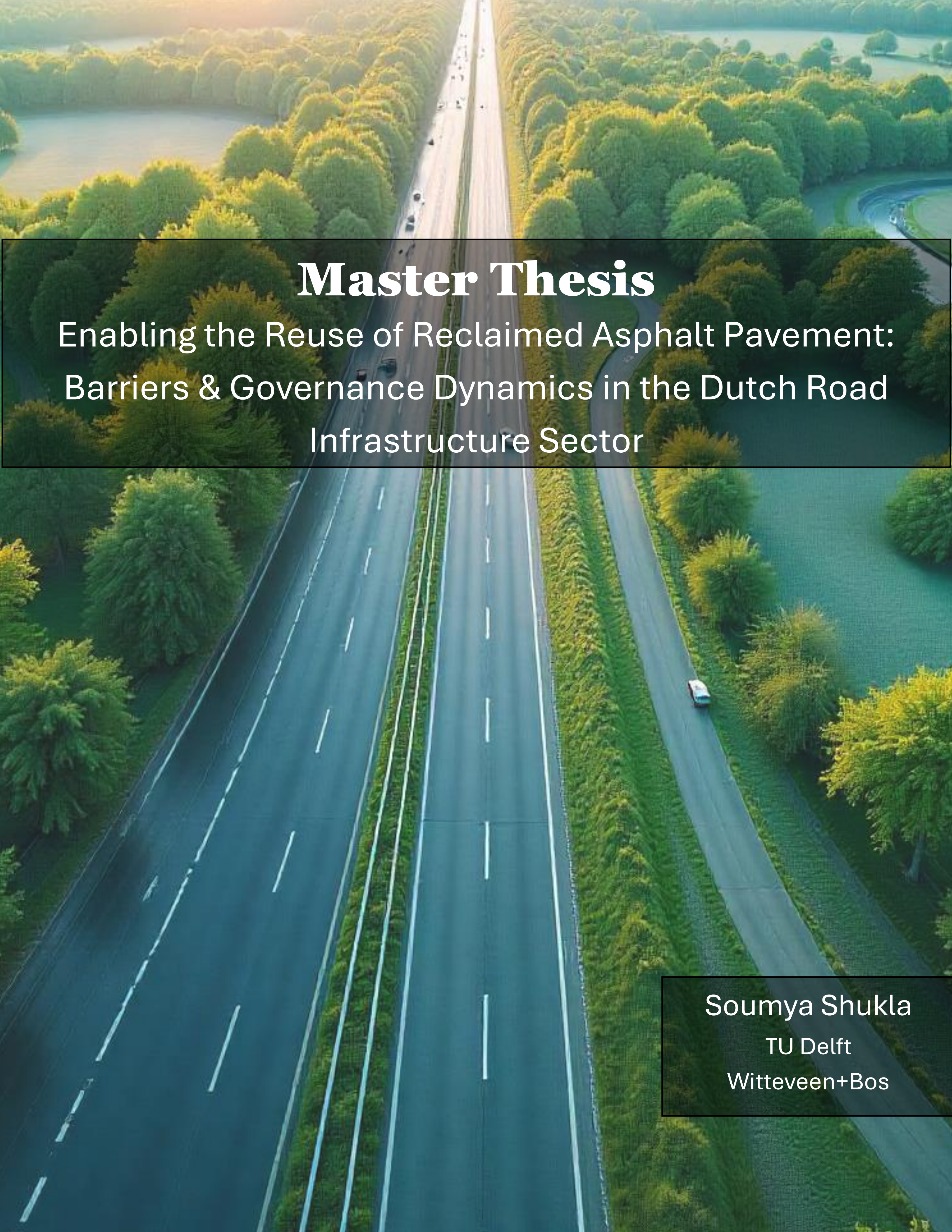

Master Thesis

Enabling the Reuse of Reclaimed Asphalt Pavement: Barriers & Governance Dynamics in the Dutch Road Infrastructure Sector

Soumya Shukla

TU Delft

Witteveen+Bos

MASTER THESIS

Enabling the reuse of Reclaimed Asphalt Pavement: Barriers & Governance Dynamics in the Dutch Road Infrastructure Sector

By: Soumya Shukla
Student Number: 5989051

In partial fulfilment of the requirements for the degree of Master of Science in Construction Management and Engineering at the Delft University of Technology

Graduation Committee

Chair:	Daan Schraven *Faculty of Architecture and the Built Environment*
First Supervisor:	Ruben Vrijhoef *Faculty of Architecture and the Built Environment*
Daily Supervisor	Felix Fröhling *Faculty of Architecture and the Built Environment*
Company Supervisors	Bas Roelofs *Witteveen+Bos* Frank Christian-Clark *Witteveen Bos*

Preface

This thesis is the final product of my master's program in Construction Management & Engineering at Delft University of Technology. It has been conducted in collaboration with Witteveen+Bos, with a focus on Reclaimed Asphalt Pavement in the Dutch road infrastructure sector.

The motivation for this research stems from my interest in circularity in the infrastructure sector. Working on this thesis has been both a challenging and a rewarding journey. It gave me the opportunity to deepen my academic knowledge while engaging directly with practitioners in the sector, whose perspectives and experience enriched this study.

I would like to sincerely thank my supervisors from TU Delft, Dr. D.F.J. (Daan) Schraven, Dr.ir. Ruben Vrijhoef, & Felix Fröhling for their valuable guidance and feedback throughout the process. I also want to thank my supervisors from Witteveen+Bos, Bas Roelofs and Frank Christian-Clark for their guidance and support and for opening doors for me to a professional network that proved crucial for this research. I also thank all the stakeholders who generously gave their time for an interview and shared their expertise.

Finally, I want to extend my gratitude to my family and friends for their constant encouragement and patience during this journey.

Enjoy Reading!

Soumya Shukla

20th September, 2025

Executive Summary

The road infrastructure sector is one of the most resource intensive sectors in Europe, requiring substantial amounts of virgin materials and contributing significantly to carbon emissions. Asphalt is the most widely used road paving material worldwide accounting for nearly 90% of total EU Road network and contributes significantly to carbon emissions, resource consumption and energy intensive production processes (Shacat et al. 2024). In the Netherlands, the annual asphalt production contributes to nearly 600 Kilotons of CO_2e emissions with material extraction and production processes contributing the most (EIB, 2022). Reclaimed Asphalt Pavement (RAP) provides substantial environmental and economic benefits including reduced virgin material demand and lower emissions, and cost savings (Ahmeti et al. 2023). Despite these benefits, the adoption of RAP reuse practices remains hindered due to several barriers that span technical and regulatory themes. The Dutch asphalt paving sector, having a significant environmental footprint, has pursued a wide range of sustainable innovations including secondary materials, life-extending agents, additives, bitumen modifiers and so on (Chen et al. 2021). However, the sector remains in early stabilization phase, where sustainable innovations and practices are emerging and challenging dominant regimes but struggle to scale up (Ruiz et al. 2024).

The existing literature identifies a wide range of barriers to the reuse of RAP like performance and quality concerns, unclear guidelines and specifications, fragmented regulations, market concerns and so on. However, most of it focuses on specifically the technical challenges and some regulatory challenges in reusing RAP while cultural barriers and specific regulatory challenges like lack of information sharing, collaboration, and misaligned circular goals also affect reuse practices. Furthermore, these barriers are treated in isolation, and the governance roots behind them are underexplored. Another gap is that little attention is given to successful RAP projects to understand what enables success. This study addresses the gaps mentioned above by applying a Multi-Level Governance lens to understand why certain barriers persist and how governance structures in a project enable or restrict RAP reuse. Moreover, MLG has not yet systematically been applied to circular construction materials. The objective of this research is therefore to identify the key barriers to the reuse of RAP in the Netherlands and to analyze how governance structures shape these barriers in practice and how they might be addressed. The overarching research question then becomes:

How do governance structures shape the barriers to the reuse of Reclaimed Asphalt Pavement (RAP) in the Dutch road infrastructure sector and what does this imply for addressing them?

To answer this question logically and sequentially, a qualitative exploratory research methodology is adopted. First, a literature review process to understand what literature says about the barriers to RAP reuse was conducted that created a baseline of barriers spanning 5 categories: regulatory, market, technical, information & knowledge sharing, and institutional & governance. This informed the first wave of interviews, with key stakeholders across the asphalt value chain, to identify which barriers actually occur in practice and see how different stakeholder groups perceive them and also verify literature identified barriers. The second wave of interviews focused on three case projects and general project practices to understand how governance arrangements are structured at the project level and how it affects RAP reuse. By applying the MLG framework by utilizing four governance characteristics: authority in decision-making, jurisdictional boundaries, coordination mechanism, and adaptability, the understanding behind why certain barriers persist is extended.

The findings of this study suggest that the barriers to increased reuse of RAP can be categorized into four main themes: Technical, Regulatory, Cultural, and Market.

- Technical Barriers: Uncertainty in the quality of RAP, Lack of long-term performance monitoring of mixes with RAP, Lack of standardized technical guidelines, Challenges in reusing RAP in surface layers, Milling and Processing challenges, Logistical challenges, and Environmental concerns in processing RAP.
- Cultural Barriers: Lack of information and knowledge sharing across actors and governance levels, Lack of stakeholder collaboration, and Limited local capacity and strategic focus on RAP.
- Regulatory Barriers: Misalignment of goals regarding RAP reuse, Fragmented regulations and lack of standardization, Restrictive and inconsistent regulatory standards, Material Traceability challenges, Constraints in the ownership of RAP, and Constraints in RAP containing tar.
- Market Barriers: Prioritization of Cost in procurement procedures, Inconsistent use of Environmental incentives, and a monopolized value chain.

Stakeholder perceptions of these categories reveal different emphases: market actors like contractors, asphalt plants, and engineering consultancy firms stressed technical challenges the most. Government bodies put the most emphasis on regulatory barriers, while research and knowledge institutes put the most emphasis on cultural barriers. Interestingly, market barriers received the least attention, which does not mean they don’t exist but might not be that critical in affecting the potential of RAP.

Importantly, the project level analysis showed that these barriers are not independent of each other. Instead, they are reinforced by governance structures in projects and general project practices. For instance, Centralized decision-making and strict jurisdictional boundaries provide stability but reinforce fragmented regulations regarding RAP reuse across the sector and risk aversion in reusing high RAP content mixes. Hierarchical coordination and limited adaptability restrict knowledge sharing about lessons learned across the levels and delays the incorporation of findings from pilot projects into national guidelines. The sector predominantly reflects Type I MLG features, like centralized decision-making, strict jurisdictional boundaries, hierarchical and top-down coordination and communication, and rigid governance structures. This provides stability and reliability but raises thresholds for change. Type II features, like task-specific collaboration, frequent communication, and flexible governance structures, only appear in pilot projects which enables successful increased RAP incorporation.

The synthesis of the results revealed that neither Type I nor Type II alone can address the barriers. Instead, their complementarity must be designed: Type I features should provide stability through national standardized guidelines and monitoring frameworks, and harmonized procurement rules. On the other hand, Type II features should provide flexibility for innovation and change by generating evidence through experiments and pilot projects, regional pooling of resources, and capacity building at the local level. Importantly, this study reveals that current governance structures in the road infrastructure sector are not sufficient to scale up RAP reuse. Dedicated governance arrangements for this are required to create continuity beyond pilot projects and prevent successful practices from remaining isolated.

The study contributes by extending MLG theory into the domain of circular construction materials offering a conceptual framework that links barrier identification with governance dynamics. Empirically, it provides a cross-stakeholder perspective on RAP reuse in the Dutch road infrastructure sector by identifying which barriers are most critical and how they are reinforced by governance structures. Practically, the research offers a base for policymakers and industry experts to refer to in designing governance-based interventions that strengthen RAP reuse practices in the Netherlands. This can be done not by replacing Type I structures with Type II but by creating a strong bridge between these two structures and utilizing their strengths.

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List of Abbreviations

Abbreviation	Definition
RAP	Reclaimed Asphalt Pavement
MLG	Multi-Level Governance
RWS	Rijkswaterstaat
ZOAB	Zeer open asfaltbeton (Porous Asphalt)
CROW	Center for Regulation and Research in Civil Engineering and Traffic Technology
NPDW	National Platform for Sustainable Road Pavements
MKI	Environmental Cost Indicator
RAW	Rationalization and Automation of Civil Engineering

Chapter 1. Introduction

1.1 Background

Road infrastructure is a crucial part of modern economies, enabling the movement of goods, services, and people. In the European Union alone, road networks span nearly 5.5 million kilometers (Riekstins et al. 2024) and maintaining such an extensive network requires significant financial and natural resources which makes it one of the most resource intensive sectors in the construction industry. The construction industry has a major contribution in global greenhouse gas emissions as it is responsible for nearly 40% of the world's total emissions (Moschen-Schimek et al. 2023, Larsen et al. 2022). Within this, the road industry contributes nearly 15% of global greenhouse gas emissions which includes transportation activities (Hasan et al. 2020, He et al 2023). Furthermore, amongst the three main drivers of resource use in Europe, the road industry is identified as one of them (Bonoli et al, 2020). This is because it not only requires substantial amounts of materials for construction, but the maintenance process is also material intensive.

The global construction industry consumes approximately 30% of virgin materials and generates 25% of waste material (Benachio et al, 2020). Conventional asphalt pavements which account for nearly 90% of the total European road network (according to European Asphalt Pavement Association (EAPA)) are well known to contribute heavily to CO_2e-emissions throughout their lifecycle, especially: material acquisition, production, construction, use, maintenance, and end-of-life (Liu et al. 2024). The carbon emissions associated with materials phase originate from production processes and therefore there is a need for sensible use of recycled materials that can significantly reduce carbon emissions in this phase (Osorto & Casagrande, 2023). The heavy reliance on virgin materials such as natural aggregates and bitumen in traditional asphalt production not only imposes substantial environmental impacts but also poses long-standing challenges in ensuring a reliable supply of these finite resources.

Annual production of asphalt in the Netherlands is 7.1 million tons which contributes to nearly 600 kilotons of CO_2e Emissions out of which 43% originates from resource extraction and nearly 42% is due to production of asphalt (Topsector Energie, n.d.) (EIB, 2022). The recycling of asphalt is beneficial because due to recycling, the steps like resource extraction and primary processing are avoided which results in reduced environmental impacts. The Dutch asphalt sector is increasingly focusing on sustainable practices evident from the goal set by Rijkswaterstaat (the Dutch directorate general for public works and water management) to achieve a climate neutral asphalt sector by 2030 (Roadmap Transitiepad Wegverharding, New foresight 2022). In this, enhancing the reuse of Reclaimed Asphalt Pavement (RAP) holds significant potential. According to Ahmeti et al (2023), the advantages of using RAP include: economic savings due to reduced material consumption, energy savings in mixed production, and environmental protection. According to EAPA (2020), the use of RAP is widespread in many European countries with a significant decline in landfill percentage.

1.2 Problem Definition

While the reuse of RAP offers substantial environmental and economic benefits, it also comes with several challenges. To begin with, RAP can vary significantly in quality due to differences in the original asphalt mix design, ageing and environmental conditions which can affect the performance and durability of the new mix. According to Al-Ghalibi & Mohamad (2021) and West et al (2013), the properties of aggregates in the reclaimed asphalt like gradation, bulk specific gravity and chemical mineralogical characteristics are critical to ensure desirable performance and pavement longevity as previous studies have shown changes in these properties, for instance, alteration in the gradation of aggregates in RAP due to the reclamation process which can cause the aggregates to be finer than originally present and can affect the workability (the ease with which the mix can be worked by hand and laid down) of the mix and the compaction characteristics. Another change can be the that the presence of aged binder in RAP can increase the stiffness of the binder and that can lead to reduced fatigue life and increased susceptibility to cracking. Thus, it is important to check these properties of the aggregates in the RAP to confirm their compliance with the standard specifications prior to their use.

According to Antunes (2019) and Sharma et al (2022), another challenge is performance concern that is a major reason limiting the amount of RAP in the production of asphalt pavements. This is because the management of RAP starting from the milling operation till its use in the asphalt pavements affects its performance. Therefore, it is necessary to ensure consistent quality and performance of recycled materials, and it also requires proper standards and testing protocols. Incorporating RAP into new mix designs requires careful consideration as high levels of RAP can affect the workability, compaction, and long-term durability of the asphalt (Austerman et al, 2020). There is often a perception that recycled materials are of lower quality than virgin materials which leads to resistance from contractors and clients in the acceptance of reusing those materials (Osorto and Casagrande, 2023). While there are concerns about quality of RAP under certain conditions like higher RAP content can lead to a stiffer mix which can cause cracking, studies have demonstrated that incorporation of rejuvenators and additives, proper mix designs and quality control can address these issues.

A study by Bianchi & Cordella (2023) concluded that while Circular Economy initiatives can reduce the extraction of primary resources, their impact is marginal compared to the effects of economic growth. The primary resources extracted annually linked to economic growth are roughly four times the resources saved by Circular Economy initiatives (Bianchi & Cordella, 2023). This suggests that CE initiatives alone are not sufficient to significantly reduce resource extraction. The findings of the study indicate that the circularity of economic systems should be approached from a systematic perspective that includes both production and consumption and waste management as well. This means that a multifaceted approach involving various stakeholders, including different levels of government, is necessary to achieve sustainable development. The need for collaboration between different levels of government is supported by the findings of a study by Wang et al (2024), that highlights the importance of environmental policy innovations and natural resource management in driving the circular economy forward. The misalignment between national and local policies creates a fragmented governance structure. National policies may promote circular economy principles, but local authorities may lack the resources and incentives to implement these principles effectively (Mantalovas et al, 2020). For instance, a study by Heurkens & Dąbrowski (2020) noted that the lack of regional coordination, rigid legal frameworks and organizational fragmentation hinder the transition to a Circular Economy in the Amsterdam Metropolitan Area and concluded that better collaboration between national and local governing bodies is required for effective transition to CE. National level government can provide framework and incentives while local level government can implement targeted policies and engage communities to drive sustainable practices. In Amsterdam, efforts such as circular procurement and asset management have faced barriers like compartmentalization and conflicting priorities policy and project departments which pose challenges to the adoption of circular ambitions in practice.

