starting point, interviewees (A1; A2; A3; M1; P1; P2) stipulated provinces could take on a more coordinating role and facilitate cooperation and mutual learning with respect to municipalities, illustrated by: *"Municipalities are busy, so the province could, for example, play a role in facilitating a working group to provide municipalities with prospects for action"* (Sulkers & Koops, 2020, p. 12). However, it seems important that the mutual relationships between provinces and municipalities are taken into account, including trust and respect for each other's abilities.

Regarding systemic barrier 2, although there are various (planned) governance actions aiming at improving market formation some aspects seem underemphasized. First, the great pressure of time on projects does not benefit the search for and implementation of circular solutions which does not seem to be reflected in the governance actions. Hence, it would be advisable to make more time available within the entire planning, design, and tendering phase, hereby it is important to include circularity as early as possible and to involve market parties at an early stage. Since time is a scarce resource, it seems important to create standards and guidelines (SF5) on how to implement circularity. By identifying high-impact solutions and creating focus (SF4b), for example within the roadmaps, this could be made easier. The governance action of the Transition Team of mapping out the most effective ways of circular procurement could also contribute.

Second, it seems as if there are few governance actions directly aimed at increasing the weights circularity criteria receive in tenders or stimulating the consistency of applying these criteria. Since continuity and reliability are important for market participants, more governance actions could be aimed at stimulating this where it seems important to actively involve decentralized governmental organizations in the process. In addition, the importance of setting stricter minimum requirements (C4; C6; D6; G14; M1; M2; P2) was stressed, such as a certain percentage of recycling granulate in new concrete or setting a maximum ECI for a particular material or project, to get the pack moving. *"To raise the minimum requirements, national laws and standards should be prescribed for this"* (P2). It would be advisable to increase the minimum requirements gradually. Overall, the various ways in which market formation will take shape in the coming years could be incorporated into the roadmaps which in turn should be communicated clearly to market players so that they can prepare for it. In workshop 2 it was suggested to *"make a kind of tender calendar per type of object and indicate how you want to make it more sustainable"* (C3) and the *"roadmap should be coupled to the calendar"* (I1).

Besides improving the weight and inclusion of minimum requirements and circular criteria, it seems important to continue experimenting with and scaling up working in other forms and with other contracts, such as working in construction teams, two-phase approaches, portfolio/framework approaches, as-a-service contracts and functional specifications, since these are seen by both market players (C3; C4; C5; C6; D6; I1) and government organizations (A1; A4; A3; G2; M2; M3; M4) as fruitful ways to integrate more circularity within projects. Subsequently, it would be advisable to create guidelines and share lessons learned at the central location to create uniformity here as well. At present, this does not seem to receive much attention considering the reviewed governance actions

Overall, it appears that to address the root causes of the systemic barriers, there is a need for a clear vision of the need for the transition to a circular infrastructure sector combined with clear examples and tools on how to get there. Creating a unified vision in combination with providing training to build internal knowledge on how to implement it and making someone or a team responsible for doing so, can help to send a single signal to the market and aid market formation. For this, it seems especially important that an organization with a mandate takes on a coordination role, whereby existing networks could be an essential role.

6. Discussion

This section discusses the results from Section 5 in relation to the theory (Section 2) and methodology (Section 4). First, the theoretical implications are discussed, followed by the limitations of this research. Moreover, recommendations for further research are provided.

6.1. Theoretical implications

This research applied the theoretical framework concentrated around the MIS by building on the work of Elzinga et al. (2021) and following to a large extent the structural-functional approach as recently developed by Wesseling & Meijerhof (2021). Based on the results of this research, several insights contribute to the further development of this MIS framework.

First, this research advocates further developments of the MIS framework since it proved to be a useful framework to map the complex innovation system dynamics that arise when a mission has been formulated. These dynamics would probably not have been done justice had other innovation system perspectives been used, such as the TIS. For example, since there are numerous technological and non-technological solutions required in pursuit of a circular infrastructure sector, the increased need for alignment and coordination would not have been captured by focusing on a single technological innovation as done within a TIS (Wesseling & Meijerhof, 2020; Elzinga et al., 2021). Here, the problem-solution diagnosis and distinguishing between ‘problem directionality’ and ‘solution directionality’ seems to be a valuable addition to explicate the complexity of the mission. Because of this, it came to light that the mission is currently vague and broadly formulated, which appears to result in divergent views on both problems and solutions, resulting in disorientation according to the problem-solution space as introduced by Wanzenböck et al. (2020).

Second, within this research, the sequences of the steps of the structural-functional approach were rearranged. It proved useful to first set out the structural analysis as this provided a good overview of the sector, its actors, networks, and institutions which allowed for a better interpretation of the formulation of ambitions, the problems and solutions, and how they were perceived by the various actors within the innovation system.

Regarding the structural analysis, this research made a first attempt to deepen the concept of the mission arena and the influence of the governance structure on the progress of the mission by taking into account the multi-level governance structure of governmental organizations. This proved useful since it showed the importance of translating national ambitions into policy frameworks at lower levels of government, which is in line with Wittman et al. (2021). Moreover, it revealed that shared decision-making competencies and variations among regions in terms of budgetary power, capacity, and competencies (Kaiser & Prange, 2007) can influence the implementation of ambitions and thereby the progress of the mission. The results seem to be consistent with the notion that a lack of policy coordination may hamper the successful completion of a mission (e.g. Weber & Rohracher, 2012; Wanzenböck et al., 2020; Janssen et al., 2021). Policy coordination seems required to safeguard consistency and provide continuity to market players (Howlett & Rayner, 2008; Rogge & Reichardt, 2016). Moreover, in line with several authors (e.g. Johannessen & Hahn, 2013; Reed et al. 2014; Gonzales-Iwanciw et al., 2019), the results of this research revealed that networks could facilitate and mediate between local and regional actors in order to support coordination and cooperation. To reveal the increased need for (policy) coordination across and within governmental layers, utilizing the function ‘coordination’ (SF8) instead of ‘reflexive governance’ (SF4c) proved to be a valuable addition. Future research could focus on gaining better insights into the effect of a multi-level governance structure on the mission arena and the progress of a mission. Additionally, more research could be done on how to achieve policy coordination and the role of networks to facilitate coordination, where recent literature regarding policy coordination and coherence could serve as a starting point (e.g. Kaiser & Prange, 2004; Bolleyer & Börzel, 2010; Milios, 2017; Trein et al., 2020).

Fourth, assessing the MIS at the level of clusters of innovation, utilizing the four different solution directions as set out by PBL, instead of at an aggregated level (Wesseling & Meijerhof, 2020; Elzinga et al., 2021), proved useful. The four solution directions provided structure to the analysis and allowed the identification of specific hampering system functions or systemic barriers per solution direction. Moreover, it reinforced the results of the "overarching" systemic barriers since they recurred in every direction. However, since every mission is unique, further research should provide more insight into the question on which level the functional performance should be assessed. In addition, in a follow-up study, more attention could be paid to the way the different solution directions fight over attention and resources and what influence this has on the progress of the mission.

Fifth, this research indicated that it is difficult to take into account the 'phasing out' of the existing practices by adding destabilizing activities as a counterpart to the system functions (Wesseling & Meijerhof, 2020; Elzinga et al., 2021). As was also noted by Elzinga et al (2020), another option would be to create a separate set of system functions to capture the essential regime transformation for a mission to be accomplished, this would be in line with Kivimaa and Kern (2016). Moreover, some highly influential activities or developments were difficult to allocate to one of the predefined functions. For example, many respondents perceived the lack of internalizing available knowledge as one of the key barriers, which does not fit within the predefined system functions accurately. Moreover, the need for behavioral change was emphasized by respondents which is also named as one of the key elements of societal challenge-led innovation policy (Haddad et al., 2019). As was stipulated by Elzinga et al. (2020), future research is necessary to determine whether the proposed assessment framework adaptations capture all relevant dynamics. This research seems to indicate that the ‘phasing out’ of existing practices and the social component that accompanies 'grand societal challenges' is not well-reflected in the current set of system functions. Therefore, adaptations to the assessment framework might be justified.

Lastly, it proved fruitful to use a Likert-scale to quantify the extent to which a system function was considered to be a barrier as it gave a first indication of the fulfillment of each function. In addition, it forced respondents to develop an overall judgment of each system function. Especially considering workshop 2: respondents were forced to consider the differences between close the loop and narrow the loop. Since scores were provided for three solution directions, this allowed comparing not only the fulfillment of the different system functions but also to compare the fulfillment of each function per solution direction. This was useful to make interpretations regarding differences between the directions, but also reinforced insights about the most prominent barriers in general. Scores can be used as a helpful tool for creating an overview and a first indication, however, it would be advisable to refrain from using them as the only method to decide which system functions act as barriers. The combination of multiple research methods, including the event analysis, workshops, and interviews, proved useful to identify the fulfillment of each system function, reviewing the reasons for weak fulfillment, and the connections between hampering system functions and structural features that may contribute to it, resulting in the systemic barriers.