1.2.1 Problem Statement

In summary to the definition of the problem discussed above, conventional pavement practices contribute heavily to resource depletion due to their heavy reliance on virgin materials. Although recycled materials like RAP offer a promising alternative, their potential is not fully realized due to several barriers including regulatory, technical, cultural, and market. Moreover, the misalignment between national and local policies further affects the widespread adoption of circular practices. In particular, a lack of coordination and alignment between different levels of governance and with the private sector (like contractors, asphalt producers, engineering consultancy firms, and research and knowledge institutions) further restricts the increase of the potential of RAP in the infrastructure sector. To support a shift toward a circular and resource efficient road construction, it is necessary to understand these barriers in depth and analyze how governance structures shape these barriers.

1.2.2 Motivation

A detailed explanation of the research gap is given at the end of the literature review chapter, in section 2.6. In brief, existing literature does identify a wide range of barriers to RAP reuse, but most of them are presented in insolation to each other. Technical and some regulatory challenges are discussed in many studies when describing the challenges to the reuse of RAP, and cultural challenges are often overlooked. Therefore, a consolidated way of representing all the barriers to the increased reuse of RAP is missing in literature. Moreover, a link to how governance structures shape these barriers in practice is missing. These gaps highlight the need for research that connects barrier identification with governance dynamics and analyses how governance structures affect these barriers, and this study aims to fill that gap.

1.3 Research Objective & Scope

The aim of this research is to identify and analyze the barriers that hinder the circular reuse of RAP in road construction and to explore how governance structures influence RAP reuse practices. Following an exploratory qualitative research methodology, this research first identifies and validates barriers to RAP reuse and then applies a multi-level governance lens to understand how authority in decision making, jurisdictional boundaries, coordination mechanisms, and adaptability of the governance structure influence the reuse practices of RAP. By identifying and categorizing these barriers and analyzing stakeholder perspectives, the study aims to develop a framework that supports improved stakeholder engagement and decision-making processes. The research aims to combine the findings regarding barriers and the role of governance structures to come up with practical insights to increase the potential of RAP reuse in the Dutch infrastructure sector.

Scope of the study

The study focuses on:

- **Identification of barriers:** The research will identify and categorize the key barriers to the utilization of RAP in road construction specifically focusing on the Dutch road construction sector.
- **Stakeholder Perspectives**: The research will gain insights from various stakeholders including- Rijkswaterstaat, municipalities, contractors, engineering consultancy firms, research institutes and asphalt producers through semi-structured interviews. This will help understand how various barriers are perceived across different stakeholder groups.
- **Governance Assessment:** The research will use an adapted MLG framework to assess whether governance structures are more hierarchical and fixed (Type I) or flexible and task-specific (Type II) and how these tendencies affect the potential of increasing RAP reuse. This analysis will also help verify barriers identified to RAP reuse at the project level. While the study does not directly measure collaboration practices, the governance type analysis will help highlight where collaboration is facilitated or constrained, hence providing insights for strengthening cross-actor and cross-level cooperation.
- **Integration of Insights**- The final step is to integrate the findings from barrier identification and governance dynamics to create a detailed understanding of how the potential of RAP reuse can be enhanced.

1.4 Research Questions

Building on the research objectives explained in the previous section, this thesis investigates the barriers to increasing the reuse of RAP in practice and the governance dynamics that shape these barriers. The overarching research question of this study is-

Main research question (MRQ):

How do governance structures shape the barriers to the reuse of Reclaimed Asphalt Pavement (RAP) in the Dutch road infrastructure sector and what does this imply for addressing them?

To provide a comprehensive answer to this research question, four sub-research questions have been formulated.

Sub-research questions:

SRQ1: *What barriers to the reuse of RAP exist according to literature?*

This question provides a theoretical foundation for the identification of barriers to RAP reuse by identifying barriers in literature to create a baseline for comparison with practice.

SRQ2: *What barriers to the reuse of RAP exist in practice according to key stakeholders in the asphalt value chain and how are they perceived differently by different stakeholders?*

This question brings in the empirical dimension by capturing perspectives from different stakeholders in the asphalt value chain. It helps to identify barriers in practice and also their importance and interpretation across the stakeholder groups.

SRQ3: *To what extent do governance structures shape these barriers at the sector and project level?*

This question applies a multi-level governance lens to the Dutch infrastructure sector as well some specific projects to examine how governance structures affect the reuse practice of RAP. It also helps explain how governance structures shape various barriers.

SRQ4: *How can insights gathered through barrier identification and governance dynamics be synthesized to identify ways to increase the potential of RAP?*

This question integrates the findings to propose practical strategies that can enhance the reuse of RAP in the Dutch Infrastructure sector.

1.5 Scientific & Societal Relevance

This research contributes significantly to academic knowledge by integrating insights from Circular Economy, Stakeholder Engagement and Material Reuse in Infrastructure sector. Existing literature on RAP often focusses on technical and economical frameworks, hence there is a lack of interdisciplinary research that examines the perspectives of value-chain stakeholders on RAP circularity. While recent studies on Circular Economy do emphasize the importance of stakeholder engagement, there is lack of practiced focused research specially in road construction (Karaca et al. 2024). This study addresses that gap by examining interactions between national government, local municipalities, contractors, producers, engineers, and researchers, thus contributing to empirical understanding of collaborative governance mechanisms in circular transitions. Current literature does identify barriers to RAP reuse but seldom analyzes them in a cross-stakeholder context. This study fills that gap by examining which actors experience which barriers and how systematic changes could lead to high RAP adoption.

Beyond its academic relevance, this research has clear societal relevance as well. The road construction sector is a major consumer of virgin materials and contributor to greenhouse gas emissions in the Netherlands. and if stakeholder engagement is enhanced then it can lead to new pathways for circular reuse of RAP. By identifying how governance arrangements can enable greater reuse of RAP, this study offers actionable insights for policymakers and practitioners. Dedicated governance could support RAP reuse and thereby reduce environmental impacts while strengthening market stability.

1.6 Thesis Structure

This thesis is organized into seven chapters, each building on the previous one to collectively address the research questions of this study.

- **Chapter 1: Introduction-** This is the introduction chapter which introduces the research topic by defining the problem and then the research scope and objectives. This is built upon by formulating the main research questions and the sub research questions. The chapter ends by explaining scientific and societal relevance.
- **Chapter 2: Literature Review-** The second chapter is an extensive literature review which forms the theoretical foundation of the study. It first provides the base by explaining topics like CE in infrastructure sector and then dives into what RAP is and what are the current practices in the Netherlands regarding RAP reuse. The main contribution of the literature review is identification of barriers to the reuse of RAP by considering specific papers. The chapter then provides how governance structures influence reuse practices. This is followed by the research gap that this study fills and the theoretical framework used in this research to do so. Provides the description of the two main theories utilized in the research: Barrier identification framework (Kirchherr et al.2018) and multi-level governance Framework (Hooghe & Marks, 2001).
- **Chapter 3: Methodology-** This chapter explains the research methodology followed in this study which is qualitative exploratory research. The chapter describes the data collection methods including literature review and the two waves of semi-structured interviews. Following this the data analysis approach for the results of both the waves is described. The chapter ends by providing an explanation of how each research question will be answered followed by a research design diagram.
- **Chapter 4: Results-** This chapter presents the empirical findings of this research. The results from both the waves of the interviews are presented and analyzed. The first part provides the updated list of barriers to RAP reuse followed by stakeholder perceptions and comparison with literature. The second part describes the findings of the second wave where case projects were subjected to MLG lens and governance structures were examined. This revealed how barriers to RAP reuse are shaped and what type of MLG is dominant in the sector and projects.
- **Chapter 5: Discussion-** This chapter reflects on the findings by linking barriers to governance structures. It discusses how MLG can help rethink governance structures for RAP reuse, what is the need for a new governance structure and what are the implications. It discusses implications for the sector in terms of MLG types and for the three levels of governance. Based on this, a set of potential directions are provided as starting steps to help address the core barriers to RAP reuse. Following this, a set of limitations of the study are described.
- **Chapter 6: Conclusion-** The last chapter provides conclusion to the research questions of the study. It explains what the final conclusion of the study is and what are some recommendations for future research.

Chapter 2. Literature Review

This chapter forms the theoretical foundation of this study. The chapter is divided into 6 sections, that progressively narrow down the focus from broad concepts of circularity economy in the infrastructure sector to the research gap this thesis addresses. The first section, 2.1, starts by explaining the context of Circular Economy in the infrastructure sector. Section 2.2 provides a detailed explanation of what RAP is followed by current practices regarding RAP in the Netherlands in section 2.3. After this, a detailed explanation of the barriers identified in literature to the reuse of RAP are discussed in section 2.4. Section 2.5 discusses the role of governance structures in circular transitions and ends with defining the research gap that this study will fulfill in section 2.6.

2.1 Circular Economy in Road Construction

Circular Economy is an emerging concept focused on moving away from the traditional 'take-make-dispose' linear model to a more regenerative model where waste is minimized and materials are kept in use through closed loops of reuse and recycling. The concept of CE has received significant attention from academia, industry, policymakers, governments, and non-governmental organizations at various levels (like local, regional, national, and international) (Geißdörfer al, 2017). It is referred to as an approach of production and consumption of resources that aims to minimize resource depletion and waste generation by applying closed loop strategies (Gamage et al, 2024). According to Polyakov et al (2021), it focuses on reducing the demand for natural resources, increasing the lifespan of products through the means of closed loop consumption and production as well as recycling materials.

Construction and infrastructure sectors are one of the most resource intensive sectors. Transitioning to a circular economy in these sectors offers multiple benefits including- reducing greenhouse gas emissions associated with material productions, targeting problems related to material scarcity, and mitigating environmental impacts from waste and extraction. International and national policy frameworks have increasingly adopted circular economy. For example, the European Union adopted a Circular Economy Action Plan (CEAP) in 2015, which was updated in 2020 under the European Green Deal, to enhance resource efficiency among member states. In the Circular Economy Action Plan, the concept of CE is defined as a system which is designed to keep the value of products and materials resources in use for as long as possible while also minimizing waste generation (European Commission, 2020). The Netherlands has been an early mover in this area, as The Dutch government's program - Nederland Circulair in 2050 set an ambitious goal to be fully circular 2050 which also includes an interim target to halve the use of primary raw materials by 2030, driving efforts in all sectors including construction.

Coenen et al (2022) note that in the context of infrastructure, the aim of CE is to maximize value per unit resource, reduce the use of virgin materials and decrease waste generation which also involves the reduction of large amounts of energy and materials. The construction of roads is a very resource-intensive activity as it requires large amounts of raw materials like asphalt and aggregates. This demand puts pressure on the stocks of natural resources and also contributes heavily to carbon emissions. In addition, the construction process puts a lot of strain on the environment as it produces large amounts of waste including debris, surplus materials, and sediment runoff (Coenen et al. 2022). According to Bianchi & Cordella (2023), the main goal of the European Circular Economy Plan is to dissociate the use of resources from economic growth by using materials more efficiently, maintaining their value through closed loop systems and supporting the market for secondary raw materials. However, CE still has a limited effect on reduction in consumption of virgin material as it is far from certain that higher recycling or circularity rates necessarily reduce the extraction of primary resources.

2.2 Reclaimed Asphalt Pavement (RAP)

One key strategy for circularity in roads is the utilization of Reclaimed Asphalt Pavement (RAP). RAP is derived from the milling or removal of the asphalt layers of flexible pavements that are undergoing rehabilitation or reconstruction (Tarsi et al, 2020). Instead of viewing this aged asphalt as construction waste, Circular Economy approach treats it as a valuable resource that can be reused and reincorporated into new asphalt mixes or other products. It consists of non-renewable resources including approximately 95% weight of aggregates 5 % weight of aged bituminous binder and can be reused in new asphalt mixtures and hence reduce the demand for virgin materials or recycled in unbound (base) layers of pavements (Tarsi et al, 2020). By recycling asphalt pavement in this way, the life-cycle of the material is extended, the same stones and binders can serve multiple generations of road , improving resource efficiency.

One of the strongest arguments for RAP use is the saving of natural resources which include both materials and energy. As asphalt is largely composed of aggregates, reusing the aggregate fraction of old asphalt eases demand on the gravel and rock sources. Similarly, bitumen is a finite fossil-based resource and RAP displaces the need for fresh bitumen, which is very valuable given its high cost and carbon intensity. According to EAPA (2020), in Europe, 36 million tons of RAP is available each year out of which 76% is reused in asphalt pavements which amounts to a significant saving of virgin aggregates and bitumen. The production process of bitumen is very energy intensive as well as aggregate mining and transport also consumes significant energy. By reducing these activities, RAP can lower energy use and greenhouse gas emissions per ton of asphalt. For instance, substituting 50% of virgin aggregates with RAP in a mix can result in reduction in GHG emissions by up to 17% (Gruber & Hofko, 2023). Recent studies show that global production of RAP is substantial. For instance, Europe and the United States of America together generated more than 100 million tons of RAP in 2020 and with reuse rates of more than 95% (EAPA, 2020; Williams et al. 2020). In terms of application across pavement layers, a study by Tsakoumaki & Plati (2024) reports that typical RAP content is an average of about 5% in surface course, 35% in binder layers and 45% in base layers. They further note that, the average acceptable RAP content in asphalt layers worldwide is generally around 30%. Incorporation of RAP in pavement layers has shown to reduce the environmental footprint of road construction. Studies suggest an overall reduction of 15- 30% in environmental footprint (Gruber & Hoko, 2023; Vidal et al, 2013).

To understand where RAP is situated within the broader asphalt system, it is important to understand the asphalt value chain. The asphalt value chain diagram as shown in Figure 1, provides a comprehensive overview of the interlinked processes involved in the production, application, and reuse of asphalt in the Netherlands. The chain begins with raw material extraction including bitumen, aggregates, and fillers which are provided by two industry sectors -oil refineries and quarry industry (Oliveira & Schure, 2020), proceeds to production then transport and paving and ends with maintenance, demolition, reuse, or disposal. This is very relevant to the circular reuse of RAP which primarily takes place at the end-of-life and production phase. Rap is milled from old pavements, processed, and reincorporated into new mixes at the production stage. Therefore, the focus of this research is also in these two stages to identify barriers to the reuse of RAP and the actors that play role in that.

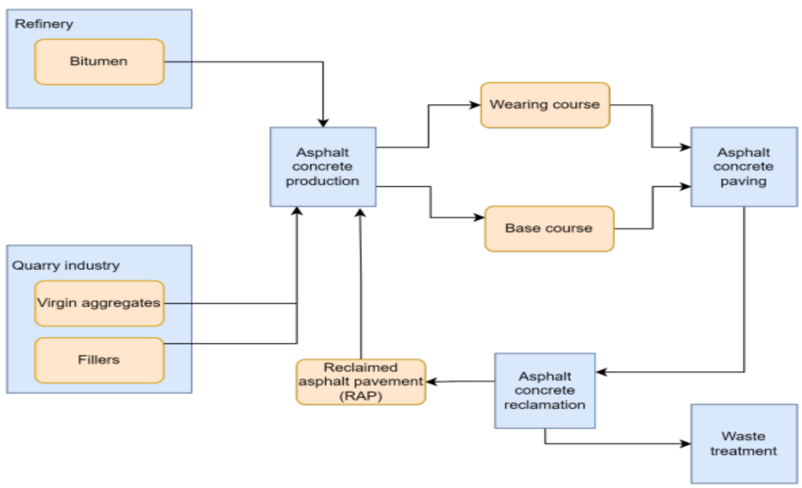

Figure 1 Asphalt value chain (Oliveira & Xavier Silva, 2022)

When discussing RAP reuse, understanding the types of asphalt mixes is also important. There are three main types of asphalt- hot-mix, warm-mix, and cold-mix asphalt. The main difference lies in the production and application temperature, rather than physical (Oliveira & Xavier Silva, 2022). Hot mix asphalt is typically produced at around 150° C to be poured as pavement. It is usually used in roads and commercial and residential pavements. Contrary to hot mix asphalt, warm mix asphalt is produced and poured at a lower temperature. This is done by using additives like waxes and zeolites, which reduce viscosity and lower energy requirements. Lastly, cold-mix asphalt does not require heating to be used. Because it cures more slowly, it is usually used for temporary applications like patching potholes or minor surface repairs.

2.3 Current Practices relating to RAP in the Netherlands

In the Netherlands, about 82% of all reclaimed asphalt is reused in new mixes or other road construction use (EAPA, 2017). The road authorities at all levels incorporate RAP into new pavements as part of standard practice. In the Netherlands, the reuse of asphalt is guided by standards and guidelines to ensure consistency and quality. The key reference is

"Standaard RAW[1] Bepalingen" by CROW[2], which is a national specification framework for civil engineering works and contracts for road projects Rijkswaterstaat, Provinces, and some municipalities all refer to these standard RAW provisions on reusing RAP. There is a distinction between layers of a pavement and so is there in the amount of RAP that can be incorporated in different layers. According to the RAW 2020 Standard (CROW, 2020),

- Surface Layers: For normal dense asphalt concrete mixes (AC Surf), the allowed percentage of reclaimed asphalt is 30%. Some special surface layers like Stone Mastic Asphalt (SMA) and Porous Asphalt (ZOAB[3]) are specified with 0% reclaimed asphalt because they have higher performance requirements.
- Base & Binder Layers: For lower layers of pavements mixes like Asphalt Concrete base and binder mixes (AC Bin/Base) a much higher reclaimed asphalt content is allowed, about 60-70%. It is considered common practice and asphalt plants routinely produce base layers with nearly two-thirds reclaimed asphalt.