6.2. Limitations

As stated in the methodology (Section 4), several measures were taken to uphold the reliability and validity of this research. However, some limitations have been identified. First, it was attempted to establish *internal reliability* by extensively discussing and reviewing the conclusions drawn from the results together with a second researcher. However, reviewing the allocation of events to the system functions by the second researcher, resulted in differences in coding which interferes with internal validation. Nevertheless, after discussing the differences in coding, an agreement was reached regarding the interpretation of both the events and system functions, thereby contributing to internal validity. Second, meeting the criterion of *external reliability* (Bryman, 2012) is difficult since an innovation system is dynamic and system functions change over time (Negro et al., 2007; Suurs & Hekkert, 2009). Nonetheless, this research attempted to rigorously record each step of data collection and MIS analysis to create an opportunity for other researchers to adopt a similar approach to analyze the case study (LeCompte & Goetz, 1982).

A clear limitation of this study is that it draws on one case study tied to the Dutch mission for a circular infrastructure sector. Since every mission is unique (Mazzucato, 2018; Janssen et al., 2021; Larrue, 2021), generalization of the results over social settings is limited (Wesseling & Meijerhof, 2020), thereby complicating *external validity*. Nevertheless, as elaborated upon in the section 'Theoretical implications', some generalizable insights could be drawn based on the theoretical constructs used within this research, e.g. the influence of a multi-level governance structure on the implementation and progress of a mission. Future research could determine whether the uncovered system dynamics prove relevant in other MISs and other geographical settings as well.

There were two limitations regarding the representativeness of actors in the MIS analysis. First, although in total 52 people have been consulted for this research, not every actor group was represented. For example, demolition companies, PIANOo, CROW, and NEN were not consulted while they do play an important role in the innovation system surrounding the infrastructure sector. Second, there are large differences regarding the level of ambition and implementation of them between the governmental layers, but also within governmental layers, which complicates drawing overall conclusions. Nevertheless, in addition to interviewing 7 people working for a decentralized governmental organization, 5 consultants were interviewed who have worked for several provinces, municipalities, and water authorities which allowed them to draw more general conclusions. An associated limitation is that the actor types have been mostly merged into the overarching terms 'provinces', 'municipalities', and 'water authorities' while there are differences in the degree of implementation and barriers experienced within these actor types. For example, some municipalities are ahead of provinces, but also quite a few are behind. Hence, it is difficult to lump them all together, but it seemed necessary to maintain an overview.

Regarding the solution directions addressed within this research, limited attention was paid to prevention while it is an important direction. However, prevention did not emerge within the event analysis, and it proved difficult to find information about it. Prevention of infrastructure is also closely linked to other sectors outside of the scope of this research, such as public transport or housing. Future research could focus on the interlinkages of these sectors and how this affects the mission.

Concerning the examination of (planned) governance actions, it proved difficult to map all (planned) governance actions by all mission arena actors as there are many. Several major actors were therefore chosen (e.g. Transition Team, Rijkswaterstaat, Platform CB'23, Approach Sustainable Infrastructure), but this probably resulted in governance actions being omitted. It is important to have a good overview of all governance actions, as they may reinforce or hinder each other and since policy consistency is regarded as important (Howlett and Rayner, 2008; Rogge and Reichardt, 2016). In a follow-up study, more attention could be paid to the (planned) governance actions, how they influence each other and what (if any) additional governance actions are required in mission pursuit.

Lastly, this research was conducted during the aftermath of the COVID-19 pandemic. This led to the limitation that interviews were conducted via video calls, which is generally seen as less preferable than face-to-face interviewing (‘t Hart, 2021). In contrast, the second workshop was live, which provided more opportunities for discussion among the participants.

7. Conclusion

Pressing societal problems, including climate change and increasing scarcity of primary raw materials, have changed innovation policy objectives and led to the formulation of societal-challenge based missions. Within this respect, the Dutch government has formulated the mission to transition to a circular economy by 2050 where the infrastructure sector is regarded as an important sector to become circular as it uses a vast amount of resources, energy, and water. To contribute to the theory of how to monitor and implement a mission and to aid a successful transition, this research applied the novel MIS framework, building upon the work of Wesseling and Meijerhof (2020) and Elzinga et al. (2021). Following the structural-functional approach of Wesseling and Meijerhof (2020), it studied the innovation system, the formulation of the mission, the problem and solution directionality, and the fulfillment of the system functions, in order to identify the systemic barriers. By comparing the (planned) governance actions to the systemic barriers this research answered the main research question of how the ongoing and planned mission arena's governance actions target the systemic barriers within the MIS of the infrastructure sector in pursuit of a circular sector by 2050. Since different levels of government have to translate and implement the national ambitions, the sub-question reviewed the implementation and coordination of the mission at the regional and local levels and how that influences the progress of the mission.

The structural analysis demonstrated that the infrastructure sector is a public sector where on the demand side mostly governmental organizations are present at different levels, including Rijkswaterstaat, 12 provinces, 21 water authorities, and 352 municipalities. Since governmental organizations outsource projects to the market via public procurement, they are in a position to shape and accelerate the transition, putting them in the mission arena. In addition to the prominent position of governmental organizations, the actors involved in drawing up the Transition Agenda, Platform CB'23, and Aanpak Duurzaam GWW attempt to shape the transition. In these networks, governmental organizations, as well as market parties, are represented. Governmental organizations depend on various market parties, including contractors, architects, engineers and advisors, recyclers, and demolition companies, for the realization of projects. In turn, the market parties depend on the requirements and projects set by governmental organizations, resulting in a public-private dependency. It is a project-oriented sector where projects are characterized by a long planning- and construction phase and are subjected to strict time and budget constraints. The projects are undertaken by temporary coalitions, where the assets produced are complex, unique, have a long lifespan, and have to uphold strict structural safety requirements.

The problem-solution diagnosis revealed that for both the problems as well as the solutions there is divergence. Circularity is mostly pursued to decrease CO_2 emissions, where the reduction of CO_2 emissions seems to receive priority over circularity as it is easier to measure and laws have been laid down. Moreover, within governmental organizations, circularity is competing over attention with other societal problems, including the energy transitions and sustainability in its full breadth, as well as day-to-day responsibilities. Concerning the solutions, there seems to be a lack of an overview of impactful solutions per asset type, and the interpretation of circularity is often left to the market, resulting in a low solution directionality. Despite that, at the moment, recycling is standard practice, which makes some parties believe the sector is already circular. On the other hand, there is also the realization that higher R-strategies need to be developed and deployed, where it seems that a lot of attention is being paid to reuse. Consequently, there appears to be a lack of attention to substitution and prevention.

Combining the insights from the structural analysis, problem-solution diagnosis, and system function analysis, this research identified three overarching systemic barriers that currently inhibit the transition to a circular infrastructure sector. Systemic barrier 1 concerns the lack of knowledge regarding the risks associated with circular innovations and internal knowledge within governmental organizations on how to implement circularity within internal processes and projects. In contrast, a lot of knowledge exists or is being developed, but because it is not properly coordinated, recorded, and diffused, a knowledge gap remains. This vicious cycle appears to be partially caused by the project-oriented nature of the sector in which unique assets are realized within temporary coalitions which hinders the learning capacity of actors in the sector.

The lack of knowledge, high structural safety requirements and existing norms for assets and materials, in combination with risk-averse and conservative governmental organizations, results in circular innovations not being sufficiently considered in regular projects, as represented by systemic barrier 2. This is fueled by the procurement laws to which tenders must comply and the lack of knowledge about what can and cannot be done within these laws. Consequently, not providing a long-term perspective and continuity to the market impedes the innovative capacity of market parties which is further hampered by low-profit margins, ever-changing coalitions, and a lack of standardization. As a result, since it is difficult for market parties to develop and scale up innovations, and risks cannot be properly estimated or safeguarded, questions about the risks remain, making governmental organizations hesitant to apply circular innovations.

Systemic barriers 1 and 2 are fueled by a lack of guidance and coordination, represented within systemic barrier 3. Circularity as a concept remains vague and the formulated goals are regarded as too abstract, distant, and non-committal, resulting in a low priority for circularity. Consequently, systemic barrier 3 demonstrates, that governmental organizations struggle with the translation and implementation of national ambitions within their own policies and internal processes resulting in circularity being included in projects sporadically. This problem seems to become greater considering lower levels of decentralized governmental organizations that face a greater lack of resources, including skilled personnel. The lack of coordination at the moment to consolidate networks and initiatives and the lack of guidance to help decentralized authorities to implement national ambitions results in an unambiguous signal to market parties, which seems to impede the transition at the moment, thereby answering the sub-question of this research.

The mission arenas governance actions that have been formulated partially address the systemic barriers, but seem to be insufficiently targeting the root causes. It appears that to accelerate circularity within the infrastructure sector, there is a need for governmental organizations to take up and fill in their prominent position. It seems important to create a clear vision of the need to transition to a circular infrastructure in combination with how to get there. The roadmaps that are currently being produced seem to be a good starting point.

Overall, it seems important that more attention is paid to the important role of coordination and who can take on this role. First, coordination is required to gather all existing information in one place, and from there to identify what knowledge is missing and who will develop it. Within this process, one could also look at the impact of innovations and which innovations are ready to be implemented on a larger scale, in order to create focus. Second, coordination is required to create one vision, in which it would be advisable to involve decentralized governmental organizations and market players. It seems important that this vision sets ambitious and concrete targets to show how the market will be shaped in the coming years. Within this respect, it could be helpful to indicate which minimum requirements and circular criteria will be used and how these will be increased over the coming years and communicate this to market participants. Lastly, coordination and guidance seem required to implement the ambitions in each layer of government. In this process, the networks could play a facilitating role as the link between the different organizations within a layer, but also between the layers. Moreover, allocating responsibility properly, by appointing someone or a team within a governmental organization, together with the necessary resources, to implement and pursue circular ambitions could help. Together, these actions could contribute to accelerating the transition towards a circular infrastructure sector.

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Appendices

Appendix I – Assets in the infrastructure sector

The infrastructure sector comprises various types of assets, including roads, bridges, viaducts and dykes. Until recently, there was no clear picture of the acreage within the various public commissioning authorities, but on April 29th 2022 the "Material flows in construction and infrastructure" was published by EIB and Metabolic. This report outlines the baseline of production, material flows, Environmental Cost Indicator (EQI) and CO2 emissions in construction, including the infrastructure sector, for 2019. They have tried to map out the acreage within the GWW. This has mostly been done using the Basic Registration of Large Scale Topography [Basisregestratie Grootschalige Topografie (BGT)]. However, they warn that the quality of the BGT is uncertain and that the overview of the acreage is probably incomplete due to a lack of data. Table 13 shows the overview taken from the EIB and Metabolic study for the asset types within the scope of this study (EIB & Metabolic, 2022).

Table 13. Overview of acreage per asset type.

Category	**Asset type**	
Roads (mln. m^2)	National roads	94.9
	Provincial roads	62.8
	Municipalities roads	737.5
	Bicycle tracks	93
	Walkways	308.2
Civil engineering structures (numbers)	Fixed bridges	68.800
	- Of concrete	57.300
	- Of steel	6.400
	- Of wood	5.100
	Viaducts	3.000
	Movable bridges	3.500
	Tunnels and subwas	3.500
	Locks	2.100
Coastal line and channel maintenance (km)	Dykes	18.900

Source: EIB & Metabolic, 2022

To give an indication of the differences in asset type per government level, Table 14 provides an overview based on a study by Bloksma and Westenberg (2021) and a study by the EIB (2021).

Table 14. Overview of acreage by asset type and government level

Category	**Assettype**	**State**	**Provinces**	**Municipalities**	**Water authorities**
Roads (km)[1]	Roads	7.588	7.817	121.220	6.821
Civil engineering structures (numbers)	Bridges and viaducts	4.502	2.882	62.514	14.675
	Tunnels and subways	429	667	1.914	32
	Locks	687	279	436	673
	Barrages	301	279	9.291	23.283
	Culverts	304	5.586	82.642	85.942
Coastal line and channel maintenance (km)	Waterways[2]	2.728	531	1.487	953
	Sheet piling[1]	181	191	354	56
	Quaysides and jetties[1]	415	35	1.785	288
	Dykes[3]	?			18.000

1. Source: Bloksma & Westenberg (2021)
2. Source: EIB, 2021
3. Source: Waterschappen

Appendix II – Materials in the infrastructure sector

Large volumes of soil, sand, clay, asphalt and concrete are required for the construction, management and maintenance of the various assets in the infrastructure sector (EIB & Metabolic, 2022; Rijkswaterstaat, 2022). The EIB and Metabolic report (2022) also maps out the material flows in the infrastructure sector. Table 15 shows the incoming and outgoing material flows in 2019 and the total materials stock in 2019 (EIB & Metabolic, 2022).

Table 15. Material streams and materials stock in the infrastructure sector in 2019

Materials	**Incoming flows stromen (ktonnes)**	**Outgoing flows (ktonnes)**	**Theoretical Match (%)**	**Materials stock**
Recycling granule[1]	7.610	3.870	51	516.700
Asphalt	7.190	5.710	79	253.100[2]
Bitumen				8.100
Concrete	4.460	2.650	59	390.300[2]
Cement				49.600
Stone	1.080	1.120	103	119.700
Industrial residues	750	370	49	58.800
Bricks[3]	260	190	70	7.400
Structural steel	110	60	55	14.700
Reinforcement steel	100	40	41	8.300
Plastics	27	4	15	2.200
Aluminium	13	14	108	600
Glass	8	7	88	100
Industrial sand	6	5	83	154.100
Insulation	5	6	120	300
Other	4	3	75	100
Other metals	2	2	100	
Subtotal excl. Filler sand, soil and clay[4]	**21.630**	**14.040**	**65**	**1.183.800**
Filling sand	23.670	620	3	1.619.300
Soil	10.020	0	0	156.900
Clay	1.730	0	0	525.200
Total incl. filling sand, soil, and clay[5]	**57.050**	**14.660**	**26**	**3.485.0**

1. Recycling granulate consists largely of mixed granulate, which is used as a foundation for roads. It has been assumed that, in 45% of cases, the granulate is released during replacement building. The outgoing flow of granulate is therefore granulate released from an asset where it was used as granulate. The outgoing flows of concrete and asphalt have also been indicated as such, but in practice they will often be released as concrete granulate and asphalt granulate respectively.
2. Asphalt and concrete are in this table, but are not included in the total weight, because the loose components of these two materials (e.g. industrial sand, water, etc.) are mentioned separately.
3. In the infrastructure sector, paving bricks are only used as street bricks.
4. The materials zinc, wood and gravel and additives not bound to asphalt or concrete are below 1 kt and have therefore not been included in this table.
5. Totals do not add up because of differences in rounding off.

Source: Metabolic & EIB, 2022

Appendix III – Overview of respondents

Code	Category	Description	From	#
A1	Advisor provinces and municipalities	Region: East of the Netherlands	Idec	1
A2	Advisor provinces and municipalities	Across the Netherlands	Idec	2
A3	Advisor provinces and municipalities	Region: South of the Netherlands	Idec	3
A4	Advisor provinces + municipalities	Across the Netherlands	Idec, W2	4
A5	Advisor municipalities	Across the Netherlands	Idec	5
C1	Contractor	Large construction company	W1	6
C2	Contractor	Large construction company	W2	7
C3	Contractor	Large construction company	W2	8
C4	Contractor	Large construction company	W2	9
C5	Contractor	Large construction company	W2	10
C6	Contractor	Large construction company	W2	11
C7	Contractor	Large construction company	W2	12
D1	Design, engineering & consultancy firm	-	W1	13
D2	Design, engineering & consultancy firm	-	W1	14
D3	Design, engineering & consultancy firm	-	ISub	15
D4	Design, engineering & consultancy firm	-	ISub	16
D5	Design, engineering & consultancy firm	-	W2	17
D6	Design, engineering & consultancy firm	-	W2	18
E1	Entrepreneur	Entrepreneur biobased materials	ISub	19
E2	Entrepreneur	Entrepreneur biobased bitumen	ISub	20
E3	Entrepreneur	Entrepreneur biobased concrete	ISub	21
G1	Governmental organization	Rijkswaterstaat	W1; W2	22
G2	Governmental organization	Rijkswaterstaat; Transition Team	W1; W2	23
G3	Governmental organization	Rijkswaterstaat; expert wood	W1; ISub	24
G4	Governmental organization	Rijkswaterstaat; Transition Team	W1	25
G5	Governmental organization	Rijkswaterstaat; Transition Team	W1	26
G6	Governmental organization	Rijkswaterstaat	W1	27
G7	Governmental organization	Rijkswaterstaat	W1; W2	28
G8	Governmental organization	Rijkswaterstaat	W1	29
G9	Governmental organization	Rijkswaterstaat	W1	30
G10	Governmental organization	Ministry (BZK)	W1	31
G11	Governmental organization	RVO	W1; W2	32
G12	Governmental organization	Water authority	W1; W2	33
G13	Governmental organization	Municipality	W1	34
G14	Governmental organization	Rijkswaterstaat	W2	35
G15	Governmental organization	Rijkswaterstaat	W2	36
G16	Governmental organization	Water authority	W2	37
G17	Governmental organization	Rijkswaterstaat; specialist reuse	Ire	38
G18	Governmental organization	Rijkswaterstaat; specialist reuse	Ire	39
I1	Industry association	MVO	W1; W2	40
I2	Industry association	Recycling industry association	W1; W2; Irec	41
I3	Industry association	Industry association construction and civil engineering companies	W1	42
K1	Knowledge institute	University	W1	43
K2	Knowledge institute	TNO; specialist substitution	ISub	44
M1	Municipality	Employee municipality of	Idec	45