The 30% cap in surface layers is a conservative default in the RAW 2020 guidelines, however, the standards are periodically updated as knowledge advances. In fact, in practice even higher percentages of reclaimed asphalt can be incorporated if properly validated. The Asphalt Quality Desk (Asfaltkwaliteitsloket), hosted by CROW, is a validation program to certify innovative asphalt mixes, and it validated AsfaltNu's, an asphalt plant in the Netherlands, recently developed surface mixes with 50% and 60% RAP (CROW, 2024). This suggests that official standards will likely evolve to allow higher reclaimed asphalt content in new mixes.

The Nationaal Platform Duurzame Wegverharding (NPDW) also known as the National Platform for Sustainable Road Pavements, is a collaboration platform for public and private actors in the road construction sector created to fulfill the need to make the road pavement sector more sustainable. The NPDW facilitates knowledge sharing, pilot projects, and the development of guidelines to reach circularity ambitions like a 50% reduction in using virgin materials in the road paving sector by 2030 and a fully circular sector by 2050. It works closely with bodies like CROW to coordinate efforts, for instance, NPDW & CROW create and spread guidelines, recent example being Warm Mix Asphalt guideline to save energy and allow more RAP, and NPDW also maintains a list of validated asphalt mixes that all local government can use. By bringing together all actors, like government bodies, contractors, consultants, asphalt plants, and research & knowledge institutions, it makes sure that innovations regarding RAP are tested, validated, and then scaled up across the country. Given that the Municipalities own nearly 70% of all roads, the efforts of NPDW in aligning their sustainability ambitions with national goals are very important.

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[1] RAW stands for "Rationalisatie en Automatisering Grond-, Water- en Wegenbouw" (Rationalization and Automation of Civil Engineering).

[2] CROW stands for "Centrum voor Regelgeving en Onderzoek in de Grond-, Water- en Wegenbouw en de Verkeerstechniek" (Center for Regulation and Research in Civil Engineering and Traffic Technology).

[3] Zeer open asfaltbeton, it has a large number of voids which improves drainage and reduces sprays during wet conditions

The Civil Engineering Industry in the Netherlands utilizes a mechanism called the Milieu Kosten Indicator (MKI) also knows as the environmental cost indicator, which is a score representing the lifecycle environmental impact of a product or a process in Euros. Basically, it monetizes the environmental footprint. In the Netherlands, calculating MKI scores, using life cycle assessment data from the Nationale Milieu database, is a common practice integrated into project procurement. In the asphalt sector, may public clients set requirements and incentives based on the MKI score of asphalt mixes. For instance, clients can impose MKI ceiling values as in a maximum allowed MKI score (in the case of asphalt, MKI per ton of asphalt mix) to ensure that contractors use environmentally friendly mixes. MKI is also used as an award criterion in tenders, for instance, if a contractor offers an asphalt mix with a lower MKI value (that is, it is more environmentally friendly), they receive a bonus or a fictional price discount in the bid evaluation.

As a result, MKI based procurement directly encourages higher RAP content in new mixes because using reclaimed asphalt and replacing virgin material is the most effective way to get a low MKI score. According to a validation report by CROW, an asphalt mix with 50% RAP has nearly 30% less MKI score than a mix with the more standard 30% RAP content (CROW, 2024). This reduction acts as a good motivator for contractors to increase RAP in asphalt mixes to get a lower MKI score to win tenders.

Overall, the Netherlands has made significant progress in integrating RAP reuse practices in asphalt production with guidelines and platforms such as CROW & NPDW. However, barriers still remain in increasing the potential of RAP in the Dutch infrastructure sector. While knowledge sharing platforms do exist, they have not yet bridged systematic barriers related to coordination and collaboration amongst different levels of governance as well as the private sector. Enhancing cross-level and cross-sector collaboration is crucial for increasing the potential of RAP.

2.4 Barriers to increasing RAP reuse

This section discusses the barriers to the reuse of RAP as identified in literature. It begins by outlining the key literature sources used to identify these barriers followed by how these barriers were categorized into categories. Then an in-depth review of the barriers with supporting literature is given.

The literature sources used in this study for the identification of barriers to the reuse of RAP are listed in Table 1. It describes the focus of the study as well as its relevance to this research. Literature sources were chosen based on their relevance to either Circular Economy transition or barriers to the practices related to RAP. While some of these studies focus directly on RAP, others are related to the challenges in circular economy transition. The barriers to the circular economy transition are still applicable to RAP reuse practices as it is also a circular material practice within the infrastructure sector. Although some these studies date back to 2016-2018, their findings still remain relevant. This is because they identify systematic and structural barriers like fragmentation in policies, cultural and market issues etc., that persist over time. The Dutch government’s policy goals, specifically regarding full circularity in 2050, still guide the CE strategies and research regarding that

(Hanemaaijer et al. PBL, 2023). Including these studies aligns with the exploratory nature of this research and serves as a foundational lens through which barriers to RAP reuse can be initially understood. These findings from literature are later used as a basis for further investigation and verification through stakeholders and shaped them from broad CE transition barriers into specific RAP reuse barriers.

The selection of the studies was done by following a simple keyword search using terms like "Challenges in reusing RAP" and "Challenges in Circular Economy transition in the infrastructure sector" in Google Scholar. The focus was placed on the most cited or top-listed studies that appeared during the search in Google Scholar. After thoroughly going through the abstract and findings of the papers, studies that specifically mentioned barriers to Circular Economy in the infrastructure sector and reuse practices related to RAP were selected. The selected studies cover challenges to both CE transition and RAP reuse. Although not all studies overlapped directly, some barriers appeared consistently across them, which suggested that the selected set of papers would be sufficient to serve as a foundation for identifying and categorizing key barriers to RAP reuse.

Table 1 Overview of key literature used (author)

Authors	Name of the study	Focus of the study	Relevance to this study
Coenen et al. (2022)	A systemic perspective on transition barriers to a circular infrastructure sector	Investigates the systematic barriers preventing the transition to a Circular Economy in the Dutch infrastructure sector	Although not specific to RAP, this study identifies key institutional, processual, knowledge sharing and governance challenges to the transition to a circular infrastructure section in the Netherlands. As a result, it can be extended and applied to RAP reuse practices as well.
Liu & Kringos (2024)	Transition from linear to circular economy in pavement engineering: A historical review	Provides a systematic literature review on the development of the Circular Economy concept in the pavement sector and identifies drivers and barriers to the transition to a Circular Economy	It gives a detailed picture of the barriers to the transition to CE in the pavement sector and hence helps in identifying and categorizing barriers to RAP reuse
Kirchherr et al (2018)	Barriers to the Circular Economy: Evidence from the European Union (EU)	Large scale study for identifying barriers to the transition to Circular Economy in the EU	Even though it doesn't specify RAP, this study helps identify market and institutional challenges to the transition to CE which are applied in this research to study challenges to RAP reuse
Zaumanis et al. (2016)	100% Hot Mix Asphalt Recycling: Challenges and Benefits	Evaluates the feasibility of fully recycled asphalt mixtures and proposes a design methodology for 100% RAP mixtures	This study solely focuses on the technical challenges and uncertainties surrounding the reuse of RAP. It helps to strengthen the arguments regarding the benefits of using RAP.

Tsakoumaki & Plati (2024)	A Critical Overview of Using Reclaimed Asphalt Pavement (RAP) in Road Pavement Construction	Provides a review of international practices regarding RAP reuse across asphalt layers and highlights the inconsistency in those practices	This study identifies some major regulatory and technical barriers to using RAP in mixes and hence shapes arguments in those categories in this study as well.
Tarsi et al. (2020)	The Challenges of Using Reclaimed Asphalt Pavement for New Asphalt Mixtures: A Review	Summarizes the global practices regarding RAP and technical constraints in incorporating RAP in new asphalt mixtures	This study helps support the technical barriers to RAP reuse in and helps justify the barrier categorization this study.

While reviewing the literature it became evident that none of these studies used a uniform set of headings for the barriers. Instead, each paper approached the challenges using its own structure and emphasis. Therefore, to bring clarity in the understanding and representation of the barriers, this study categorized them into 5 main categories namely:

- Regulatory Challenges
- Institutional & Governance Challenges
- Technical Challenges
- Market Challenges
- Information Sharing Challenges

Some of these categories like technical, market, and regulatory were commonly reflected in several studies and were hence used in their original form. However, others like information sharing and institutional & governance challenges were introduced to capture specific challenges that did not fit clearly in the existing categories but were clearly visible in literature. In the following section, each of the five categories and the barriers under them are discussed in detail.

2.4.1 Regulatory Challenges

To begin with regulatory challenges, misalignment in policies and restrictive regulations are frequently cited as barriers to the transition to a circular infrastructure sector. The Dutch Government set an ambitious mission to be fully circular by 2050, and the Resource Agreement stated that the infrastructure sector should reduce its use of virgin resources by 50% by 2030 (European Environmental Agency, 2016). Coenen et al. (2022) noted that, despite the widely shared intentions and strategies for achieving circularity, developments lag in practice as implementation gaps exist between national vision and local practice. This study found that the circular economy mission for the infrastructure sector is contested and lacks clear directionality from the government, meaning a clear and consistent policy pathway to provide guidance and alignment for regional and local governments. This misalignment can lead to national and municipal bodies pursuing different or even conflicting goals. Coenen et al also note that, for the national mission of Nederland Circulair in 2050, Rijkswaterstaat was delegated the operationalization national mission, and the goals and strategies were adopted by other public bodies including the municipalities.

However, the operationalization of these strategies differed between these government bodies and appeared to have been poorly aligned and coordinated (Coenen et al. 2022). This highlights that there is misalignment of goals and strategies across governance levels that can hinder the transition to a circular economy in the infrastructure sector including the reuse of RAP. While this misalignment can be interpreted as an institutional & governance barrier, in this study it is categorized as a regulatory barrier. This is because misalignment creates fragmented rules (regarding RAP reuse), inconsistent incentives, and conflicting priorities between governance levels (Coenen et al. 2022; Kirchherr et al. 2018).

Another barrier is strict regulations that can inhibit the use of high RAP content. For instance, Liu & Kringos (2024) note that underdeveloped legal systems and unclear guidelines inhibit the adoption of circular economy and limit the utilization of RAP due to undefined policies. The same study further notes that there is a need for standardization especially for performance tests (mechanical performance of the mix) as the current guidelines are highly vague. Therefore, there is a demand for policy support on standardization. According to Zaumanis et al (2016), one of the primary regulatory hurdles in the widespread reuse of materials in road construction is the lack of unified and comprehensive standards and specifications for reclaimed and reused materials. Tsakoumaki & Plati (2024) highlighted the inconsistencies in using RAP in pavement courses worldwide, like the inconsistency in the selection of RAP mass percentage for incorporation in different layers. The study found that for RAP content higher than a certain threshold (often 15% to 25%), additional testing may be required which indicates that regulations often become more stringent with increased RAP usage. The paper concludes that the inconsistent global strategy for the use of RAP confirms a knowledge gap about its behavior, which likely contributes to the varied and sometimes restrictive regulatory approaches. Differences in road design processes, weather conditions, speed limits and the geology of a country can lead to variability in the approach and more restrictive regulations in some areas (Tsakoumaki & Plati, 2024). The adoption of RAP can also be influenced by a country's policy decisions regarding resource and fiscal management as well as available technological knowledge which can act as barriers of supportive policies. The alignment of national and local regulations, updating standards to enable the use of RAP in high quality applications and introducing incentives is necessary.

Therefore, under regulatory barriers category the following challenges are covered:

- Misalignment of goals across governance levels
- Fragmented policies
- Restrictive and unclear standards.

2.4.2 Institutional & Governance Challenges

Institutional and governance factors like how organizations and stakeholders coordinate play a crucial role in the implementation of circular strategies. One such challenge is the fragmentation of roles and poor collaboration across the value chain. Coenen et al (2022) in their study looked into the Dutch infrastructure sector and noted that circular transition efforts are governed through a fragmented landscape of governance arenas, where different groups of actors (ministries, agencies, and sectoral platforms) have their own specific goals. At the same time, the formal strategy that includes Nederland Circulair in 2050 and the Resource Agreement, is scattered among several ministries. This fragmentation increases the complexity and requires new coordination mechanisms to bring actors together in order to solve problems. An interview-based study by Kirchherr et al (2018), note that government officials themselves acknowledge willingness to collaborate in the value chain is a major challenge in transitioning to a Circular Economy.

Despite the existence of high-level policies promoting circularity, there are some gaps in its implementation in practice which can be attributed to factors at project and organization level where circularity is not a primary metric to measure the performance of projects. Traditional factors like cost efficiency and risk mitigation still take precedence over circularity objectives (Coenen et al, 2022). The conservative and risk-averse nature of the industry contributes to this as it favors proven technologies over innovative circular solutions (Coenen et al, 2022). Trust and communication between actors are crucial as without collaboration between national and local bodies, even well-intended circular initiatives like RAP utilization, can stall.

Therefore, under institutional and governance barriers category the following challenges are covered:

- Lack of stakeholder collaboration
- Unclear division of responsibilities

2.4.3 Technical Challenges

The effective and sustainable reuse of Reclaimed Asphalt Pavement (RAP) is significantly affected by a range of technical factors and addressing these is important for ensuring the performance and economic viability of pavements incorporating RAP. Many studies note that asphalt mixtures with a large percentage of RAP have different properties than all-virgin mixtures. These include lower fatigue life[4] and higher susceptibility to moisture, particularly stripping of binder from aggregate which can further cause surface deterioration like potholes. (Tarsi et al, 2020). Reclaimed asphalt often contains aged binder which makes the mixture stiffer and leads to cracking (West et al, 2013). Tarsi et al (2020) note that because of the concerns mentioned above, many countries limit the RAP content to 15-20% in surface layers and hence effectively capping the circular potential of RAP. Specifically, in the Netherlands, RAP content in mixtures is set in the RAW Handbook, as explained in section 2.3. It allows 30% in surface layers and about 60-70% in base and binder layers.

Challenges are posed by the inconsistent quality of RAP as when it is derived from different sources, its composition can vary based on its origin and previous maintenance activities (Praticò et al, 2013; Liu & Kringos, 2024). Zaumanis et al (2016) also note that a primary challenge in maximizing RAP reuse is the variability associated with its quality and that this variability arises from differences in the original materials, construction practices, environmental conditions and age of the pavement being reclaimed. Due to this variability,

[4] The number of repeated loads a pavement can withstand before it develops cracking

road authorities might be reluctant in using RAP in large quantities, particularly in critical layers (surface layers). In the Dutch content, this variability translates into a cautious approach where road authorities restrict the use of RAP in surface layers. This is because surface layers are more sensitive to traffic, weather conditions, and quality concerns (Liu & Kringos, 2024).

The milling[5] process of asphalt also affects its quality as the depth and precision of milling can determine the homogeneity[6] of the material (Tarsi et al, 2020; Tsakoumaki & Plati, 2024). Storage capacity limitations at asphalt plants does not allow RAP from different projects to be stockpiled separately which in turn leads to RAP with variable quality and source to be mixed together. Tarsi et al (2020) also note that milling of asphalt leads to changes in the gradation of RAP i.e., RAP after milling contains more fine particles which makes the mixture unable to meet specific gradation requirements and hence causes limited RAP reuse.

Another technical challenge is the lack of long-term performance data on RAP mixtures. While there is increasing recognition for materials like RAP, inconsistencies in the long-term performance of pavements constructed with high percentages of reused materials persists (Zaumanis et al, 2016; Tsakoumaki & Plati, 2024). Liu & Kringos (2024) also note that while extensive laboratory research has been done on high-RAP mixes, there have been relatively less field trials to prove long-term performance owing to budget restrictions and regulatory constraints. The paradox is that field trials often rely on regulatory support and regulatory changes require field trials (Liu & Kringos, 2024). Therefore, this conservative approach becomes a technical barrier, which is, that even if higher RAP mixes could perform adequately, lack of confidence and evidence from field trials mean they can't be permitted. The lack of standardized testing methods for recycled asphalt mixtures is another gap as different jurisdictions use different procedures which makes it hard to compare results and set common guidelines (Liu & Kringos, 2024).

Data on processing RAP and about its composition is needed to enhance reliability but they are not always readily available. Therefore, there is a growing importance for transparent and standardized data, like material composition, processing history, and performance related data, across the whole supply chain. Logistical considerations influence the availability and cost of RAP. Transportation distance between milling site and the asphalt plant are a key factor because longer haul distances reduce the economic and environmental benefits of recycling (Liu & Kringos, 2024). Also, limited storage capacity at the plants and need for separate stockpiling of RAP based on quality and type of asphalt cause storage issues. While not always a central focus in technical discussions, logistical considerations can impact the feasibility and overall sustainability of RAP utilization.

To summarize, key challenges in reusing RAP under the category of technical barriers include

- Challenges in using RAP in surface layers.

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[5] The process of grinding down the surface layer of a pavement to a specific depth

[6] The uniform composition and properties of a material throughout its volume

- Uncertainty in the quality of RAP
- Challenges due to milling process
- Lack of long-term performance of RAP
- Lack of standardized technical guidelines
- Logistical challenges.