		Heerenveen + Province Friesland		
M2	Municipality	Employee municipality of Nijmegen	Idec	46
M3	Municipality	Employee municipality of Dordrecht	Idec	47
M4	Municipality	Employee municipality of Apeldoorn	Idec	48
P1	Province	Employee Province Noord-Brabant	Idec	49
P2	Province	Employee Province of Zuid-Holland	Idec	50
U1	Water authorities	Union of Water authorities (UVW)	Idec	52

Legend

- W1 = Workshop 1: Problem-solution diagnosis
- W2 = Workshop 2: Circular design, reuse and recycling
- Ireu = Interview reuse
- Irec = Interview recycling
- Isub = Interview experts substitution
- Idec = Interview decentralized governmental organization

Appendix IV – Overview policy documents

Level	Document	Abbreviation
National		
Rijksbreed programma circulaire Economie	Nederland circulair in 2050 – Rijksbreed programma Circulaire Economie	
Grondstoffenakkoord	Grondstoffenakkoord – Intentieovereenkomst om te komen tot transitieagenda's voor de Circulaire Economie	
Transietieagenda Bouw	Transitie-Agenda Circulaire Bouweconomie	TA, 2018
Uitvoeringsprogramma 2019	Naar een circulaire bouweconomie - Uitvoeringsprogramma 2019	UP, 2019
Uitvoeringsprogramma 2020	Uitvoeringsprogramma 2020	UP, 2020
Uitvoeringsprogramma 2021-2023	De inrichting van het basiskamp – Uitvoeringsprogramma 2021-2023	UP, 2021
Rijkswaterstaat - IenW	Naar klimaatneutrale en circulaire rijksinfrastructuurprojecten Website: https://www.duurzame-infra.nl/	KCI, 2020
Provinces		
Limburg	Circulaire Economie Limburg 2.0 - Beleidskader 2020-2023	
Noord-Brabant	Circulaire Atlas Noord-Brabant	
Zeeland	Zeeuwse Omgevingsvisie Economische Agenda	
Zuid-Holland	Circulair Zuid-Holland – Samen versnellen	
Noord-Holland	Actieagenda Circulair Economie 2021-2025	
Utrecht	Beleidsvisie Circulaire Samenleving 2050	
Flevoland	Meerjaren Strategie 2020-2025	
Drenthe	Roadmap Circulaire Economie	
Gelderland	Circulaire Atlas Gelderland	
Overijssel	Regionale Transitie-agende Infrastructuur Provincie Overijssel	RTA, 2020
Friesland (Steunt agenda Circulair Friesland)	Transitie-Doe-Agenda Bouw – Circulair Friesland	
Groningen	Uitvoeringsprogramma 2020-2023	
Overkoepelend – Interprovinciaal Overleg	Kansenkaarten Circulaire Economie 2021	
Municipalities		
Amsterdam	Strategie Amsterdam Circulair 2020-2025	
Rotterdam	Rotterdam Circulair	
Utrecht	Utrecht Circulair 2020-2023	
Water authorities		
Unie van Waterschappen	Het verhaal van de circulaire waterschappen	UVW, 2021
Regional		
Metropoolregio Arnhem-Nijmegen	Regionale Agenda 2022	
Noord-Nederland (Friesland, Groningen, Drenthe0	Noord-Nederland Circulair	
Other		

Duurzaam GWW	Manifest Duurzaam GWW 2030	DGWW2030
Betonakkoord	Betonakkoord	
Bouwakkoord staal	Bouwakkoord staal	

Appendix V - Structure and questions workshop 1

Workshop 1 was organized as follows. First a short introduction of the MIS-analysis and especially the problem-solution diagnosis was provided. Thereafter, three different components of the problem-solution diagnosis were discussed using MentiMeter. After each question, a short discussion about the results that appeared on everyone's screen was conducted to provide more insight into the underlying reasons for the answers provided.

Type of question	Question	Possible answers
Problem directionality		
Open	Why it is important for the infrastructure sector to become circular?	
Ranking	Why it is important for the infrastructure sector to become circular?	○ Climate Change (CO_2-emissions) ○ Pollution of air, water and soil ○ Biodiversity loss ○ Supply risks of raw materials ○ Other
Goals in the infrastructure sector		
Open	Which agendas/agreements are leading for you?	
Open	What are the most important circularity goals within your organizations? (what keeps you awake at night?)	
Solution direction		
Open	What are the most important solution(direction)s to realize a circular infrastructure sector?	
Ranking	Which solution direction is currently receiving more attention?	○ Close the loop (recycling) ○ Slow the loop (life extension, repair, reuse) ○ Narrow the loop (using less raw materials) ○ Substitution

Appendix VI – Formulier scores functies MIS-analyse close the loop and slow the loop (Dutch)

In dit bestand staan de functies zoals uitgezet binnen het MIS-raamwerk. We willen u vragen om voor iedere functie aan te geven hoe belemmerend deze wordt ervaren om te versnellen naar een circulaire GWW. Doe dit door het cijfer dat u aan deze functie wilt geven dik te drukken of te markeren. Daarnaast is er ook ruimte om een korte toelichting te geven op u antwoord. Doe dit voor hoogwaardige recycling en hergebruik, gedefinieerd volgens het Lexicon Circulaire Bouw door CB'23.

- Hoogwaardige recycling (materiaalhergebruik): Terugwinnen van materialen en grondstoffen uit afgedankte producten en opnieuw inzetten hiervan voor het maken van producten van dezelfde of betere kwaliteit, functionaliteit en/of waarde.
- Hergebruik (producthergebruik): bouwproducten of bouwonderdelen /-elementen opnieuw gebruiken in dezelfde functie, al dan niet na bewerking.

Voor meer achtergrond informatie van de verschillende functies, kunt u het document "*Het Missie-gedreven Innovatiesysteem: Uitbreiding 'Technologisch Innovatie Systeem'-raamwerk ter monitoring van de Circulaire Economie*" (Elzinga et al., 2020)" doornemen.

Vraag 1: Experimenteren door ondernemers					
Is er voldoende ondernemerschap (startups, nieuwe technologieën, pilots) voor hoogwaardige recycling en hergebruik binnen de GWW? Op een schaal van 1 tot 5, hoe belemmerend is het (eventuele) gebrek aan experimenten? (1 voor niet problematisch, 5 voor zeer problematisch)					
Hoogwaardige recycling (materiaal hergebruik)	1	2	3	4	5
Hergebruik (product hergebruik)	1	2	3	4	5
Korte toelichting:					
Vraag 2: Kennisontwikkeling					
Wordt er voldoende onderzoek gedaan naar/kennis ontwikkeld over hoogwaardige recycling en hergebruik binnen de GWW? Op een schaal van 1 tot 5, hoe belemmerend is het (eventuele) gebrek aan kennisontwikkeling? (1 voor niet problematisch, 5 voor zeer problematisch)					
Hoogwaardige recycling (materiaal hergebruik)	1	2	3	4	5
Hergebruik (product hergebruik)	1	2	3	4	5
Korte toelichting:					
Vraag 3: Kennis uitwisseling					
Wordt de opgedane kennis over hoogwaardige recycling en hergebruik binnen de GWW goed gedeeld en verspreid? Op een schaal van 1 tot 5, hoe belemmerend is het (eventuele) gebrek aan kennis uitwisseling? (1 voor niet problematisch, 5 voor zeer problematisch)					
Hoogwaardige recycling (materiaal hergebruik)	1	2	3	4	5
Hergebruik (product hergebruik)	1	2	3	4	5
Korte toelichting:					
Vraag 4: Oplossing directionaliteit					
Worden er verwachtingen uitgesproken voor de potentie van oplossingen gericht op hoogwaardige recycling en hergebruik? En zijn er concrete overeenkomsten om een oplossing prioriteit te geven? Op een schaal van 1 tot 5, hoe belemmerend is het (eventuele) gebrek aan deze verwachtingen en prioriteit voor hoogwaardige recycling en hergebruik? (1 voor niet problematisch, 5 voor zeer problematisch)					
Hoogwaardige recycling (materiaal hergebruik)	1	2	3	4	5

Hergebruik (product hergebruik)	1	2	3	4	5
Korte toelichting:					
Vraag 5: Marktformatie					
Wordt er voldoende markt gecreëerd voor hoogwaardige recycling en hergebruik in de GWW, bijvoorbeeld middels aanbestedingen, standaarden, certificering? Op een schaal van 1 tot 5, hoe problematisch is het (eventuele) gebrek aan markt formerende activiteiten? (1 voor niet problematisch, 5 voor zeer problematisch)					
Hoogwaardige recycling (materiaal hergebruik)	1	2	3	4	5
Hergebruik (product hergebruik)	1	2	3	4	5
Korte toelichting:					
Vraag 6: Mobiliseren van middelen					
Zijn er voldoende middelen beschikbaar voor het ontwikkelen en opschalen van hoogwaardige recycling en hergebruik in de GWW, o.a. financiële middelen, personeel met kennis en materialen. Op een schaal van 1 tot 5, hoe problematisch is het (eventuele) gebrek aan middelen? (1 voor niet problematisch, 5 voor zeer problematisch)					
Hoogwaardige recycling (materiaal hergebruik)	1	2	3	4	5
Hergebruik (product hergebruik)	1	2	3	4	5
Korte toelichting:					
Vraag 7: Legitimiteit					
Is er vertrouwen in hoogwaardige recycling en hergebruik in de GWW? Wordt het gezien als een legitieme oplossingsrichting? Op een schaal van 1 tot 5, hoe problematisch is het (eventuele) gebrek aan legitimiteit? (1 voor niet problematisch, 5 voor zeer problematisch)					
Hoogwaardige recycling (materiaal hergebruik)	1	2	3	4	5
Hergebruik (product hergebruik)	1	2	3	4	5
Korte toelichting:					
Vraag 8: Coördinatie					
Is er voldoende coördinatie en reflectie voor hoogwaardige recycling en hergebruik binnen de GWW? Is er voldoende monitoring? Op een schaal van 1 tot 5, hoe problematisch is het (eventuele) gebrek aan coördinatie en reflectie? (1 voor niet problematisch, 5 voor zeer problematisch)					
Hoogwaardige recycling (materiaal hergebruik)	1	2	3	4	5
Hergebruik (product hergebruik)	1	2	3	4	5
Korte toelichting:					

Appendix VII – Form scores system functions MIS-analysis close the loop and slow the loop (English)

This file contains the functions as set out within the MIS framework. We would like to ask you to indicate for each function whether it is perceived to be a barrier for the transition to a circular infrastructure sector. You can do this by putting a thin mark on the number you want to give to this function. There is also space to give a short explanation of your answer. Do this for high-quality recycling and reuse, defined according to the Lexicon Circular Construction by Platform CB'23.

- High-quality recycling (material re-use): Recovering materials and raw materials from end-of-life products and reusing them to make products of the same or better quality, functionality and/or value.
- Re-use (product re-use): re-using construction products or building components/elements in the same function, whether or not after processing.

For more background information on the different functions, we refer to the document "The Mission-Driven Innovation System: Extension 'Technological Innovation System' Framework to Monitor the Circular Economy" (Elzinga et al., 2020).

Question 1: Experiments by entrepreneurs					
Is there sufficient entrepreneurship (start-ups, new technologies, pilots) for high-quality recycling and reuse within the infrastructure sector? On a scale of 1 to 5, how problematic is the (possible) lack of experimental development? (1 for not problematic, 5 for very problematic)					
High-quality recycling (material re-use)	1	2	3	4	5
Re-use (product re-use)	1	2	3	4	5
Brief explanation:					
Question 2: Knowledge development					
Is there enough research/knowledge being developed on high quality recycling and reuse within the infrastructure sector? On a scale of 1 to 5, how problematic is the (possible) lack of knowledge? (1 for not problematic, 5 for very problematic)					
High-quality recycling (material re-use)	1	2	3	4	5
Re-use (product re-use)	1	2	3	4	5
Brief explanation:					
Vraag 3: Kennis uitwisseling					
Wordt de opgedane kennis over hoogwaardige recycling en hergebruik binnen de GWW goed gedeeld en verspreid? On a scale of 1 to 5, how problematic is the (possible) lack of knowledge diffusion? (1 for not problematic, 5 for very problematic)					
High-quality recycling (material re-use)	1	2	3	4	5
Re-use (product re-use)	1	2	3	4	5
Brief explanation:					
Question 4: Solution directionality					
Are expectations expressed for the potential of solutions aimed at high-quality recycling and reuse? And are there specific agreements to prioritise a solution? On a scale of 1 to 5, how problematic is the (possible) lack of these expectations and priority for high-quality recycling and reuse? (1 for not problematic, 5 for very problematic)					
High-quality recycling (material re-use)	1	2	3	4	5
Re-use (product re-use)	1	2	3	4	5

Brief explanation:					
Question 5: Maret formation					
Is there a sufficient market created for high-quality recycling and reuse in the infrastructure sector, e.g. through tenders, standards, certification? On a scale of 1 to 5, how problematic is the (possible) lack of market formation? (1 for not problematic, 5 for very problematic)					
High-quality recycling (material re-use)	1	2	3	4	5
Hergebruik (product hergebruik)	1	2	3	4	5
Brief explanation:					
Question 6: Mobilizing resources					
Are there sufficient resources available to develop and scale up high-quality recycling and reuse in the infrastructure sector, including financial resources, materials, and personnel with knowledge? On a scale of 1 to 5, how problematic is the (possible) lack of resources? (1 for not problematic, 5 for very problematic) possible					
High-quality recycling (material re-use)	1	2	3	4	5
Re-use (product re-use)	1	2	3	4	5
Brief explanation:					
Vraag 7: Legitimiteit					
Is there confidence in high-quality recycling and reuse in the infrastructure sector? Is it seen as a legitimate solution direction? On a scale of 1 to 5, how problematic is the (possible) lack of legitimacy? (1 for not problematic, 5 for very problematic)					
High-quality recycling (material re-use)	1	2	3	4	5
Re-use (product re-use)	1	2	3	4	5
Brief explanation:					
Vraag 8: Coördinatie					
Is there sufficient coordination and reflection for high-quality recycling and reuse within the infrastructure sector? Is there sufficient monitoring? On a scale of 1 to 5, how problematic is the (possible) lack of coordination and reflection? (1 for not problematic, 5 for very problematic					
High-quality recycling (material re-use)	1	2	3	4	5
Re-use (product re-use)	1	2	3	4	5
Brief explanation:					

Appendix VIII - Interview guide experts substitution (Dutch)

#	Question	Theme
	Introductie	
1	Kunt u uzelf voorstellen en kort vertellen wat uw rol is binnen uw organisatie?	Introductie
2	Hoe ziet circulariteit in de GWW er volgens u uit?	
3	Wat zijn de hoofdroutes om tot 100% circulaire GWW te komen?	Oplossings-directionaliteit (SF4b)
	Substitutie: onder substitutie verstaan we het vervangen van eindige grondstoffen door hernieuwbare grondstoffen of alternatieve primaire grondstoffen met minder milieudruk	
4	Hoe staat deze oplossingsrichting ervoor? Hoe belangrijk is deze route binnen de GWW?	SF7/SF4b
	In de GWW onderscheiden we voor substitutie **twee richtingen**: 1) hout als constructiemateriaal in bijvoorbeeld bruggen en damwanden en 2) bio-based ingrediënten die toegevoegd worden aan producten (zoals asfalt, beton) om (gedeeltelijk) abiotische stoffen te vervangen (zoals olifantsgras, geopolymeren of lignine)	
5	Deze twee richtingen bevinden zich onzes inziens in verschillende ontwikkelingsfasen – 1: technologisch al toegepast en 2: nog in pilot fase – projecten nog in ontwikkeling - Is dit een juiste verdeling van de hernieuwbare (biobased) alternatieven? En zijn er nog andere belangrijke (biobased) alternatieven die niet binnen deze 'categorieën' vallen? - Op welk van deze twee richtingen bent u gespecialiseerd/zit uw kennis?	Twee richtingen substitutie: oplossings-directionaliteit (SF4b)
6	Wat zijn de drie grootste problemen voor (richting 1/2) om naar een volgende ontwikkelingsfase te gaan? - *Waar komen die vandaan? Hoe komt dit zo? Wat is de oorzaak?* - *Hoe problematisch is dit op een schaal van 1 (totaal niet) tot 5 (heel erg)?*	Systemische barrières
	Functionele analyse Uit de literatuur zijn er een aantal componenten die potentieel blokkerend kunnen zijn oplossingsrichtingen in transities (in dit geval substitutie). Graag gaan we in de volgende vragen in op de onderdelen die zojuist nog niet aan bod zijn geweest. Daarbij is de vraag wederom of u kunt aangegeven hoe problematisch deze factoren ervaren worden op een schaal van 1 tot 5?	
7	Welke activiteiten door ondernemers vinden er nu plaats op het gebied van substitutie in de GWW? Verloopt dit goed? - *Op een schaal van 1 tot 5, hoe belemmerend is het (eventuele) gebrek aan experimenten? (1 voor niet problematisch, 5 voor zeer problematisch)*	SF1
8	Wordt er voldoende onderzoek gedaan naar/kennis ontwikkeld over hernieuwbare grondstoffen? - *(Op welk gebied) mist er nog kennis/informatie? (Implementatie/gebruik, kwaliteit, technische functionaliteiten)* *Op een schaal van 1 tot 5, hoe belemmerend is het (eventuele) gebrek aan kennisontwikkeling? (1 voor niet problematisch, 5 voor zeer problematisch)*	SF2
9	Hoe wordt kennis gedeeld? - *Op een schaal van 1 tot 5, hoe belemmerend is het (eventuele) gebrek aan kennisdeling? (1 voor niet problematisch, 5 voor zeer problematisch)*	SF3
10	Wat is het belangrijkste probleem waar hernieuwbare grondstoffen een goede oplossing voor kunnen zijn?	SF4a