2.4.4 Market Challenges

Economic factors can strongly influence the uptake of RAP. Even if it is technically feasible, the market conditions and cost considerations can pose barriers. Procurement practices are also considered as a key barrier to circularity. A major obstacle is the continued dominance of cost as the primary decision criterion in public procurement which often overshadows sustainability considerations. Even though Green Public Procurement aims to integrate environmental factors, its effectiveness is limited when cost remains the overriding factor. This can lead to a preference for conventional materials over potentially more sustainable yet perhaps initially more expensive options involving higher rates of material reuse (Lewis & Machlowska, 2022). Despite ambitions to implement environmental targets in procurement decisions, they still play a small role in award decisions (Bouwend Nederland, 2020). Therefore, the procurement cost remains a very common and primary decision-making criterion.

Another issue, cited by Kirchherr et al (2018), to the transition to a Circular Economy is low prices of virgin materials which contest the cost competitiveness of circular alternatives. If the price of virgin materials increases, circular materials will become more attractive. Additionally, high upfront costs associated with transitioning to a Circular Economy also pose challenges to a circular business model. This is because actors are uncertain about performance (in this case performance of RAP), economic returns (on upfront investments), and regulatory acceptance (of high RAP mixes). There are certain techniques to accommodate higher RAP in mixes like adding recycling agents and rejuvenators[7] and warm-mix asphalt[8] processes but they often require new equipment or technological modifications. Even though these equipment and technologies exist, the upfront cost acts as a barrier for their adoption and this shows how operational adjustments act as challenges in utilizing RAP. These upfront costs may include costs for upgrading asphalt production plants and modification of the production technology and usually falls on asphalt plant owners and contractors to upgrade their plants. As a result, higher investment costs act as barriers to the adoption of CE strategies, in this case adoption of RAP.

Studies show that reference data for products and individual materials are accessible to a limited extent, and this lack of transparency and availability of data hinders the creation of a robust market for these resources (Teigierova et al. 2023). The adoption of new materials or new technologies can require new partners in the value chain and substitute existing ones, for instance for RAP to reach its full potential it is necessary that there is a constant and reliable source for it and this may require the existence of specific suppliers and contractors

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[7] Chemical or biological agents that restore the physical and chemical properties of old asphalt

[8] The process of heating the mix at a temperature lower than traditional hot mix asphalt

outside of the existing asphalt supply chain, which can lead to resistance and uncertainty among actors.

Therefore, the barriers identified in this category are:

- Cost-driven procurement practices
- High initial investment costs
- Resistance to expand the value chain or monopolized value chain.

2.4.5 Information Sharing Challenges

Effective utilization of RAP relies on transparent information flows and knowledge transfer among stakeholders and organizations. However, studies point out barriers in terms of poor data sharing and knowledge gaps. In the Netherlands, Coenen et al (2022) identified a knowledge diffusion cycle problem which means difficulties in spreading and adopting knowledge and data about circular innovations and practices across projects and organizations. Simply, lessons learnt from one project, or an organization are often not communicated to others. This is mainly because of market competition and reluctance to share data, especially from market parties because they are worried, they might lose their competitive advantage in the market. The same study, Coenen et al (2022), notes that even though there are initiatives like Communities of Practice (CoPs), implementation programs and more places to showcase circular examples in the infrastructure sector, the diffusion of information, knowledge and lessons learnt still remains a bottleneck in the transition to a circular infrastructure sector. This is because it would lead to a shared understanding of the CE strategy, in this case a shared understanding of the reuse practice of RAP. This would help to understand the technical performance and limitations of RAP, and how to better integrate it in projects.

This leads to a lack of knowledge infrastructure which makes access to relevant information and knowledge (about long-term performance, material properties and supply, mix designs etc.) challenging, especially for newcomers and small organizations that might lack the capacity to search, develop and apply such knowledge effectively. This can be extended to RAP reuse practices as well. Even though Coenen et al (2022) don't specifically mention RAP, it is a circular practice within the pavement sector and requires specific technical knowledge about material quality, performance, logistics. In the absence of consistent information and knowledge sharing, some stakeholders, like small municipalities and provinces, may lack access to best practices and lessons learnt. This way they may remain unaware of innovations tested elsewhere.

Another challenge in this category is the data transparency about materials as circular construction requires information about what materials and how much is available for reuse as well as their quality. For instance, Life Cycle Assessment (LCA) tools from various National Road Authorities utilize Environmental Product Declaration (EPDs) Databases, which documents the life cycle environmental impacts of a material in a standard form and is verified by a third party. However, there is still a need for continuous updates of information after the material is utilized as EPDs alone do not capture the technical characteristics of a material after its exposure to traffic and climate (Liu & Kringos, 2024).

Therefore, there is a need for accessibility to standard information about both material related factors like performance, flow and composition and non-material related factors like cost, energy performance and geography. Material Passports are a possible solution that offers a platform and repository for storing and providing such information (Heinrich & Lang, 2019). Unlike EPDs which are documents focusing on life cycle impacts, Material passports can be continuously updated. However, a major challenge considered in this regard includes ensuring that information from continuously fed into such passports, and also to facilitate free and easy communication among stakeholders along with data interchangeability (Liu & Kringos, 2024). Therefore, lack of an integrated information platform for reclaimed materials acts as a barrier for their full utilization.

To summarize, lack of knowledge exchange and data transparency about material properties, availability, and reuse potential across the value chain and the absence of shared lessons from projects between municipalities, national road authorities and contractors etc., poses challenges for stakeholders to make informed decisions and build trust in circular practices.

Overview of Barriers

The various barriers to the circular reuse of RAP identified in the section above are shown in Figure 2. These 5 categories form the starting point of this research but notably, this framework consisting of 5 categories is not the final structure to represent the barriers. For the empirical analysis, the barriers are reorganized under four categories, as explained in section 2.7.1.

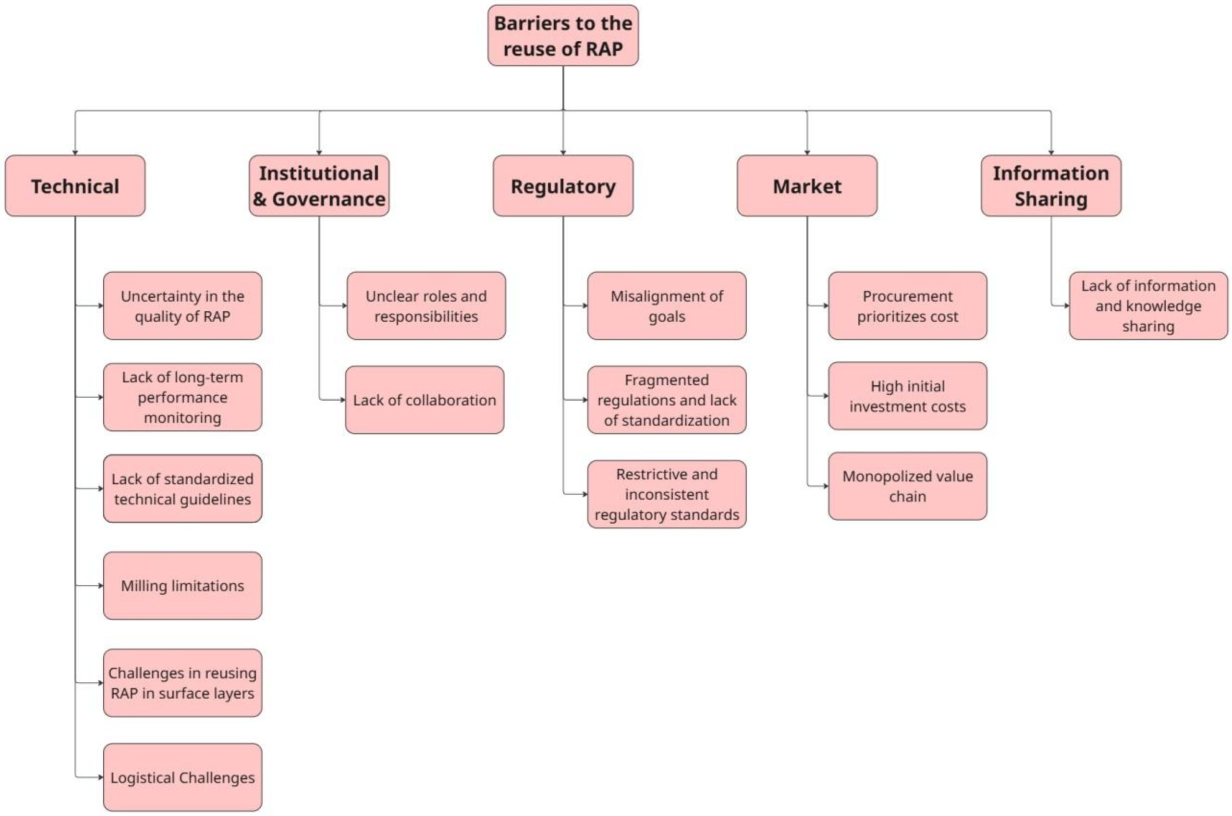

Figure 2 Barriers to RAP reuse identified in literature.

2.5 Governance in Circular transitions

When studying topics related to the transition to a Circular Economy, especially in the infrastructure structure, it is also important to understand the governance structure. This is because the reuse of RAP in the Dutch infrastructure sector is embedded in a governance structure that spans across three governance levels. The three primary levels of governance in the Netherlands are – national, the provinces, and the municipalities. The way these levels interact with each and with the private sector shapes the persistence of various barriers described in section 2.4.

National Level

The national government formulates the policies and frameworks that set the direction for Circular Economy Initiatives. In the context of the infrastructure sector, the Ministry of Infrastructure and Water Management plays the most important role in the establishment of regulations and standards that influence the adoption of circular practices. As the executive agency of the Ministry, Rijkswaterstaat plays an important role in implementing these policies and given its operational responsibilities, it is a major stakeholder concerning the reuse RAP. This is because they translate ambitions into technical standards and contract requirements and implement major national road projects.

However, the literature highlights gaps in national ambition and local implementation (Ruiz et al, 2025). Or encourage higher RAP content in their projects, local authorities are not obliged to do the same in their projects. This creates regulatory misalignment, and fragmented policies across governance levels which in turn lead to market barriers as contractors must adapt to different specifications across projects.

Provincial & Municipal Levels

The provinces serve as intermediaries between the national and municipal levels and help translate national policies into regional strategies. They are well positioned to coordinate regional demand for RAP and help reduce market fragmentation by pooling projects and enabling economies of scale. On the other hand, municipalities hold direct responsibility in the construction and maintenance of local roads. They act as both regulators and as public clients in public procurement which gives them the significant influence over whether RAP is specified and allowed in project contracts or not. They also have the autonomy to set local regulations and standards that can facilitate the adoption of RAP. Focusing on municipal-level governance can help provide insights into the barriers and opportunities for RAP reuse (OECD, 2024; Salmi et al. 2022). Municipalities are positioned at the intersection of various actors and activities involved in construction and that makes them influential in driving Circular Economy transition.

However, literature notes that there are variations in ambitions, technical capacity, and resource availability among municipalities. Even though provinces and municipalities collectively own nearly 80% of the roads, because of the misalignment or variation in ambitions, the transition towards a circular economy in the infrastructure sector is hampered (Ruiz et al, 2025). This again points towards misalignment of goals across governance levels, and technical barriers as there are no standardized technical guidelines for RAP across these levels.

Coordination across levels

The interactions between all these governance levels are not seamless. A study by Spaans et al (2013) found that national government involvement in local redevelopment projects may be conceptually justified but there were no added values in terms of economic benefits or urban quality. Similar coordination challenges are seen in RAP reuse where the misalignment forces the market parties to adapt to different specifications which increases complexity. Each governance level can introduce and set requirements and policies that affect reuse of RAP. But the literature suggests that, when these levels are misaligned, circular practices, in this case reuse of RAP, are affected. Ruiz et al, (2025) note that the Dutch asphalt sector's multi-level governance structure follows different sustainability objectives and procurement approaches which leads to inconsistent rules and difficulty in scaling up innovations.

Therefore, the barriers described in section 2.4 cannot be understood by looking at a single level of governance. Instead, it involves different levels as well as the private sector actors and the responsibilities and interactions between them are interdependent. This perspective aligns with the Multi-level Governance Theory developed by Hooghe & Marks (2001) and is explained in detail in section 2.7. It explains how authority and decision making is distributed across different governance levels and between public and private actors. Applying this perspective in this research about RAP reuse is essential because it seeks to explain the fragmentation in governance structures similar to what is observed in the Dutch Infrastructure Sector.

Governance linkages to overcoming barriers to RAP reuse

The connection between governance structures and the barriers to the reuse of RAP has been touched upon in literature but often indirectly and without a clear governance framework. The literature reviewed for this research to identify barriers to RAP reuse, explained in section 2.4, shows that governance related issues are not absent from literature. For instance, Coenen et al (2022) identify fragmented governance structures across road authorities and how they follow different sustainability objectives and procurement approaches. This leads to inconsistent implementation of policies related to reuse of RAP and variations in the practices across the sector. Liu & Kringos explain the pavement sector's transition to a circular economy as obstructed by the lock in mechanisms of take-make-dispose linear model. They note that transition towards a circular pavement sector will require multi-dimensional interactions and changes to the current unsustainable system. Kirchherr et al (2018) also describes some market challenges like high investment costs, and prioritization of the cost factor in procurement processes challenges to the transition to a Circular Economy. This is reinforced by the way contracting rules are set at different governance levels. While studies like Zaumanis et al (2016), Tsakoumaki & Plati (2024) , and Tarsi et al (2020) specifically elaborate on what technical uncertainties and regulatory challenges like varying limits on RAP content, limited standardization in the validation process of mixes, and different acceptance criteria across levels, affect the uptake of RAP reuse practices. Even though these are technical challenges, most of them stem from how responsibilities and authority is distributed across various stakeholders in the sector and how they coordinate.

When viewed collectively, it can be concluded that governance shapes each category of barriers. Regulatory and institutional barriers like misalignment of goals across governance levels, fragmented policies regarding RAP, and lack of collaboration amongst stakeholders stem from limited or no vertical coordination (national-provincial-municipal) between governance levels. Market barriers like cost-driven procurement limiting innovation like RAP can also be associated with how these procurement models are governed or implemented across road authorities. Technical barriers like lack of long-term performance monitoring, logistical challenges, lack of standardized guidelines, and challenges in incorporating high RAP in surface layers can be associated with how the absence of aligned governance structures creates variation in specifications and guidelines. Information and knowledge sharing challenges in itself stem from when governance structures don't allow information and knowledge sharing across levels and actors.

Some studies do explain how governance arrangements can provide potential solutions. As explained in the study by Ruiz et al (2025) where they analyze sustainability transition in the

Dutch asphalt sector, governance choices directly influence if certain barriers are reduced or mitigated. For instance, they cite a study where they concluded that splitting responsibilities for construction and maintenance in a road project between different actors, because of the long-term asset lifecycle of roads, leads to short term thinking and weakens accountability for material choices. This points to a governance set up that disadvantages innovation like higher RAP content in asphalt mixes. Moreover, they cite another research which shows that procurement models that integrate long-term maintenance responsibilities acts as incentives for contractors to adopt durable and circular material. This is because they have to bear the responsibility of the performance over the road asset's life cycle. Ruiz et al (2025) point towards the need for better vertical (across governance levels) and horizontal (public and private sector actors) coordination to move towards a circular economy.

Combining all these insights, the following conclusions can be made. Firstly, the barriers to the scaling up of RAP reuse practices identified in literature do not exist in a vacuum (separately). Instead, they are affected by how responsibilities and decision-making authority are distributed and coordinated across governance levels and the private sector. Taken together, these studies provide a foundation for identifying barriers to the reuse of RAP, but they don't explicitly make use of governance as an analytical lens to understand these barriers. This leaves a gap in understanding how interaction between public and private actors as well as across governance levels contribute to these barriers. To address this gap, this study combines two complimentary frameworks: barrier identification and categorization based on Kirchherr et al (2018) and Multi-Level Governance Lens as described by Hooghe & Marks (2001). Together, they provide the theoretical foundation to systematically identify barriers and analyze their governance roots, and they are described in detail in section 2.7.

2.6 Research Gap

Several Circular Economy initiatives are present in reducing resource depletion and environmental impacts in road infrastructure, still significant gaps remain in understanding how to effectively govern these transitions at multiple scales. While existing literature highlights the barriers that hinder the reuse of RAP, very few studies link them to governance structures that shape them. They are rarely presented in a consolidated way that integrates the full spectrum of technical, regulatory, cultural, and market barriers. In most cases these barriers are presented in isolation with each other, and governance is often stated as a subset of regulatory and market barriers like in the study by Kirchherr et al (2018). Therefore, the institutional dynamics that explain why these barriers occur and how they might be potentially addressed through deliberate governance design remain underexplored.

From a theoretical perspective there is a clear gap. Many studies note the technical uncertainties and challenges that affect the uptake of RAP and propose engineering solutions. However, they don't consider how governance structures determine whether those solutions are adopted. In practice, it can be the case that certain barriers may endure because the level of governance required for addressing it is not effectively engaged.

Literature specifically highlights technical and political obstacles to the reuse of RAP but often overlooks how regulatory and procurement rules and knowledge sharing can help enable reuse of RAP. Another point is that the multi-level governance theory (MLG) lens has been missing from the studies regarding circular economy transitions, particularly scaling up of RAP reuse practices. MLG has been applied to environmental policy and climate governance research to illustrate how decisions and authorities are distributed across levels (Fairbrass & Andrew, 2004; De Gregorio et al, 2019). However, in the domain of circular construction materials, this approach has not been adopted so far. The consequence of this gap is that the current literature is missing a deeper causal explanation. That means, barriers are treated as if they are independent problems to solve without realizing that they may be embedded in governance structures which might be the real root cause of why they persist.