	- *Op een schaal van 1 tot 5, hoe belemmerend is het (eventuele) gebrek aan duidelijkheid over het probleem waar substitutie een oplossing voor zou kunnen zijn? (1 voor niet problematisch, 5 voor zeer problematisch)*	
11	Hoe worden hernieuwbare alternatieven meegenomen in het behalen van circulaire doelstellingen? - *Op een schaal van 1 tot 5, hoe belemmerend is het (eventuele) gebrek aan prioriteit voor substitutie? (1 voor niet problematisch, 5 voor zeer problematisch)*	SF4b
12	Op welke manier kan er markt gecreëerd worden voor hernieuwbare alternatieven? - *Worden (biobased) alternatieven specifiek uitgevraagd in tenders? Zou dit hulpvol zijn?* - *Op een schaal van 1 tot 5, hoe problematisch is het (eventuele) gebrek aan markt formerende activiteiten? (1 voor niet problematisch, 5 voor zeer problematisch*)	SF5
13	Welke middelen zijn er beschikbaar voor hernieuwbare alternatieven en zijn dit er voldoende? (Financieel, materialen, capaciteit) - *Op een schaal van 1 tot 5, hoe problematisch is het (eventuele) gebrek aan middelen? (1 voor niet problematisch, 5 voor zeer problematisch)*	SF6
14	Is er vertrouwen in hernieuwbare alternatieven binnen de GWW? - *Op een schaal van 1 tot 5, hoe problematisch is het (eventuele) gebrek aan legitimiteit? (1 voor niet problematisch, 5 voor zeer problematisch)*	SF7
15	Op welke manier spelen routekaarten en actieplannen een rol in de stimulering van hernieuwbare alternatieven? - *Hoe wordt er gemonitord op hernieuwbare alternatieven?* - *Welke coalities/partijen zijn er gevormd die een coördinerende/sturende rol uitoefenen m.b.t. het gebruik van hernieuwbare alternatieven?* - *Op een schaal van 1 tot 5, hoe problematisch is het (eventuele) gebrek aan coördinatie en reflectie? (1 voor niet problematisch, 5 voor zeer problematisch)*	SF8
	Governance acties	
16	Wat is er nodig om substitutie tot een succes te maken?	Governance actions
17	Wat werkt er het beste om substitutie te versnellen?	Governance actions

Appendix IX - Interview guide experts substitution (English)

#	Question	Theme
	Introduction	
1	Could you briefly introduce yourself and your role within your organization?	Introduction
2	What does a circular infrastructure sector looks like according to you?	
3	Wat zijn de hoofdroutes om tot 100% circulaire GWW te komen?	Solution-directionality (SF4b)
	Substitution: substitution concerns the replacement of finite materials by renewable raw materials (such as bio-based raw materials) or alternative primary raw materials with less environmental impact	
4	What is the …? How important is substitution in pursuit of the mission?	SF7/SF4b
	Within the infrastructure sector it appears as if there are two directions for substitution: 1) wood as construction material for bridges and sheet piling and 2) bio-based ingredients (such as elephants grass, geopolymer or lignin) that (partly) replace abiotic materials (within asphalt or concrete)	
5	The two solution directions are according to our observations in different development phases: 1) applied in practice 2) still in pilot phase - Is this division of renewable (biobased) alternatives correct? Are there any other important (biobased) alternatives that do not fit within these 'categories'? - In which of these directions are you specialised?	Solution-directionality (SF4b)
6	What are the three biggest problems for (direction 1 or 2) to go to the next development phase? - Where do they stem from? Why? What is the cause? - How problematic is this barrier on a scale from 1 (not at all) to 5 (very much)?	Systemic barriers
	Functional analysis From the literature, there appear to be several components that can form a barrier for a solution within transitions. We would like to go through the components that we have not discussed yet. Thereby we would like to ask again, if you could indicate how problematic each factor is on a scale from 1 to 5.	
7	Which activities by entrepreneurs are currently undertaken for substitution within the infrastructure sector? - *On a scale of 1 to 5, how problematic is the (possible) lack of experimental development? (1 for not problematic, 5 for very problematic)*	SF1
8	Is there sufficient research/knowledge development regarding alternative (renewable) resources? - *(In which area) is there a lack of knowledge/information?* - *On a scale of 1 to 5, how problematic is the (possible) lack of knowledge? (1 for not problematic, 5 for very problematic)*	SF2
9	How is knowledge diffused? - *On a scale of 1 to 5, how problematic is the (possible) lack of knowledge diffusion? (1 for not problematic, 5 for very problematic)*	SF3
10	What are the most important problems to which (renewable) alternative materials could be a solution? - *On a scale of 1 to 5, how problematic is the (possible) lack of clarity of the problem(s) to which substitution can contribute? (1 for not problematic, 5 for very problematic)*	SF4a
11	Are (renewable) alternative materials taken into account within circular goals?	SF4b

	- *On a scale of 1 to 5, how problematic is the (possible) lack of goals set for substitution? (1 for not problematic, 5 for very problematic)*	
12	To what extent is there market formation for (renewable) alternatives? - *Are (biobased) alternatives explicicately requested within procurment? Would this be beneficial?* - *On a scale of 1 to 5, how problematic is the (possible) lack of market formation? (1 for not problematic, 5 for very problematic)*	SF5
13	Which resources are available for (renewable) alternatives and are these sufficient? (financial, materials, human) - *On a scale of 1 to 5, how problematic is the (possible) lack of resources? (1 for not problematic, 5 for very problematic) possible*	SF6
14	Is there confidence in (renewable) alternatives within the infrastructure sector? - *On a scale of 1 to 5, how problematic is the (possible) lack of legitimacy? (1 for not problematic, 5 for very problematic)*	SF7
15	What role play roadmaps and agreements in stimulating the development of (renewable) alternatives? - *To what extent is there monitoring for (renewable) alternatives?* - *Which coalitions/parties are there with a coordinating/guiding role with respect to substitution?* - *On a scale of 1 to 5, how problematic is the (possible) lack of coordination and reflection? (1 for not problematic, 5 for very problematic)Is there sufficient coordination?*	SF8
Governance actions		
16	What is necessary to make substitution successful?	Governance actions
17	What needs to happen to speed up the development of substitution?	Governance actions

Appendix X – Interview guide decentral governmental organizations (Dutch)

Main interview question: How is the goal of a 100% circular infrastructure sector being implemented at the sub-national level (provincial, regional and municipal) and what barriers are being experienced?

Interview objective: From the interviews, workshop and event analysis, it appears that there are major differences in the implementation and pursuit of circularity within the infrastructure sector at the national level (Rijkswaterstaat) and regional, provincial and local levels. The purpose of the interviews is to verify this and to find out which obstacles are slowing down the transition on the sub-national level and how these can be overcome.