From an empirical perspective, there are some studies which are case-specific (the Dutch asphalt sector), and they do recognize governance issues such as fragmented policies and oversight. For instance, Ruiz et al (2024) uses a system innovation and Multi-level Perspective to show the interactions between niche innovations and sectoral regimes. Another study By Ruiz et al (2025) builds on this by recognizing feedback loops that sustain stagnation in innovation. This results in a gap in the formal explanation of how the interplay between different governance levels and the public and private actors produces and perpetuates the barriers to the scaling up of RAP reuse practices. This study complements those studies by opting for a multi-level governance lens that is material specific (RAP) and utilized at the project level. Moreover, Ruiz et al (2024) highlights the need for analysis of cases with successful implementations. This study analyzes projects involving successful incorporation higher RAP percentages to learn how collaboration and joint decision-making lead to increased RAP reuse. Also, the literature has a limited number of studies that involve interviews or surveys with key actors in the asphalt value chain and the Dutch Road Infrastructure Sector to note and understand their attitudes towards RAP reuse. As a result, there is a need for thorough analysis and recognition of major challenges, through the perspectives of the key stakeholders in the value chain, that hinder RAP to reach its full potential.

There is a need for more research in integrated governance frameworks that can effectively manage the transition towards a Circular Economy across different levels of government. This is because the current literature often focuses on individual levels or sectors and neglects the interdependencies and synergies that can be achieved through a coordinated approach. The spatial implications of resource flow and the need for coordination between governments at different aggregation levels is critical but often overlooked (Heurkens & Dąbrowski, 2020). There are studies that recommend integrated governance frameworks for Circular Economy (EAPA Technical Review, 2022) but specific studies on RAP are absent. While both national and local governments play crucial roles in promoting sustainable construction practices, there is a significant gap in understanding how collaboration between these levels can optimize material reuse and reduce resource depletion in road and pavement construction. Literature suggests that while various CE initiatives exist, they are fragmented and uncoordinated and prevent a comprehensive regime shift towards sustainability (Aksel et al, 2024). Furthermore, the impact of long-term, cross-boundary collaboration on material reuse, specifically in pavement construction, remains underexplored.

Therefore, there is a need for research that applies governance lens to the case of RAP reuse. Such an approach can provide explanations of why barriers occur and highlight how better alignment across governance levels, and the private sector can enable scaling up of RAP reuse practices. This need is urgent because RAP represents one of the most significant secondary material streams in the Dutch infrastructure sector and has significant potential to reduce carbon emissions and contribute to circular economy initiatives, as explained in section 2.2. Without a clear understanding of how governance structures restrain or enable RAP reuse, opportunities for scaling up of those practices are difficult. Therefore, by integrating governance lens, through MLG, with barrier identification, this study aims to fill the identified gap and contribute to circular economic transition studies.

2.7 Theoretical Framework

This chapter presents the theoretical foundation of this research. This study draws inspiration from two theories and frameworks: a barrier analysis framework and a multi-level governance framework to analyze governance structures. The first section explains the barrier identification framework which categorizes and structures the various barriers to the reuse of RAP into four main categories- Technical, Cultural, Regulatory, and Market. The second section introduces the Multi-level Governance Framework adapted from literature to analyze governance structures, coordination mechanisms, and decision-making dynamics in projects involving RAP and the broader asphalt sector. At the end of this chapter, a conceptual framework combining both these theories is presented.

2.7.1 Barrier Identification Framework

In this research, the barriers to the reuse of RAP are analyzed by using the framework proposed by Kirchherr et al (2018) in which identify and analyze obstacles to CE implementation in the EU by providing a comprehensive overview of barriers in the form of 4 categories. They built up on the categorization framework proposed by de Jesus & Mendonça (2018), Kirchherr et al, categorized barriers into four broad categories which helps structure the identification process and ensures that no major obstacles are overlooked. The four main categories as described by Kirchherr et al are:

- Cultural Barriers: The barriers refer to the mindset, awareness, and organization culture. For instance, lack of consumer awareness, or hesitant company culture etc., as these factors can slow adoption of new practices and innovations.
- Market Barriers: These include market and economic considerations that affect adoption of CE like procurement challenges, higher costs, limited economic incentives and supply-chain issues. It has been observed that market challenges underlie many cultural challenges, for example, if sustainable options are not economically competitive, businesses and consumers can be hesitant.

- Technological/Technical Barriers: This category includes technological limitations and insufficient infrastructure like lack of technical expertise and guidelines, quality, and performance issues of the material, and logistical challenges.
- Regulatory Barriers: These refer to challenges due to government policies, laws, regulations, and incentives that can enable or hinder a certain process or transitions. It can include a lack of supportive government interventions, restrictive regulations and standards, and mismatch between goals and timelines.

By organizing barriers into these categories, the framework provides a clear picture of what to look for when diagnosing barriers. Adopting this framework in this research involves systematic barrier identification wherein barriers to circular reuse of RAP identified through literature review were verified and validated through expert interviews with relevant stakeholders and then categorize each identified barrier to one of the four categories. The justification for choosing this framework is that it is a holistic framework backed by empirical evidence as Kirchherr et al.'s classification emerged as a large-scale study which lends it credibility and the generic nature to its categories. Therefore, using this framework grounds this research in a proven scheme rather than using a narrow set of barriers. The findings highlight the importance of soft barriers like cultural and policy driven issues which might be overlooked if one only focuses on technological and operational barriers. Following the framework provided by Kirchherr et al, the research is less likely to ignore these critical dimensions. In conclusion, using Kirchherr et al.'s framework helped identify what barriers exist and why they exist, which increased the analytical rigor of the research.

2.7.2 Multi-Level Governance

Multi-level governance (MLG) is a theory that explains the dispersion of power and authority across multiple, interconnected levels of government and among a wide range of public and private actors (Hooghe & Marks, 2001). The concept of MLG emerged as a response to increasing fragmentation of political authority across different levels of governments and sectors, especially in the European Union (Hooghe & Marks, 2001). Hooghe & Marks (2001) add another layer to this by recognizing that private sector, civil society, and other non-state actors also play an important role in shaping and implementing policies. The necessity for multi-level governance becomes clear in contexts like infrastructure and environment management as many different stakeholders on different levels and with different goals are involved. MLG examines the dynamics between these varying groups and seeks ways to bridge the gaps between different levels as it recognizes that governance is a complex mix of hierarchies, networks, and markets and that the authority is dispersed and must be negotiated among levels and sectors (Cairney,2019).

Hooghe & Marks (2001) proposed two ideal types of MLG -Type I & Type II, which represent distinct responses to the coordination challenges that arise when authority is shared between multiple actors and levels. The two types of MLG are described below.

- **Type I**: This type is characterized by stable, general-purpose jurisdictions that include various functions and responsibilities. The jurisdictions are organized in a nested and non-overlapping hierarchy and include territorially defined entities such as national government, provinces, and municipalities.

- **Type II**: This type includes a large number of task-specific jurisdictions that are designed to address particular policy problems or deliver specific services. It is characterized by flexible, overlapping, and task specific governance arrangements and are often temporary and created for specific policy objectives.

A detailed explanation of the distinction between the two Types of MLG is provided in Appendix A: Characteristics of the two Types of MLG.

Relevance & Application in this Research

The circular reuse of RAP in the Dutch road infrastructure is a multi-level challenge that involves national (Rijkswaterstaat), provincial, and local road authorities (Municipalities), contractors, asphalt suppliers and producers, engineering firms and research institutes. These actors operate at different levels and often under different timeframes and sustainability goals. MLG perspective is relevant here as it recognizes vertical complexity that is the need to align national ambitions with local practices. It also accounts for horizontal relationships, which is the interdependence between government agencies and market actors. Finally, it provides a framework to distinguish which type of governance is dominating the asphalt sector. Therefore, MLG was chosen as the theoretical basis to guide this research.

In this study, MLG is used as an analytical lens to examine how governance structures influence the reuse of RAP in the Dutch asphalt sector. Even though MLG is often discussed in relation to government-to-government interactions and that the presence of private actors or non-state actors automatically means that its Type II governance, it is important to consider that Type I can also involve private actors. Saito-Jensen (2015) hinted towards the fact that Type I MLG can also involve non-state actors. The main difference between the two types lies in how governance is structured and coordinated and not simply in who participates. As noted by Cairney (2019), it is the design and operation of governance rather than the mix of participants that distinguishes the two types. Therefore, this study makes the assumption that the presence of both public and private actors doesn't automatically point towards Type II governance.

Framework

MLG in this study is applied to both specific RAP projects and the general project practices of the Dutch asphalt sector to determine which MLG type is dominant. This is crucial as it allows the study to assess whether governance structures currently in place support the collaboration, and flexibility required for increasing RAP reuse. In the Netherlands, governance is structured across three levels: national, regional/provincial, and local, as described in section 2.5. This pans out as Rijkswaterstaat responsible for national roads, Provincial level responsible for provincial roads and regional coordination, and the municipal level responsible for local roads. These levels together with market parties form the governance landscape where RAP related decisions are made. To apply the framework in this landscape, the theoretical distinctions between two Types of MLG as described by Hooghe & Marks (2001) have to be translated into observable features so as to assess the governance structure of RAP reuse in the Dutch infrastructure sector. Therefore, the four key characteristics described by Hooghe & Marks (2001) were adapted to reflect the structure, inclusiveness, complexity, and flexibility of governance arrangements. The four characteristics are explained below and their indicators for the two Types of MLG and how to interpret them is given in Table 2.

1. **Authority in Decision Making:** This characteristic is concerned with the distribution of authority over decisions related to the reuse of RAP, for instance, how much RAP is allowed in the new mix, what type of mix and so on. So basically, who decides on RAP use and how is authority distributed across the three governance levels.
2. **Jurisdictional Boundaries: This** characteristic is concerned with how the responsibilities regarding the reuse of RAP are distributed amongst the national, provincial, and local levels, are they distinct or over-lapping.
3. **Coordination Mechanisms:** This characteristic is concerned with the structure of communication and coordination between different actors as well as the three levels, by exploring how information flows occur.
4. **Adaptability of governance mechanisms:** This characteristic is concerned with to what extent can the governance arrangements adjust to changing circumstances, technical developments, or innovating project opportunities.

A detailed explanation of how the two types are interpreted according to these characteristics is provided in Appendix A.

Table 2 Difference between Type I & Type II MLG considering the four characteristics.

Characteristic	Type I	Type II
Authority in Decision Making	Centralized, single authority decides (e.g., road authority)	Shred and collaborative decision making (road authority, contractor, and others)
Jurisdictional Boundaries	Distinct and non-overlapping (national, provincial, and local each manage their own roads and material)	Overlapping and flexible, joint responsibilities across levels
Coordination & Communication Mechanisms	Hierarchical and top-down communication with predetermined reporting lines	Multi-directional communication with open and frequent information flows
Adaptability of Governance Mechanisms	Stable, long-standing but less responsive to changes	Flexible and task-specific, allows experimentation and project-based adjustments

The framework provides a tool for analyzing the governance arrangements for RAP reuse in projects as well as the broader Dutch asphalt sector. This will help understand why some barriers to the reuse of RAP exist at the project level. Each characteristic can be assessed using evidence from interviews with different actors to enable a systematic classification of

Type I or II MLG. This way, it will help to figure out whether the sector's prevailing governance type supports or constrains the collaborative approach needed to increase RAP reuse.

2.7.3 Conceptual Framework

To analyze the barriers to increasing the reuse of RAP in the Dutch road infrastructure sector, this study combines the two theories (explained in sections 2.7.1 & 2.7.2) into a single conceptual framework. The rationale is that these barriers are not isolated from each other but are interlinked and might be affected by how governance arrangements are in road infrastructure projects and in the general project practices. Taken together, the conceptual framework acts as a two layered lens as explained below:

- The first perspective is drawn from Kirchherr et al's (2018) four barrier categories (Technical, Cultural, Regulatory, & Market) to provide a structured way to identify and categorize barriers encountered in the reuse of RAP.
- The second perspective is drawn from the Multi-level Governance Theory (MLG) by Hooghe & Marks (2001). This framework allows these categories to be interpreted in relation to governance characteristics (authority in decision-making, jurisdictional boundaries, coordination mechanisms, and adaptability of governance mechanisms) and see how these lead to some barriers persisting in the sector. It is also used to identify which Type of MLG is demonstrated by the Dutch road infrastructure projects.

This integration allows the research to move beyond static inventory of barriers towards understanding their governance roots. In combination, this framework treats barriers as symptoms and governance structures as their underlying conditions. This means, barriers are not only something that stakeholders complain about, but they are shaped by deeper governance dynamics. This dual lens technique has been used by several studies, for instance, De Gregio et al. (2019) show in climate policy how power dynamics across levels lead to implementation and communication barriers. Similarly, Dorst et al (2022) show that in urban infrastructure, technical and social obstacles are influenced by governance norms. Therefore, the framework used in this study does not just catalogue barriers but diagnoses why they persist. This makes it both a diagnostic tool (what barriers exist) and an interpretive tool (how governance structures influence their existence). This forms the backbone of this study's analytical approach.

Chapter 3. Methodology

This chapter describes the research methodology used in this study. The chosen research approach is qualitative exploratory research with two waves of semi-structured interviews. Section 3.1 explains the rationale for choosing qualitative methodology followed by section 3.2 which describes the data collection process. The primary data collection processes used are literature review and semi-structured interviews. The procedure for both waves of semi-structured interviews is explained in section 3.2.2. The ethical considerations for conducting the interviews are described in section 3.3. After this, the data analysis method for the transcripts of both the waves of interviews is discussed in section 3.4. Section 3.5 describes how validity and reliability of the data collected is ensured. The chapter ends with explaining the research strategy for each research question explained in section 3.6.

3.1 Research Approach

The chosen research method for this research is explorative qualitative research. A qualitative research approach allows in-depth understanding of stakeholders' perspectives, experiences and motivations which are often missed out in quantitative approach and hence is well-suited for exploratory research about circular transitions and challenges. And explorative research is well-suited as it this study addresses a phenomenon with less existing empirical evidence. By focusing on a Dutch context of road construction and RAP reuse, this research can be considered as a single-case study with different embedded units i.e., the various stakeholders. It has been noted that in-depth qualitative research is ideal for investigating 'little-known' or complex phenomena, like transition to a circular economy, in this case specifically regarding reuse practices related to RAP, in real-life contexts (Marshall & Rossman, 2014; Ho et al, 2025). It is common in circular infrastructure research to directly engage with practitioners and experts to gather rich data and interviews, and case analyses are some of the frequently employed methods (Kirchherr et al 2018; Ho et al, 2025).

3.2 Data Collection

The primary methods for data collection in this study include literature review and semi-structured interviews conducted in two waves. The literature review process mainly served as a way to gather background information, explore key theories, and identify barriers to circular reuse of RAP and also to guide the designing of questions for the two waves of interviews. The interviews were used to verify barriers identified in literature, gain perspectives of various stakeholders and information about the governance structures in specific projects involving RAP. This section further describes the purpose of literature review and the interviews.

3.2.1 Literature Review

The first phase of the research began with literature review, serving as a foundational step for both the waves of the interviews. For the first wave, to gather existing knowledge and to identify potential barriers to the circular reuse of RAP. For the second wave, to create a conceptual framework to assess governance type using Multi-Level Governance theory. The ability of the literature review process to provide a broad perspective on established practices and theories, highlight existing gaps in research and consequently design a conceptual framework that further guides the empirical stages of a research make it a perfect fit for an exploratory qualitative research methodology (Bolderston, 2008).

For the first wave, the initial step in this was to gain understanding of the key concepts relevant to the research so as to properly and clearly define the scope of the research (McNabb, 2017). This included gaining understanding of topics like Circular Economy and transition to CE specifically in the infrastructure sector, understanding of RAP as a material, current practices, and its role in reducing resource depletion, and the role of national and local authorities in the transition to CE and reusing RAP. This included going through academic papers and studies on circular economy implementation, the barriers to the transition to a circular economy, and asphalt recycling and reuse. The goal was to create a baseline inventory of barriers mentioned in previous studies and then these can be examined and validated in the later empirical stages.

For the second wave, the literature review expanded to include studies about Multi-Level Governance theory and its application in the infrastructure sector. The existing papers on this theory were used to create a framework to understand and analyze the governance structures and arrangements in the sector and specifically projects involving reuse of RAP.

Another important role of the literature review was to inform the design of the subsequent interviews. This was to ensure that the interview questions were firmly rooted in existing academic research on relevant topics. This approach helped provide theoretical foundations while still leaving space for new themes to emerge inductively during interviews.

3.2.2 Semi-structured Interviews

After building up on the literature review this research's core empirical work consists of interviews with the key actors across the road construction sector of the Netherlands including road authorities, contractors, engineering consultancy firms, asphalt producers and research institutions. An interview is a method involving direct interactions with a participant to gather detailed insights and information (Longhurst, 2009). The type of interview style chosen in this study is semi-structured interviews as they offer a flexible yet focused way of gathering in-depth qualitative data. This method makes use of an interview guide that covers all key topics or questions derived from literature review but allows for the conversation to flow naturally and explore unforeseen issues. This way semi-structured interviews help probe deeper into complex issues while maintaining enough structure to cover all relevant themes (Creswell, 2009). This allows for exploration of subjective experiences, perceptions, and institutional dynamics.

In this study, the interviews were conducted in two waves with their own specific purpose.

- **First Wave:** To understand and identify barriers to the reuse of RAP through stakeholder perspectives and also verify the barriers already identified through literature.

- **Second Wave:** To explore and understand governance structures in projects involving RAP to understand how these structures shape barriers to RAP reuse and assess which type of MLG (Type I or II) was more dominant.

The interviews were conducted online via Microsoft Teams to ensure accessibility and scheduling flexibility, and the interviews were recorded and transcribed with the participant's informed consent.

3.2.2.1 Interview Design & Conduct

This section describes the interview process followed in the first and second waves of interviews, covering the purpose and approach, sampling technique, and stakeholder groups identified and interviewed.

First Wave

The first wave of interviews was conducted for the purpose of validation and exploration to verify and refine the list of barriers to RAP reuse, identified through literature review, in the Dutch context. The rationale was to test whether the identified barriers in literature truly apply in practice in the Netherlands and to reveal any additional barriers that the literature review might have missed. In this wave, the interviewees were asked to first engage in an open ended question about what kind of barriers exist or are experienced in the reuse of RAP and then presented with and asked to comment on all the barrier categories from literature including whether they have encountered it, if it is indeed a barrier faced in practice, and how significant it is. This approach helped ensure that interviewees first presented their perspective in their own words, allowing richer insights to emerge rather than limiting their responses to a predefined list of barriers from literature. This helped complement the literature review process and validate it at the same time. The expected result of the first wave of interviews was a refined list of barriers relevant to the Dutch context, a new set of barriers if any emerge and if there are any divergent or conflicting views. The plan was to conduct anywhere between 10-12 interviews in the first as it was assumed that after conducting nearly 10-12 interviews, a point of saturation, where no new barriers to RAP utilization are likely to emerge, will be reached and that the identified set of barriers are properly grounded in stakeholder perspectives.

The interview guide for the first wave of interviews was prepared which includes standardized questions common to all stakeholders and targeted questions specific to each stakeholder group. The standardized questions will help reveal general perceptions about the reuse of RAP and associated barriers, while targeted questions will help dive into issues pertaining to each group's unique roles and experiences within the road construction sector. The interview guide was reviewed and refined with the help of supervisors to enhance its relevance and clarity and is added to Appendix C: Interview Guide: Wave 1.

Sampling Technique

A purposive sampling technique was used to select interview participants with rich and relevant experience considering the scope of the research. The study targeted a diverse range of stakeholders from across the RAP value chain and the Dutch road infrastructure sector which included representatives from national governing body – Rijkswaterstaat, local governing bodies- Municipalities, road contractors and engineering firms, asphalt producers and suppliers, and research institutions. Individuals were identified based on their direct knowledge of RAP, its reuse practices, or circularity related policies. Circular Economy is a multi-actor domain and therefore, it is necessary to incorporate perspectives from businesses, government, and academia to construct a systematic overview of identified barriers (Kirchherr et al, 2018). As a result, it was important to ensure diversity in the sample to capture multiple perspectives on challenges and dynamics of RAP reuse. To further expand the participant base, snowball sampling technique was used. It is a non-probability sampling technique in which initial respondents refer or recommend other potential participants keeping in mind their relevance to the research (Parker et al. 2019). This approach is valuable in accessing experts with highly specific roles or niche experience in RAP reuse. Participant anonymity and confidentiality were guaranteed through informed consent so that they can speak freely, which is known to improve the depth of qualitative research.

Stakeholder Overview

To gain a diverse understanding of the barriers to the reuse of RAP, the first wave of interviews involved a wide range of stakeholders from across the Dutch infrastructure sector specifically actors involved in and having knowledge regarding RAP reuse practices. Given the nature and objective of this research to enhance the circular reuse of RAP, stakeholder identification is crucial as it provides a structured approach to understand the diverse perspectives, experiences and influences of various stakeholders involved in the adoption of RAP. The identification process helped pinpoint the relevant actors while mapping them into logical categories based on roles and areas of expertise. A convenient sampling strategy which involves leveraging the contacts of the company was used to create a baseline for the actors involved. The 5 main stakeholder groups identified and interviewed are:

- **Government Bodies:** including representatives from three levels of governance- National (Rijkswaterstaat), provincial, and municipal.
- **Contractors:** responsible for implementing RAP reuse
- **Asphalt Producers & Suppliers:** expertise in all aspects of technical, regulatory, and market dimensions of RAP.
- **Engineering Consultancy Firms:** involved in design, procurement, and implementation of RAP reuse.
- **Research & Knowledge Institutions:** contributing academic, technical, and standardized insights.

A detailed overview of all the stakeholder groups is given in Appendix B: Overview of Stakeholder Groups interviewed in Wave 1.

Second Wave

The second phase of the research involved analyzing projects through the lens of multi-level governance to verify barriers identified in the first wave. That is why a case study approach, or more like case examples, were used to fulfil the objective of this phase. The detailed explanation of the case study approach followed by the interviews is described below.

Case Study Approach

In the second stage of this research specific project cases were included to verify if the barriers identified in the first wave actually experience on a project level, by analyzing the governance arrangements within the project. The intention was not to conduct full scale case studies but rather to use case examples to see how governance structures shape RAP reuse in projects.

This choice is supported by case study literature. Case studies allow for an inquiry to explore complex and context dependent phenomena and answering how and why questions (Crowe et al. 2011). In this research, the project cases serve to verify barriers to RAP reuse through a governance perspective. This research uses case examples instrumentally - that means to gain insights into broader governance issues around RAP reuse rather than studying the case for its own uniqueness. As this study involves the use of three projects, it can be called a collective case study approach, as described by Stake (1995). Stake describes a collective case study where multiple cases are studied simultaneously or sequentially to get a broader understanding of a phenomenon. This is well suited for this research to verify patterns across different projects and compare them to the general sector perspective, which basically means how projects involving RAP are usually governed and how these three projects followed the same pattern or diverged from this pattern.

However, unlike traditional case studies that utilize multiple data sources and deep contextual analysis, this research adopts a multiple mini case study approach. This approach was coined by Käss et al, (2024), where each case is studies primarily through the perspective of single stakeholder rather than through multiple sources and triangulation. This leaner approach is becoming more recognized in qualitative research as way to explore governance phenomenon when access to multiple sources per case is limited (Käss et al, 2024). The advantage of this approach lies in the cross-case comparison, which means while individual cases may be limited in depth the consistency or divergence of patterns across multiple projects provides meaningful insights.

Case selection process was purposive rather than random. Which was guided by the objective of understanding governance mechanism to verify barriers to RAP reuse. Therefore, following the best practices for case study sampling by Yin, (2014), projects were chosen to represent different governance contexts. At least one project was led by the national road authority (Rijkswaterstaat), and one led by a municipality. In total three projects were chosen - Two led by Rijkswaterstaat and one led by a municipality. The second criterion was that cases were chosen to reflect different stakeholder perspectives. One project was studied through the perspective of the contractors; one was studied through the perspective of the client and third project involved both client and contractor's perspective. This was to ensure that governance dynamics are not interpreted from a single actor type alone. Lastly, the projects were selected based on practical feasibility and willingness of the stakeholder to share project experiences. Therefore, the selected projects are:

- Project A: Middenweg Project Amsterdam (municipal level)- studied through the perspective of the contractor.
- Project B: Rijkswaterstaat GVO WNN Project (national level)- studied through the perspective of both the client and the contractor.
- Project C: A1 Apeldoorn-Azelo (national level)- studied through the perspective of the client.

The three case examples are introduced in detail in section 4.3.

Interviews

The second wave of interviews was designed to move beyond the understanding of barriers at the sector level and instead focus on the governance structure within projects involving RAP. The interviews were structured around the four main characteristics adapted for the Multi-Level Governance framework, explained in section 2.7.2.

The interviews began with an open question about the interviewee's experience with RAP. This was followed by questions aimed at identifying recent projects that could serve as case examples for this research. When participants could point to a specific project, the discussion shifted towards understanding governance structures, roles and responsibilities, and coordination mechanism within the project. If participants were unable to identify any projects, they provided insights from a broader sector perspective, reflecting on how governance structures affect barriers to RAP reuse. In this way, the interviews not only allowed the identification of relevant case projects but also ensured that the research captured both project-specific and general sector governance insights.

From the beginning, the aim was to consider at least two case projects, one involving the national road authority (Rijkswaterstaat) and one involving a municipality. This way it could be analyzed how projects involving reuse of RAP are governed across levels, which is an important dimension of MLG (Hooghe & Marks, 2001). National authorities often operate under standardized, formalized practices, while municipalities tend to display more fragmented and context specific approaches (Cairney, 2019). By including both governance levels, the study ensures to capture the variation in governance arrangements that exists in practice. The interview guide for the second wave of interviews is added to Appendix D: Interview Guide: Wave 2.

Sampling Strategy

A purposive sampling technique was used in this wave as well, to select interview participants with rich and relevant experience considering the scope of the research. This time with a narrower and project- specific focus. While in the first wave, many different stakeholder groups were involved, the second wave only involved clients and contractors, as these actors play the most important roles in decision making and implementation of RAP reuse practices in a project. Participant anonymity and confidentiality were guaranteed through informed consent so that they can speak freely, which is known to improve the depth of qualitative research.

Stakeholder Overview

As the objective was to understand the governance structures within a project (and also how it is within the general sector), two main groups of stakeholders were interviewed- clients and contractors.

Client: For Project B (RWS GVO WNN) and Project C (A1 Apeldoorn-Azelo) the clients side perspective was represented by two representatives from Rijkswaterstaat involved in the two projects. Another representative from RWS was interviewed to explain and give perspective on the governance structure followed in projects in the broader sector.

Contractor: For Project A (Middenweg) and Project B (RWS GVO WNN) the contractor's perspective was taken which came from the same organization and hence the same person, one interview, was interviewed to gain insights from both projects. Two additional representatives of contracting firms were interviewed to share broader sector level insights about projects involving RAP.

By focusing on these two groups, the study ensured that perspectives were drawn from both sides of the governance relationship- those who commission the project (clients) and those who implement it (contractors). This dual focus was intended to capture the governance dynamics more comprehensively while also remaining feasible given the study's scope and access constraints.

3.3 Ethical Considerations

The guiding principle for conducting the interviews was respect, confidentiality, and consent. Participation of the interviewees across all interviews was voluntary, and they were made aware of the study's objectives, scope of their involvement, how the data would be used, and the measures in place to safeguard their identities and information. Informed consent form (attached in Appendix E) was created sent to each interviewee before the interview and also prior to the recording of the interviews consent was taken. To ensure participant's privacy, all personally identifiable information about the interviewees was taken off the transcripts and they were stored securely. Participation in the interviews was voluntary, and participants had the right to withdraw at any moment. These measures made sure that participants could share their opinions freely with proper measures in place in line with the accepted ethical standards.

3.4 Data Analysis

This section describes the data analysis approach followed for both waves of interviews. The first wave of interviews involves gaining perspective of stakeholders across the asphalt value chain regarding the barriers to RAP reuse and understanding how they perceive them. As a result, to fulfil this a thematic analysis of the transcripts are done. For the second wave, to understand governance structures across road infrastructure projects, MLG lens will be applied. As a result, the transcripts are analyzed using the MLG framework.

First Wave

The data gathered through the semi-structured interviews was analyzed through thematic analysis of the transcripts as it helps in identifying, analyzing, and reporting patterns or themes, in this case barrier themes, within qualitative data (Braun & Clarke, 2006). This approach is well-suited for this explorative study as it helps identify themes through stakeholder perspectives and it also helped to analyze a wide range of interview responses into coherent themes. The platform used for the thematic analysis process was Atlas.ti. Braun & Clarke (2006) describe a step-by-step process for thematic analysis, and a similar process will be used for this research, it is described below:

1. **Preparing the data:** The first step is to generate transcripts of semi-structured interviews which will be done via MS Teams (the platform through which the interviews were conducted) with the informed consent of the participants. The transcripts were the primary source of data through interviews for the thematic analysis and helped in the next step of familiarization of the data.
2. **Data Familiarization:** This step involved repeated reading of the transcripts by the researcher to familiarize oneself with the data and helped in coming up with initial ideas and recognize emerging patterns. This phase was important in understanding how different actors perceive different barriers to the circular reuse of RAP.
3. **Generation of Initial Codes (Open Coding):** This step involved categorization of data by assigning labels or codes to different segments of the qualitative data (Khokhar et al, 2020). In the transcripts of the first wave, various segments were assigned codes based on what they actually convey (open coding).
4. **Searching for Themes (Axial Coding):** This step involved developing themes based on the open codes assigned by grouping those codes into broader themes. For instance, codes concerning how quality of the material is affected by integrating RAP were grouped under the theme- uncertainty in quality of RAP and so on.
5. **Interpretation of Data (Selective Coding):** The focus of this step was on interpreting the results from the assigning of codes and grouping them into broader themes. For this purpose, the resulting axial codes (group of open codes) were further grouped under categories - Technical, Cultural, Regulatory, and Market Barriers, and this is called selective coding. This helped in defining what each theme actually means and how it helps answer the main and sub research questions.
6. **Reporting the Data**: This last step involves presenting the results of the thematic analysis in a coherent and logical manner by quoting relevant excerpts from the transcripts using the codes assigned. This phase is not just about stating what is already known but also analyzing the data and coming up with arguments that help answer the research questions of the study.

Refinement of Barrier Categories

Initially, to represent the barriers to RAP reuse identified through literature were categorized under 5 categories: Technical, Regulatory, Market, Institutional & Governance, and Information Sharing challenges, which were created due to the recurring themes in literature (as discussed in section 2.4). However, during the analysis of interview data some refinements were made to better capture the diverse nature of stakeholder perspectives. The institutional and governance and information sharing challenges categories were merged into a broader theme called Cultural Barriers. This was grounded in both literature and empirical evidence. Kirchherr et al (2018) define cultural barriers as soft barriers that occur due to norms, trust, attitude, and institutional behavior. Studies show that cultural barriers are rooted in weak trust and transparency between actors, lack of collaboration across organizational boundaries, and conservative or risk-averse nature that reinforces linear practices over circular ones (Bremer et al. 2021; Rajčić et al. 2024).

The barriers initially categorized under Institutional & Governance (unclear rules, limited collaboration), and Information Sharing (lack of information & knowledge sharing) align closely with these cultural dimensions. This is because both reflect a willingness, or the lack thereof, of stakeholders to coordinate, share knowledge, and collectively adjust practices. Given this overlap, and the fact that there is only one challenge under Information Sharing category in literature, merging the two categories under Cultural category was a coherent and balanced way of presenting results. This refinement is also consistent with the framework by Kirchherr et al (2018) that categorizes barriers to CE transition into four broad categories: Technical, Regulatory, Market, & Cultural. As a result, the final categories used to present the interview findings are: Technical, Regulatory, Market, & Cultural. While this categorization is justified in this study, it's not uncontested in literature and a more detailed argument is resented in Chapter 5 Discussion, under limitations.

Second Wave

The data gathered in the second wave of interviews was analyzed through a framework-guided approach, rather than inductive thematic analysis as done in wave 1. This was necessary because the purpose of the second wave was not to generate new barrier categories but to interpret the governance structures of projects and to verify existing barriers.

The analysis was guided by the adapted Multi-level Governance Framework described in section 3.2. This focused on four analytical characteristics- Authority in decision making, jurisdictional boundaries, coordination and communication mechanism, and adaptability of governance mechanisms. For each interview relevant excerpts were coded deductively, using Atlas.ti, under the four characteristics of the MLG framework. The structured coding helped generate two levels of analyses.

- **General project practices:** which describe how governance arrangements usually are in infrastructure projects involving RAP reuse.
- **Project-level:** which describes how governance arrangements were within specific projects that involved RAP reuse.

A key step in this process was linking these results back to wave 1 results where barriers to RAP reuse were identified. Under each of the MLG characteristics and across each case, instances where barriers re-emerged were explicitly connected. This helped in understanding why certain barriers emerge in the first place.

The next step was to interpret the data under the four characteristics and across project to identify which Type of MLG (Type I or II) is more dominant. This revealed whether the governance characteristics aligned more with Type I or Type II MLG. Therefore, the results from the second wave were synthesized in two ways- first to explain how each project and the general sector reflect the four different characteristics of MLG and how these shape the occurrence of various barriers, and second, the interpretation of the MLG type across the projects and the general sector.

3.5 Validity and Reliability

The validity and reliability of qualitative data is a crucial step in any research. Validity of qualitative research refers to the correctness or credibility of the interpretation of data and conclusions drawn from it (Maxwell, 2010). Many different strategies were employed to ensure the validity of the data in this research. The first step is triangulation of data, which involves engaging a diverse range of stakeholders including national and local governing bodies, technical experts, contractors, and research institutes, to collect a broad range of perspectives and to help reduce bias (Leung, 2015). Another strategy is member checking, where all the interviewees are presented with their transcripts for review and to check the accuracy of their statements. Lastly, the results from the thematic analysis were cross-checked with the literature gathered through the literature review process to align empirical insights with scientific knowledge. Reliability refers to the appropriateness of the research methods used and the integrity of the final conclusions (Noble & Smith, 2015). In this research reliability will be ensured by, first, going thoroughly through all the transcripts to ensure their accuracy and then the coding process will be documented well by recording how codes were derived and evolved.

3.6 Research Strategy

This section revisits the research questions in order to outline how each sub-research question will be answered with the help of the chosen research methods. A complete overview of the research design followed in this study is presented in Figure 3.

SRQ 1- *What barriers to the reuse of RAP are identified in literature?*

The methodological approach chosen to address this question is literature review. This question will be answered by synthesizing the existing knowledge on the barriers to the reuse of RAP from academic literature. Both general barriers to CE transition and specific barriers to RAP reuse are included in creating a baseline inventory of barriers which later serves as the basis for comparison with empirical findings.