#	Vraag	Draagt bij aan:
	Introductie	
1	Zou u uzelf en uw rol binnen uw organsiatie kort kunnen introduceren?	Introductie
2	Waarom is het belangrijk dat de GWW circulair wordt?	Problemen (SF4a)
	Doelstellingen	
3	Welke circulaire doelstellingen/ambities voor de GWW zijn er binnen uw organisatie geformuleerd? - *In welke mate zijn deze beïnvloed door de nationale doelstellingen/agenda's?*	Doelstellingen (SF4/SF8)
4	Hoeveel draagvlak is er binnen uw organisatie voor de circulaire ambities binnen de GWW? - *In welke mate streven mensen binnen uw organisatie de doelen na?* - *Is het moeilijk of makkelijk mensen aan boord te krijgen?*	Draagvlak (SF7)
	Implementatie	
5	Hoe komen de circulaire ambities voor de GWW in de praktijk tot uiting? - *Wat zijn hier voorbeelden van?*	Implementatie (SF1/SF5)
6	In welke mate wordt circulariteit meegenomen in inkoop en aanbestedingen binnen uw organisatie (m.b.t GWW)? - *Waarom wel/niet?* - *Hoe wordt het meegenomen? (MKI, EMVI, stellen van eisen, etc.)*	Inkoop/aanbesteden (SF5)
7	Zijn er voldoende mensen met kennis beschikbaar binnen provincies/gemeenten/waterschappen om circulaire ambities te implementeren?	Kennis(deling) (SF2/SF3) en capaciteit (SF6)
8	In welke mate ontvangen provincies/gemeenten/waterschappen steun/coördinatie bij het implementeren en doorvoeren van circulaire ambities? - *Is dit voldoende?* - *Zo nee; van wie zouden ze meer steun moeten krijgen?*	Coördinatie (SF8)
9	Wat zijn volgens u de grootste verschillen tussen het implementeren en nastreven van circulair ambities op nationaal, regionaal, provinciaal en gemeentelijk niveau?	Verschillen implementatie
	Obstakels en interventies	
10	Wat zijn de (drie) grootste obstakels/belemmeringen die de transitie naar een circulaire GWW binnen uw organisatie vertragen? - *Waarom? Wat is hier de oorzaak van?*	Systeem functies en barrières
11	Wat kan er gedaan worden om deze obstakels te verminderen?	Governance acties

Appendix XI – Interview guide decentral governmental organizations (English)

Main interview question: How is the goal of a 100% circular infrastructure sector being implemented at the sub-national level (provincial, regional and municipal) and what barriers are being experienced?

Interview objective: From the interviews, workshop and event analysis, it appears that there are major differences in the implementation and pursuit of circularity within the infrastructure sector at the national level (Rijkswaterstaat) and regional and local levels. The purpose of the interviews is to verify this and to find out which obstacles are slowing down the transition on the sub-national level and how these can be overcome.

#	Question	Contributes to:
	Introduction	
1	Could you briefly introduce yourself and your role within your organization?	
2	Why is it important that the infrastructure sector becomes circular?	Problems (SF4a)
	Ambitions	
3	Which circular goals/ambitions for the infrastructure sector have been formulated and are pursued within your organization? - *To what extent are they influenced by the national targets/agenda?*	Goals and ambitions (SF4/SF8)
4	How much support is there within your organization for the circular ambitions within the GWW? - *To what extent do people within your organization pursue the goals? Is it difficult or easy to get people on board?*	Support (SF7)
	Implementation	
5	How are the circular ambitions for the infrastructure sector implemented in practice? - *What are some examples of this?*	Implementation (SF5)
6	To what extent is circularity taken into account in your organization's procurement and tendering processes (in relation to the infrastructures sector)? - *Why or why not?* - *How is it included? (MKI, EMVI, setting requirements, etc.)*	Procurement (SF5)
7	Are there enough people with knowledge available within provinces/municipalities/water authorities to implement circular ambitions? - *Is knowledge shared within and between organizations?*	Knowledge (sharing) (SF2/SF3) and capacity (SF6)
8	To what extent do provinces/municipalities/water authorities receive support/coordination in the implementation and execution of circular ambitions? - *Is this sufficient?* - *If not, from whom should they receive more support?*	Coordination (SF8)
9	What do you think are the biggest differences between implementing and pursuing circular ambitions at national, regional, provincial and municipal level?	Differences in implementation
	Barriers and governance actions	
10	What are the (three) biggest barriers/obstacles that slow down the transition to a circular infrastructure sector within your organization? - *- Why? What is causing them?*	Systemic barriers
11	What can be done to reduce these obstacles?	Governance acton

Appendix XII – Mapping scheme

Measurement scheme for mapping empirical events to system functions adapted to a MIS based on Suurs and Hekkert (2009).

System function	Event type	Description	Effect
SF1: Entrepreneurial experimentation, upscaling and business model phase-out	Portfolio expansion	A (vested) actor explores activities without any previous experience	+
	New company	New (circular) company	+
	Project entry	Experiment or pilot with (circular) solution started	+
	Project exit	Experiment or pilot with (circular) solution stopped	-
SF2: Knowledge development and unlearning	Learning by exploring/searching	Assessment research which stimulates the understanding of new technical and social knowledge on problems and solutions (scientific and professional publications)	+
	Learning by doing	Practical research into new technical and social knowledge on problems and solutions	+
	Patents	New patents on products or process	+
SF3: (Withholding) Knowledge diffusion	Networks, Coalitions	Co-operation between actors	+
	Meetings	Workshops, symposiums, conferences, etc.	+
SF4a: Problem directionality	Direction of the problem	Attention for the societal problem is increased through publications of agendas and roadmaps	+
	Prioritization of the problem	Signing of covenants or industry agreements	+
	Lack of clarity about prioritization	Different societal problems who fight over attention and resources	-
SF4b: Solution directionality	Conceptualization solution	Uncertainty/ambiguity about the conceptualization of a circular economy and it being a (feasible) solution	-
	Direction for solutions	Providing guidance/expressing expectations through roadmaps, factsheets and agenda-setting for solutions	+
	Agreements	Concrete agreements to prioritize a solution	+
	Feasibility solution	Portraying potential of solutions (e.g., feasibility studies)	+

SF5: Market formation and destabilization	Tax exemption starts	-	+
	Tax exemption stops	-	-
	Policy reform	Creation of formal or informal policies to support the diffusion of innovative solutions to complete the mission or phase-out harmful practices	+
	Circular procurement	Requesting circularity within regular projects through procurement	+
SF6: Resources (re)allocation	Investments, subsidies	Dedicated subsidy programs	+
	Procurement	Circular procurement practices in pursuit of the mission	+
	(Re)allocation human resource	Increasing human resources (e.g., through education) to support system activities	+
SF7: Creation and withdrawal of legitimacy	Dissent	Conflicting interests around the mission	-
	Lobby or advice pro	Pressure on actors in power to change institutions in pursuit of the mission	+
	Lobby or advice contra	Pressure on actors in power to change institutions, hampering mission completion	-
	Creation awareness	Creation of awareness through public campaigns, tv-commercials, posters, documentaries, etc.	+
SF8: Coordination	Evaluation activities	Deliberation, (progress) monitoring, anticipation, evaluation, and impact assessment procedures	+
	Insufficient evaluation activities	Lack of (transparently) monitoring mission's progress and measures to reorient the mission (if necessary) and catch up	-
	Incorporating lessons learned	Redirecting the system's problem framing and search for solutions based on lessons learned and the changing context.	+
	Coordination	Creation and publication/abandoning of roadmaps to structure transition	+
	Policy coordination	Coordination activities between the different governmental levels	+

Appendix XIII – Specific technological and non-technological innovations

Solution direction	Subsector	Solution	Source/example
Narrow the loop	Road pavement	Construct fewer or narrower roads	Versmalling Malderburchstraat
	Civil engineering structures	Construct fewer civil construction	Vervangingsopgave bruggen Amersfoort
		Civil constructions using less material for example by realizing them more efficiently through 3D printing or using leaner designs	3D-geprinte fietsbrug Nijmegen Slanke constrcutie Weerwaterbrug
Slow the loop	Road pavement	Life extending treatment of asphalt road through rejuvenation creams	Besproeien zoab met verjongingsmiddelen Latexfalt
		Asphalt mixtures with an extra-long service life	Ecopave XL COlt® Light
		Improving the maintenance of asphalt (using sensors and data)	Hightech = Lowcost (Asfalt-Impuls)
		Reduce variability of the asphalt construction process thereby reducing the variability of life span in asphalt pavement by systematic use of available, modern measuring and control techniques	Hightech = Lowcost (Asfalt-Impuls) + ASPARi-systematiek
		Lifetime predictive asphalt model [Levensduurvoorspellend Asfaltmodel] for improved maintenance	Levensduurvoorspellend Asfaltmodel (Asfalt-Impuls)
		Self-healing asphalt to increase life span	Healroad
		Modular concrete bicycle path	Ritspad®
	Civil engineering structures	Self-healing concrete	Basilisk Self-Healing Concrete

		Predict maintenance of locks and bridges through monitoring and data	Programma Vitale Assets Rijkswaterstaat
		Reuse of entire bridges	Bruggenbank
		Design with and reusing components of bridges, such as concrete beams	Hergebruik prefab liggers
		(Sustainable) preservation of steel bridges	Preservation steel bridges
		Modular and dismountable design and construction (for future reuse)	IFD-principe Demontable fietstunnel
Close the loop	Road pavement	In- situ recycling of old asphalt directly into new asphalt	Asphalt recycling train
		Applying (higher percentages) asphalt granules in new asphalt	Toepassingsmogelijkheden recyclinggranulaat Ecopave R (100%)
		Applying bitumen from roofs for roads	RooSF2Road
		Using concrete granule as a foundation material	Toepassingsmogelijkheden recyclinggranulaat
		Recycled and modular plastic road	Plastic Road
	Civil engineering structures	Concrete granulate as an aggregate in new concrete	Toepassingsmogelijkheden recyclinggranulaat
		Breaking down concrete into its components (sand and cement) after which new concrete can be produced	Slimbreker [Smartcrusher]
Substitution	Road pavement	(Partly) substituting bitumen with biobased alternatives	Chaplin (lignine) Bitumen uit mest KonwéBio Grasfalt
		Biological rejuvenators for recycled asphalt	Neomex ® HR Lynpave Ecopave R
	Civil engineering structures	Wooden structures, including wooden sheet piling, decking, lock gates, various jetties and different types of (mostly) bicycle and pedestrian bridges	Hout in de GWW
		Geopolymer concrete	Proeftuin Geopolymeren
		Applying miscanthus grass as filler in concrete	BioBound
		Using biocomposite (for bicycle and pedestrian bridges)	Biocomposite bicycle bridge

Table 16. Non-technological/institutional solutions

Strategy/mean	Solution	Source/example
Circular procurement	Requesting or stimulating circular solution within public tenders, via: - Setting a max. ECI on a material or project - Rewarding a low ECI - Setting minimum requirements - Rewarding circular criteria	PIANOo
Circular design	According to Platform CB'23, there are six different design strategies: (1) designing for prevention; (2) designing for reduction of life cycle impact; (3) designing for future-proofing; (4) designing with re-used objects; (5) designing with secondary raw materials; (6) designing with renewable raw materials.	Rijkswaterstaat, 2020; Platform CB'23, 2021
Materials passport	The materials passport of an asset is a means of providing insights into which materials were used in construction and maintenance, and how they were processed. This makes circular asset management, reuse and recovery of materials during demolition or dismantling of assets easier.	Cirkelstad, 2021c; Platform CB'23, 2022b
Different contract forms/methods for cooperation	- Construction teams - Infra-as-a-service - A portfolio approach - Two-phase tendering	- Construction teams - The circular road - Portfolio approach bridges - Rijkswaterstaat, 2019
Valuing assets differently	Total cost of ownership	Total cost of ownership
Certification of innovative materials	Asphalt quality desk	Asfaltkwaliteitsloket

Appendix XIV – Overview identified (planned) governance actions

Systemic barrier	Governance actions	Source
Systemic barrier 1	Inventory of what the current bottlenecks are for completing the National Environmental Database (NMD) and how these can be removed.	UP, 2021
	Conduct research on how to introduce a Materials Passport and applying it in practice	UP, 2021
	Action team of Platform CB'23 focused on Materials Passport, including: identifying required data, creating uniformity, formulate the goals of the passports, improve accessibility of the guidelines	Platform CB'23
	Determining how to value circular constructions	UP, 2021
	Sharing of knowledge, experiences and examples of circular procurement	UP, 2021
	Streamline and bundle all knowledge in one central place on the website www.circulairebouweconomie.nl and sharing this knowledge through various media;	UP, 2021
	Disseminating best practices of business models that are useful in construction	UP, 2021
	Advise on ongoing circular construction initiatives in curriculum development	UP, 2021
	Active communication and knowledge sharing about the buyer groups with municipalities and provinces	UP, 2021
	Action team of Platform CB'23 focused on measuring circularity, including: what data do you need and how do you calculate the impact of circularity compared to other activities	Platform CB'23
	"Programme CE in the infrastructure sector" ["Programma CE in de GWW"] of Rijkswaterstaat to develop knowledge of circular infrastructure and translating it into practice, focussing for eight themes: materials; measuring and monitoring; data and passports; circular management and maintenance; circular construction; high-end reuse; internal organisational change; external cooperation.	Rijkswaterstaat (bron)
	Development "Climate dashboard" [Klimaatdasboard] by Aanpak Duurzaam GWW. Through the dashboard, the progress of various KPIs can be easily monitored to gain insight into the sustainable performance of civil engineering construction and maintenance.	Aanpak Duurzaam GWW
	Knowledge procurement "Circular working in 2030 towards being circular in 2050" in the infrastructure sector by Rijkswaterstaat	Rijkswaterstaat (bron)

	Strengthening knowledge and innovation programmes that focus on the transition towards climate neutral and circular infrastructure. Developing new frameworks, forms of contract and working methods that can be used to carry out these assignments.	KCI, 2020
Systemic barrier 2	Sharing of knowledge, experiences and examples of circular procurement	UP 2021,
	Working towards a 'context-specific assessment for tenders' that project-specific	UP, 2021
	Draw up an inventory or a toolbox for circular requirements within procurement	UP, 2021
	Investigate how the business community deals with circular tenders from the government: What is asked for (requirements)? Is there room for own design (functional questions)? Are award criteria used and how heavily do they weigh? And how do client and contractor coordinate (e.g. in a construction team)?	UP, 2021
	Map out circular procurement practices: what are the most effective ways?	UP, 2021
	Further development of EQI; advise for which aspects it is necessary and feasible to add before 2023 to the statutory system by which sustainability/circularity is measured	UP, 2021
	Develop a tool that make it possible to assess the expected effect during design (among others on the EQI)	UP, 2021
	Advise on how circular aspects can be taken into account in the preliminary stages of the construction process	UP, 2021
	Gain insights into obstructing regulations	UP, 2021
	Rijkswaterstaat wants to implement a 'leader-pack' [koploper-peleton] approach, in which leaders who score well on the ECI in tenders are rewarded with a contract and the pack is taken along by tightening up (minimum) requirements along the way.	KCI, 2020
	Rijkswaterstaat serves as a launching customer and develops strategies to scale up scaling up promising innovations	KCI, 2020
	Within the buyer groups, agreements are made between various government organizations in order to be able to send a unified signal to the market	PIANOo (source)
Systemic barrier 3	Sharing of knowledge, experiences and examples of circular procurement	UP 2021
	Map out circular procurement practices: what are the most effective ways?	UP 2021
	Active communication and knowledge sharing about the buyer groups with municipalities and provinces	UP 2021
	Develop a concrete, measurable, widely supported end goal (by 2050) of the circular construction economy and a roadmap or timeline towards it, including a milestone for 2030. In which cooperation must be sought with other initiatives	UP 2021
	Streamline and bundle all knowledge in one central place on the website www.circulairebouweconomie.nl and sharing this knowledge through various media;	UP 2021
	Support and connect practice initiatives	UP 2021
	Roadmaps produced for each theme within the "Programme CE in the infrastructure sector" of Rijkswaterstaat	Rijkswaterstaat (source)

	Roadmaps produced by Rijkswaterstaat for “Strategy climate neutral and circular infrastructure” [Strategie klimaatneutrale en circulaire infra], for areas with the greatest climate impact: road surfacing, engineering works, shoreline & channel maintenance, construction site & construction logistics, railway superstructure and railway energy supply.	KCI, 2020
	Target pathway [doelentraject] to give the circular economy goals more substance	Doelentraject
	Development “Climate dashboard” [Klimaatdasboard] by Aanpak Duurzaam GWW. Through the dashboard, the progress of various KPIs can be easily monitored to gain insight into the sustainable performance of civil engineering construction and maintenance. Governments gain insight into which sustainability efforts contribute a lot (i.e. really work) and which less so.	Aanpak Duurzaam GWW
	Under the guidance of the UVW, each water authority has drawn up its own policy framework and now, under the guidance of the UVW, they are looking at how this can be implemented.	Water authorities and UVW
Systemic barriers slow the loop	Reviewing how to ensure supply of secondary materials from demolition and repair and renovation match the demand for new projects and renovation.	UP 2021
	Reviewing developments circular material hubs and bringing them together	UP 2021
	Test selected promising segments and improve them through action research.	UP 2021
	Conduct research on how to introduce a Materials Passport and applying it in practice	UP 2021
	Develop an assessment method for detachability in the infrastructure sector	UP 2021
	Develop an assessment method for detachability in the infrastructure sector	UP 2021
	Action team of Platform CB’23 aimed at future reuse, focusing among other things on: information required for reuse, legislation and technical regulations, future design, performance requirements	Platform CB’23
	SBIR – Circular viaducts	Rijkswaterstaat
Systemic barriers substitution	Gain transparency as to whether renewable materials (bio-based) meet the right quality requirements (next step could be to develop a quality certificate)	UP 2021
	Identify the high-impact streams of renewable materials in the coming years	UP 2021
	Find out what is needed to stimulate the production side of high-impact renewable streams	UP 2021