SRQ 2- *What barriers to the reuse of RAP are identified in practice by key stakeholders in asphalt value chain and how are they perceived differently by different stakeholders?*

This research question is answered through the first wave of semi-structured interviews with stakeholders across the asphalt value chain (government bodies, contractors, engineering consultancy firms, asphalt producers, and research and knowledge institutes). Thematic analysis is conducted on Atlas.ti to divide barriers into 4 categories: Technical, Cultural, Regulatory, and Market. This also helped to see how different stakeholder groups emphasize different categories and helped with the comparison with literature.

SQR3- *How do governance structures shape these barriers at the sector and project level?*

The methodological approach chosen for answering this question is the second wave of semi-structured interviews. This wave was guided by the theoretical framework developed through the lens of MLG. A mini case study approach (with three case projects involving RAP reuse) was utilized where insights from selected projects were analyzed using the MLG) framework. An adaptation of the characteristics of two types of MLG from literature helped guide the analysis to assess how governance structures are arranged across three case projects and in general project practices in the Netherlands. This helped to see which barriers identified in wave one emerged at the project level and how governance structures shape them. Also, the MLG framework applied helped identify the Type of MLG (I or II) reflected in projects and the general sector.

SRQ4- *How can insights gathered through barrier identification and governance dynamic be synthesized to identify ways to increase the potential of RAP?*

The fourth sub question is answered by integrating the insights from both the waves of the interviews. By triangulating the results from both waves, the question is answered by presenting which barriers to the increased reuse of RAP are most crucial and which are secondary. This helps in suggesting potential directions to address these barriers combining both Type I and Type II MLG features.

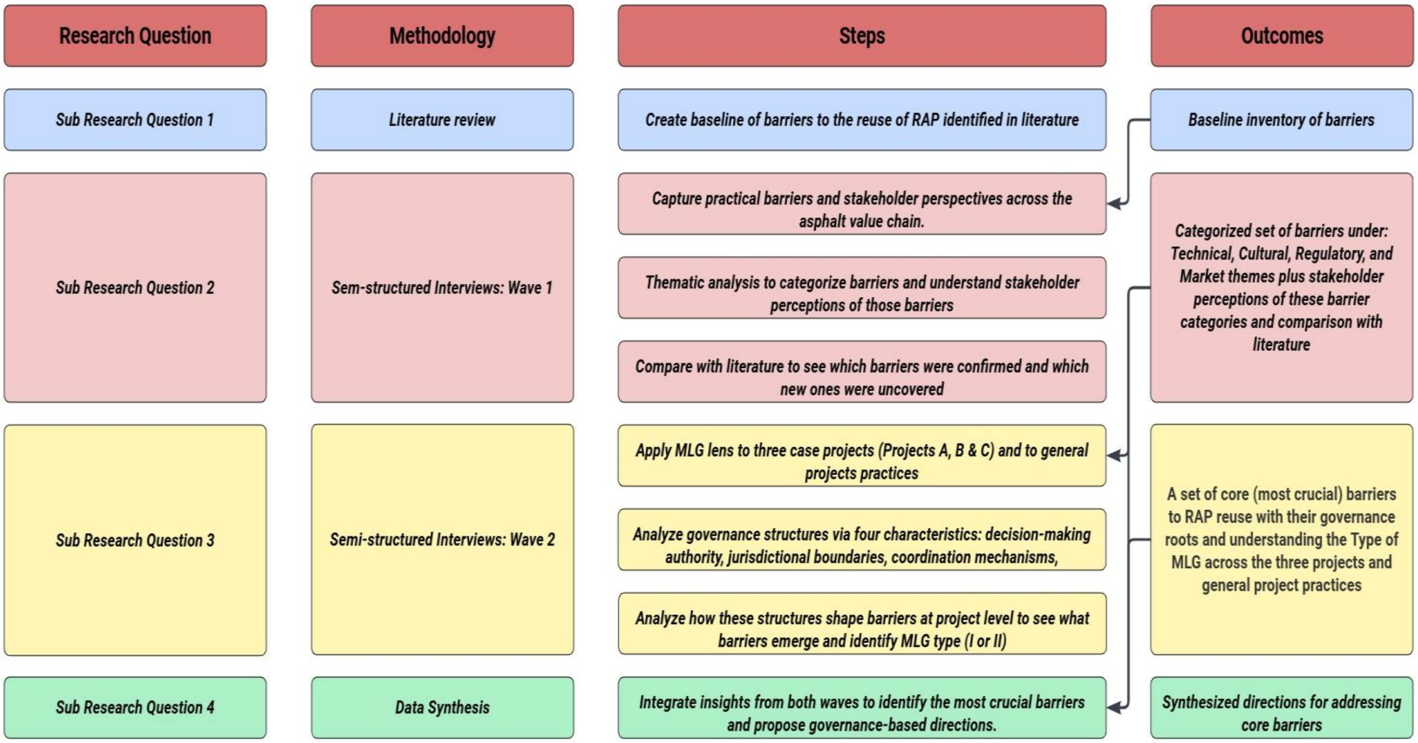

Figure 3 Research Design (author)

Chapter 4. Results

4.1 Introduction

This chapter presents the empirical findings of this study and brings together insights from two waves of stakeholder interviews. The first wave provided a wide range of barriers to the increasing the reuse of RAP, identified by practitioners in the Dutch road infrastructure sector. The second wave provided depth to this analysis by applying the multi-level governance lens at the project level to explain how governance characteristics shape and influence these barriers.

The chapter is divided into three main sections which are further divided into sub-sections. The first section after introduction is 4.2 Wave 1: Barrier Identification & Analysis which describes the identified barriers to the reuse of RAP through stakeholder interviews followed by their analysis. It is divided into 3 subsections: Section 4.2.1 describes in detail all the barriers identified through interviews and are presented under 4 broad categories-technical, cultural, regulatory, and market barriers followed by which barriers were most and least emphasized during the interviews. Section 4.2.2 describes which stakeholder group emphasizes which barrier category the most. Lastly, section 4.2.3 compares the findings of the interview with literature by showing which barriers were identified in literature and which were confirmed or uncovered through interviews.

The second section is 4.3 Wave 2: Project-level analysis of governance structures, which focuses on specific road projects to analyze decision making authority, jurisdictional boundaries, coordination mechanism, and adaptability of governance structures. The section is divided into two sub sections: 4.3.1 which applies the MLG characteristics to the projects and reveals which barriers emerge from this and the MLG type across the projects and general project structures.

4.2 Wave 1: Barrier Identification & Analysis

This section presents the empirical findings from the first wave of semi-structured interviews solely focusing on identifying the key barriers to the reuse of RAP in the Dutch infrastructure sector. The section begins by giving an overview of the interviewees. Following this, a thematic presentation of the barriers to RAP reuse identified in the interviews under the four key barrier categories namely: Technical, Cultural, Regulatory, and Market, is discussed. To maintain clarity, the barriers are provided in a synthesized manner. The detailed supporting evidence in the form of quotes from interviews and extended explanation is provided in Appendix G: Interview Quotes- Barriers to RAP Reuse. This is followed by an overview diagram of the identified barriers and complemented by a frequency analysis which presents which barriers was mentioned by how many stakeholders to identify which issues are more widely recognized. Next, the section presents the stakeholders' perspectives on the barriers by analyzing how different groups emphasized different categories. The final section compares the findings from literature with the findings from the interview which highlights which challenges were confirmed, which were rejected, and which were newly revealed.

A total of 16 semi-structured interviews were conducted with both public and private actors from the five main stakeholder groups interviewed were: government bodies (consisting of Rijkswaterstaat, municipality and a province), contractors, asphalt producers, engineering consultancy firms, and research and knowledge institutions. The resulting list of stakeholders from this process is given in Table 9 in Appendix G.

4.2.1 Barriers to the reuse of RAP

This section presents the core findings from the first wave of interviews by specifically focusing on the barriers to the reuse of RAP in the Dutch infrastructure sector. After the coding process on Atlas.ti, the coded data was organized thematically to capture the range of challenges discussed by various stakeholders. A representation of all the open, axial, and selective codes used for this analysis is presented Table 8 in Appendix F: Open, Axial, & Selective Codes for Wave 1 Results.

As explained in Chapter 3 under refinement of barrier categories, Initially, the barriers to RAP reuse were categorized under 5 themes: Technical, Regulatory, Market, Institutional & Governance, and Information Sharing challenges, which were created due to the recurring themes in literature (as discussed in section 2.4). However, during the analysis of interview data it became clear that information sharing challenges and institutional and governance themes overlap significantly. Information sharing challenges were raised only in a limited way, as in just a single challenge under the category, and always in connection with broader institutional and governance issues, such as misaligned incentives or lack of collaboration. Keeping them separate would have created an imbalanced framework with one category representing a single barrier, while in practice both themes reflect cultural behaviors. As a result, the final categories used to present the interview findings are: Technical, Regulatory, Market, & Cultural.

4.2.1.1 Technical Barriers

Technical barriers refer to the limitations in the availability, maturity, and performance of technologies and processes necessary for the effective reuse of RAP. An extended overview with quotes from interviews for each barrier is given in Appendix G. The 7 technical barriers to the reuse of RAP are:

Uncertainty in the quality of RAP: This can be due to several reasons including source of the material, additives or modifiers used in older asphalt, and processing and milling methods[9]. Another reason is lack of consistent quality rules and over diversification of asphalt mixtures across projects and regions. This variability reduces confidence in the consistency and performance of RAP which acts as a barrier for its wider adoption.

Lack of long-term performance monitoring of mixes with RAP: Another challenge is the lack of reliable data and validation methods to guarantee the long-term performance of asphalt mixtures with high RAP content, especially in surface layers. The challenge is twofold- first, the performance and durability of these mixtures remain largely unvalidated and second, the absence of a monitoring and feedback mechanism prevents the sector

[9] The process of grinding down the surface layer of a pavement to a specific depth

from learning and improving systematically. Therefore, the sector is caught in a loop- performance cannot be guaranteed without data and data cannot be generated without broader experimentation and long-term monitoring.

Lack of standardized technical guidelines: There is currently fragmentation in the technical landscape, as in no standardization in the validation procedures and guidelines regarding RAP reuse. This results in every organization coming up with their own procedures and no sector-wide standardization in mix designs and applications. This causes inefficiencies and limits the uptake of RAP reuse across the sector.

Milling & processing limitations: The milling and processing stage is not always selective, which means that surface, binder, and base layers are often milled together as one mass. This reduces the quality of the reclaimed material. Selective milling is a time-consuming process and cannot always be done considering traffic congestion. Additionally, milling process alters the gradation[10] of the material which makes it difficult to achieve the original mixture balance. Post-milling processing is carried out to restore material control, but it often leads to material losses, especially 0-5 mm fraction. The practical limitations introduced by non-selective milling, changes in gradation, and post-processing losses act as barriers to RAP's potential.

Challenges in reusing RAP in surface layers: While its common practice to use RAP in base and binder layers, its integration in the surface layers specially in high performance mixes like porous asphalt (ZOAB) is limited. This is because these mixes are sensitive to material variability and demand more structural durability, and long-term performance under environmental and traffic loads (Mantalovas et al, 2023). As a result, even if the material is technically reusable, often it is downcycled to lower layers because of the difficulty in meeting surface layer specifications.

Logistical Challenges: Logistical challenges manifest in three interrelated themes- limited supply of RAP compared to demand, storage capacity issues and planning uncertainties. Firstly, the limited availability of RAP is a significant issue in relation to the growing demand for circular road construction. Another issue is the planning, asphalt production is tightly scheduled, and reuse of RAP requires the knowledge of when, where and what kind of reclaimed material will be available. But this doesn't always happen in practice. Another challenge is the physical storage at the asphalt plants. Because of space and cost constraints, some asphalt plants cannot store large volume of RAP. To add to this, efforts to separate RAP by type to maintain quality, further increase requirements for space.

Environmental Concerns: A new challenge that emerged is the emissions of PAHs[11] and benzene[12] during the processing of RAP, particularly in heating stages. These substances are carcinogenic in nature and hence several asphalt plants who have not been able to comply with the emission limits set by legislation were forced to close their operations (RTV,

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[10] Particle size distribution of the material

[11] Polycyclic aromatic hydrocarbons are pollutants released due to incomplete combustion of fuel and are present in bitumen fumes during high-temperature processing of bitumen.

[12] Benzene is a hazardous substance found in crude oil which is used in manufacturing of asphalt.

2022; GLD, 2021). Beyond the environmental and health risks, this creates uncertainty for the sector as stricter regulations can further constrain the use of RAP in production. This adds another layer of complexity to its wider adoption and application.

Taken together, these technical barriers show that even though RAP reuse is well established in base and binder layers, its scaling up to higher percentages and application in surface layers require systematic improvements. These include standardization, long-term performance monitoring, coordinated approaches to milling, processing and logistics, which are essential to unlock RAP's full potential.

4.2.1.2 Cultural Barriers

Cultural barriers refer to institutional, behavioral, or organizational attitudes and practices that impact the reuse practices related to RAP. An extended overview with quotes from interviews for each barrier is given in Appendix G. The 3 cultural barriers identified are:

Limited local capacity and strategic focus on RAP: There is a perception among national actors and contractors that municipalities, especially smaller ones, are not prioritizing the reuse of RAP. They often do not have the staff or expertise to actively utilize RAP in their projects, and circularity advisors are often responsible for more than asset type. This capacity gap leads to risk-averse behavior and reliance on existing norms and standards rather than experimenting with high-RAP content mixes. The municipal perspective on this, specifically the Municipality of Amsterdam, is that they pointed out limitations in supply and quality assurance. Therefore, the absence of targeted knowledge sharing, building capacity and system wide coordination has created gaps in adoption and implementation of RAP at the local level.

Lack of information and knowledge sharing: There is a lack of sharing of information and knowledge concerning reuse practices, mixtures, guidelines etc., across the sector. Even though technical knowhow and pilot projects exist, there are challenges that limit the sharing of knowledge and information. These include contractors being reluctant to share insights into practices and mix designs to keep a competitive advantage in the market, and reputational concerns and lack of control over downstream application. The implications are that it creates information asymmetry for instance, municipalities may set sustainability targets, but they often lack technical knowledge needed to implement them effectively. This fragmentation in information and knowledge landscape is further increased by the lack of centralized or uniform data systems for RAP reuse. Even though knowledge sharing platforms exist like- CROW and NPDW, their impact remains limited. Another challenge is lack of accurate asset level information about the materials used in existing roads like types of stones, binders, and possible contaminants. It becomes an added task to assess whether the milled material is suitable for reuse purposes or not.

Lack of stakeholder collaboration: The nature of collaboration between the stakeholders in the asphalt value chain was described in contrasting terms. While some stakeholders believe that the current state of collaboration is adequate, others identified some coordination and communication gaps. There is disconnect between road authorities operating at different governance levels and also the type of mix they use on their roads.

Such differences in organizational structure and technical standards can limit collaboration and potential for material reuse across governance levels. These insights taken together present a nuanced picture of stakeholder collaboration considering RAP reuse. On one hand, formal platforms and long-standing practices suggest that collaboration is taking place. However, the effectiveness of existing collaboration appears to be uneven and heavily dependent on actor types, governance level, and regional context. This fragmentation in collaboration can limit collective goal-setting, and synchronized material flows. Therefore, the interviews reveal that even though collaboration is acknowledged as important and partially in place, it remains uneven and often informal.

These cultural barriers show that the reuse of RAP is not only a technical issue but also a matter of organizational practices and relationships. Without stronger capacity at the local level, transparent information and knowledge sharing, and more consistent collaboration across the sector, RAP reuse will remain limited and inconsistent.

4.2.1.3 Regulatory Barriers

Regulatory barriers include constraints arising from legal frameworks, policies and governance structures that limit the potential of RAP. An extended overview with quotes from interviews for each barrier is given in Appendix G. The 6 regulatory barriers identified are:

Misalignment of goals: There is misalignment of goals regarding circularity across governance levels. While national level sets ambitions and targets, municipalities interpret and implement them differently. This issue is magnified by the fact that the Netherlands has 342 municipalities each with its own capacity and priority, some are more circularity driven compared to others. This reflects the absence of a unified direction across governance levels, especially for the reuse of RAP. It can be concluded that, considering national ambitions and targets for circularity, the implementation burden lies on the local authorities like municipalities, many of which operate with limited capacity and priorities.

Fragmented regulations and lack of standardization: The regulations for RAP reuse are fragmented in nature and there is an absence of clear national norms. Even though standard guidelines for asphalt exist in the Netherlands, for instance the Standaard RAW Bepalingen 2020 by CROW, it still leaves significant room for interpretation for both contractors and road authorities, which leads to each party creating their own standards. Another challenge is the need for standardized validation procedures of mixes containing different amounts of RAP. The absence of specific standards has led to a situation where contractors and asphalt plants must validate their new mixtures themselves often through lengthy processes involving test sections and prolonged monitoring. This project-by-project validation procedure is very time and resource consuming and also results in unequal reuse opportunities.

Restrictive and inconsistent regulatory standards: Unlike the general absence of clear standards, RAP reuse in surface layers face a specific challenge, which is strict regulations. Even when it is technically feasible, additional specific requirements such as Polished Stone

Value[13] required for roads pose regulatory constraints for reclaimed asphalt. For example, porous asphalt has strict requirements for type of aggregate, gradation, and other technical specifications. These material specific requirements combined with strict regulations pose challenges in the adoption of higher RAP content mixes even if the technical capacity exists.

Material traceability challenges: There is a lack of a centralized oversight for RAP quality and availability tracking. It was mentioned that without centralized tracking or coordination of the incoming and outgoing RAP material, a big share of the material remains unaccounted for. Therefore, there is a need for a centralized system that tracks the flow and quality of RAP to ensure long-term planning and equitable reuse of material. While several stakeholders pointed out the need for such a system, no one mentioned an existing framework addressing this issue.

Constraints in the ownership of RAP: In most Dutch contracts, the ownership of RAP typically transfers from the road authority to the contractor upon the removal of the material. So, it's the contractor's responsibility to handle, process and reuse it as they see it fit. From the perspective of the client, this transfer of the ownership of the material poses limitations as it removes the ability of the road owner to control the quality of the material, its destination and intended reuse. From the contractor's perspective the existing system works efficiently for them and aligns with commercial incentives, as it allows them to stockpile RAP at their plant and reuse it according to internal needs. Yet, not all contractors agreed, one suggested that road authorities should remain owners because it's their material, thereby it should be their responsibility to reuse it. These variations in the views reveal that there is no sector-wide consensus on the optimal ownership model of the reclaimed material.

Constraints on RAP containing tar: According to environmental standards, RAP that contains tar is considered hazardous and cannot be used in new mixes and hence needs to be disposed of. This results in extra costs and reduces the pool of reusable material. What adds to this complexity is the ambiguity around the responsibility for identifying tar containing RAP. Even though the ownership transfer process is clear, that often after milling the material belongs to the contractor, the operational roles and financial liabilities are not. Therefore, material tracking is crucial to understand the amount of contamination present in the material. This links back to the need for centralized tracking of RAP for quality and availability.

These regulatory barriers reveal a picture where misaligned goals, fragmented and strict regulations, unclear directions for ownership models and an absent material oversight limit the scaling of RAP reuse. The call is for more coordinated and consistent regulations, and clearer institutional arrangements for aligning circularity ambitions.

[13] A test for skid resistance of the road surface, the higher the PSV of the aggregate, the better the skid resistance of the road

4.2.1.4 Market Barriers

Market barriers are the economic and structural challenges within the asphalt market which affect the adoption of RAP reuse practices. An extended overview with quotes from interviews for each barrier is given in Appendix G. The 3 market barriers identified are:

Procurement prioritizes cost over innovation: Across the value chain, RAP was regarded as a cost-effective alternative. However, while market dynamics support RAP reuse, current tendering procedures often prioritize low initial cost potentially at the expense of long-term performance. This is not always the case, but this cost-orientation leads to mixed outcomes. While some municipalities sometimes enable RAP reuse, others avoid RAP out of concerns about reduced pavement lifespan and thereby limiting the potential for innovation.

Inconsistent use of environmental incentives: The Environmental Cost Indicator (or Milieu Kosten Indicator (MKI) was frequently cited during interviews as a driver within procurement processes. However, MKI as a tool has not yet reached its full potential as some municipalities, especially smaller ones, lack the capacity or experience to implement MKI-based systems effectively. This creates inconsistency for contractors as they face different rewarding criteria for different road authorities. Moreover, innovative asphalt mixtures with low MKI value are often retained as proprietary knowledge which can limit the diffusion of knowledge in the market.

Monopolized value chain: Some general contractors frequently own and maintain their own asphalt plants which help them maintain material supply and reuse strategies. Even though this structure leads to efficiency gains and might lead to better collaboration as there are only few major players to collaborate with, it raises questions about distribution in responsibility in material reuse. It reinforces closed innovation systems where those who control production are better positioned to win tenders.

These market barriers show that while economic drivers support RAP reuse, structural procurement practices, uneven application of incentives, and concentrated market power create conditions that limit wider adoption. Addressing them will require procurement reform and standardization, stronger alignment of sustainability incentives and transparency in RAP flow within the market.

Overview of Barriers

The thematic analysis of the first wave of interviews verified already known barriers and uncovered some new ones regarding the reuse of RAP. The interviews and analysis also confirmed that reducing the barrier categories from 5 to 4 was an appropriate choice. Figure 2 shows barriers under 5 categories and Figure 4 shows final and verified barriers under 4 categories, where Information Sharing and Institutional & Governance Categories from Figure 2 were combined under broader Cultural category, as shown in Figure 4. This refinement was necessary, because information sharing challenges were linked to competitive advantage, reputational risk, or absence of willingness for data sharing and platforms for sharing. So, rather than standing alone, they are rooted in trust, collaboration, and attitude towards openness. These are dynamics that are cultural in nature and hence belong under this category.

Moreover, challenges like lack of stakeholder collaboration, and limited local capacity and focus on RAP reflect deeply embedded ways of working in the sector. These are issues that stem from organizational culture, risk aversion, and reluctance to depart from traditional already known ways. Therefore, they all collectively belong under Cultural category and hence the decision to merge them together was a logical one. An overview of all these barriers is presented in Figure 4, which enlists the barriers to reuse of RAP.

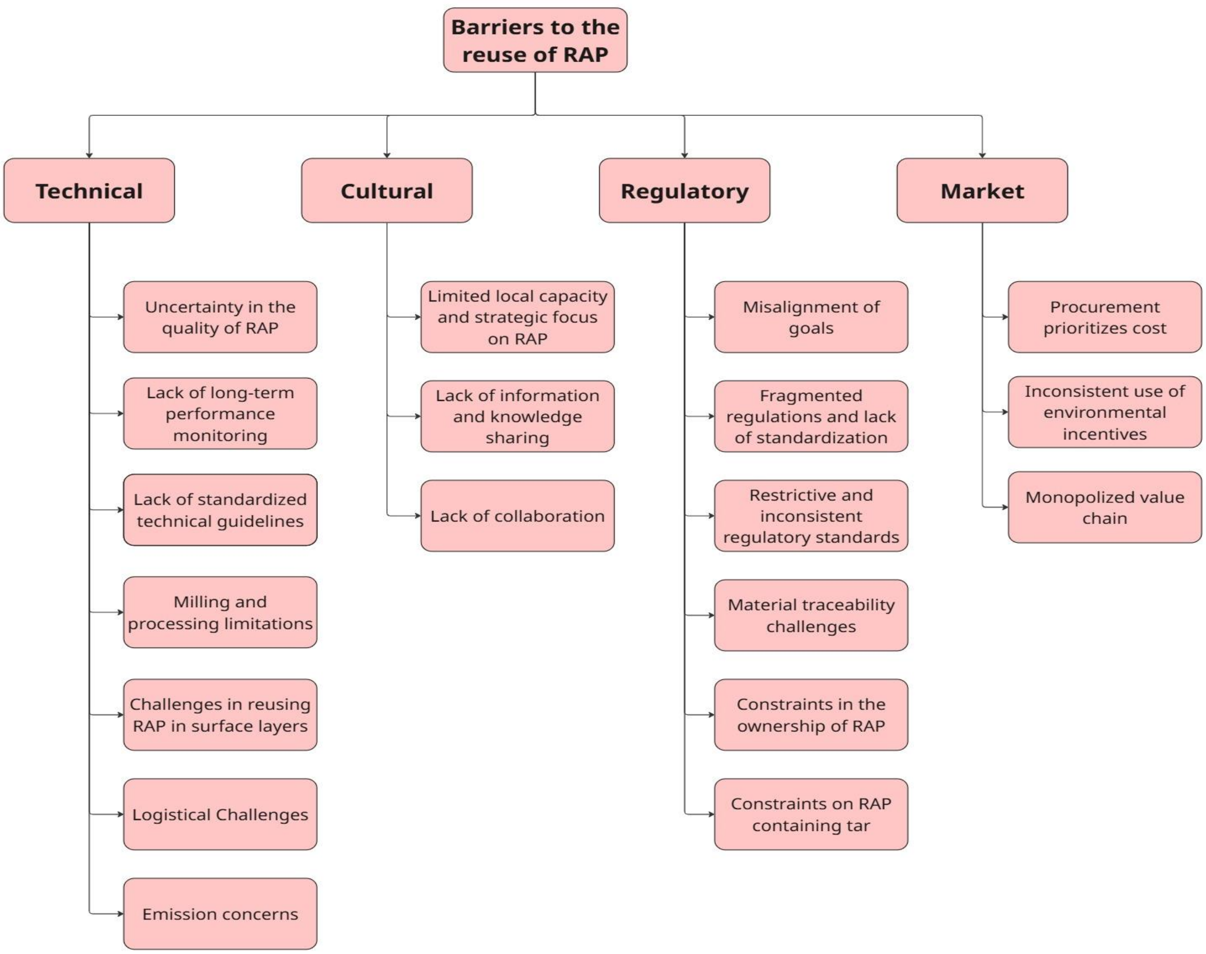

Figure 4 Overview of barriers to the reuse of RAP.

Beyond providing an overview, it is equally important to understand which barriers were most widely mentioned across stakeholders. For this purpose, a frequency analysis was conducted on Atlas.ti which helps understand how many times a code was mentioned at least once by an interviewee. In this case, it was aimed to understand which barrier was mentioned by how many interviewees at least once to see which barriers are more universally perceived and which are more context dependent. This also helped understand which problems may require most immediate attention. An overview of the frequencies of each challenge is shown in Figure 5.

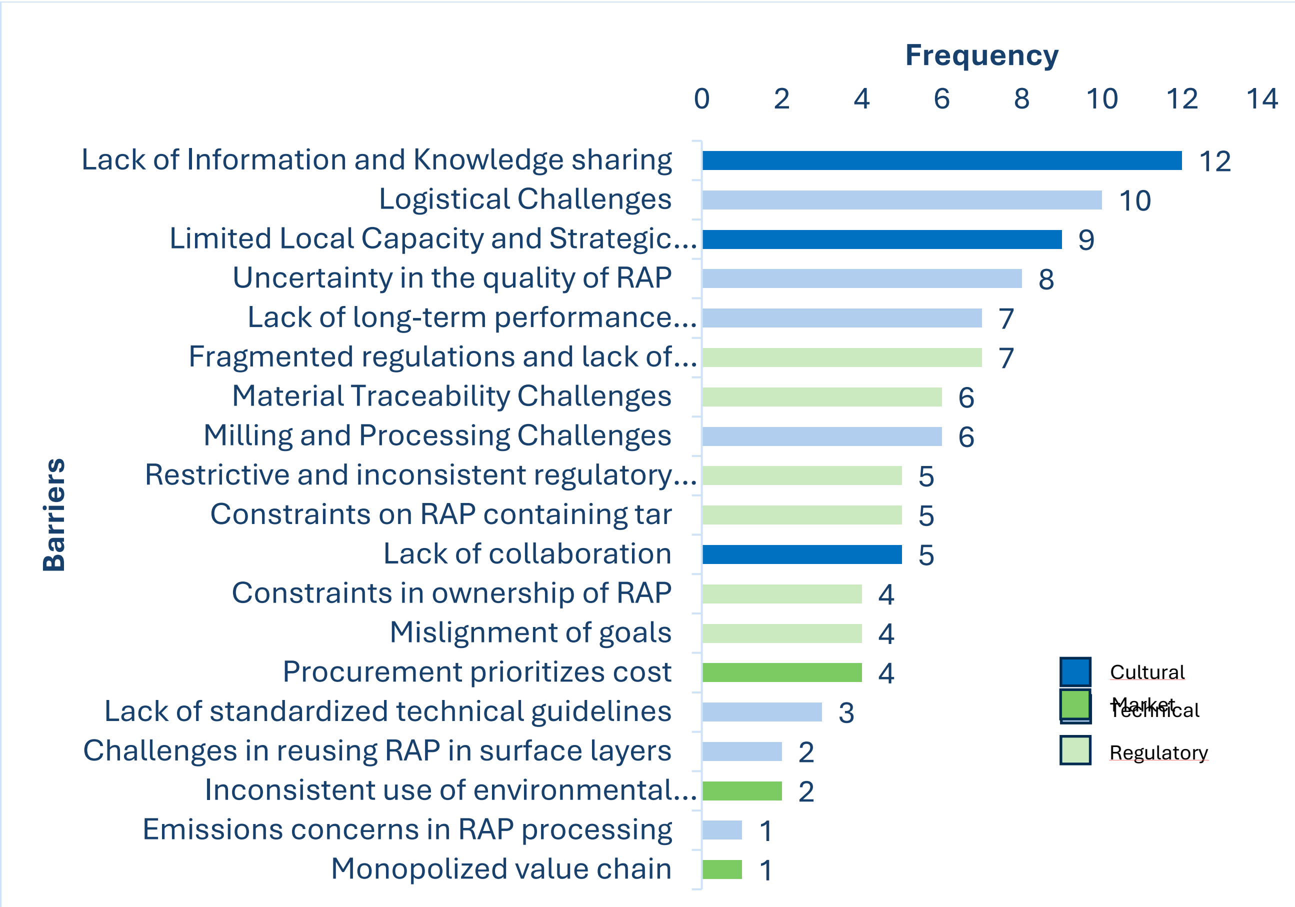

Figure 5 Frequency analysis of barriers mentioned across the interviews (author)

This graph provides insights into how each challenge is perceived across the asphalt value chain. The most widely acknowledged barrier is Lack of information and knowledge sharing (12 interviewees). The prevalence of this issue suggests that sector-wide coordination mechanisms and knowledge sharing platforms are needed to enable increased sharing of knowledge, experiences and lessons learned regarding RAP reuse practices.

Following this, Logistical challenges (with 10) and Limited local capacity and strategic focus on RAP (with 9) were mentioned quite frequently during the interviews. The high frequency of logistical challenges suggests that even though the technical expertise required for the reuse of RAP exists, operational issues such as storage capacity, availability of RAP, and planning uncertainty, continue to affect the reuse of RAP. The second challenge reflects limitations at the municipal level that hinder the full-scale adoption of RAP.

Uncertainty in quality (8) and lack of long-term performance monitoring (7) were also mentioned frequently suggesting that technical uncertainties play an important part in inhibiting the uptake of RAP in the infrastructure sector. Another technical challenge that got much attention was the challenges associated with milling and processing (6) suggesting that these issues occur specifically in a few phases and that's why they were mentioned not as much as the others.

On the regulatory side, fragmented regulations and lack of standardization (7) and Material Traceability (6) challenges were mentioned by some stakeholders which suggest that inconsistent regulations and no standardization in mixes and practices affect scaling up RAP.

Barriers with less frequency present at the bottom of the graph like emission concerns, monopolized value chain, challenges in reusing RAP in surface layers and inconsistent use environmental incentives still represent targeted challenges that should not be dismissed as they still persist in the sector.

Therefore, examining the frequency graph reveals that cultural and technical barriers were the most frequently mentioned categories across the stakeholders. This suggests that while regulatory and market challenges remain relevant, overcoming cultural and technical barriers may unlock greater immediate potential for scaling up RAP reuse. infrastructure sector.

4.2.2 Stakeholder Perspectives on Barrier Categories

This section examines how these barriers are perceived across the various stakeholder groups. To compare stakeholder perspectives, rather than analyzing each individual challenge separately, the four main themes (technical, cultural, regulatory, and market) were used. This was done because not all stakeholders mentioned or commented on each individual challenge. This allowed for a meaningful comparison as the analysis remained inclusive and while still revealing patterns about how different actors perceive the barriers to RAP reuse. This was achieved through by transforming code frequencies into relative proportions, this was easily done on Atlas.ti platform. The results of this are presented in the form of stacked bar charts. As highlighted in the qualitative research literature, the use of frequencies and proportions in thematic analysis is not about making statistical claims. Instead, it is a way to show which issues stand out the most across different groups, helping to highlight patterns of emphasis rather than absolute measurement (Sandelowski, 2001). Based on this, two types of visualizations were created - barrier category centric and stakeholder group centric. The first visualization presents barrier categories and shows the proportional contribution of each stakeholder group to that barrier category. The second visualization reverses the perspective by presenting stakeholder groups and showing their internal distribution of attention across the four barrier categories. The two visualizations are presented below.

4.2.2.1 Barrier Category Centric View

This illustrates which group drives the discussion for which barrier category. The first graph, Figure 6, shows which barrier theme was most discussed by which stakeholder group. The findings are explained below-

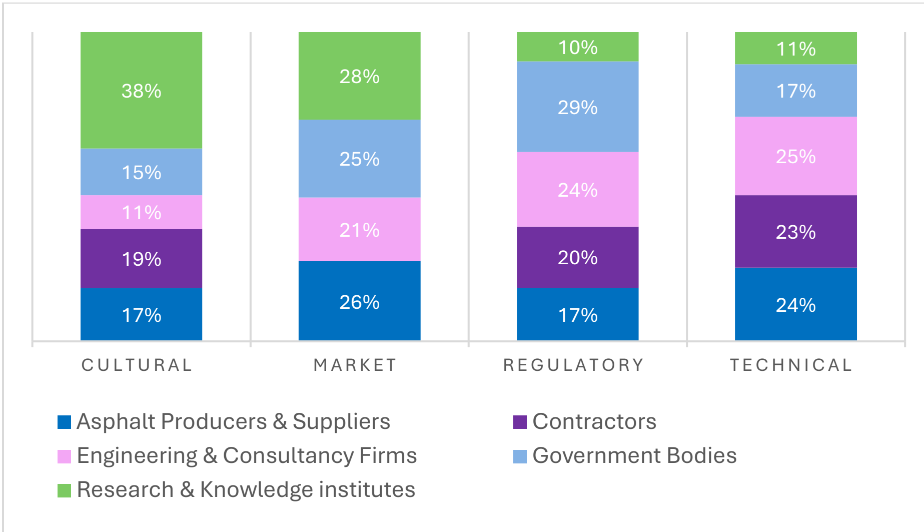

Figure 6 Stakeholder Perception: Barrier categories centric view (author)

Cultural: Research and knowledge institutes emphasized cultural barriers the most, contributing nearly 38% of all related codes about cultural barriers. This suggests a systematic viewpoint as these stakeholders consider lack of information and knowledge sharing, and lack of collaboration as major bottlenecks in achieving circularity with RAP. This is supported by the findings presented in the previous section where representatives of this group explained how there is no sharing of lessons learned from projects between different levels of governance as well as between public and private actors, in section 4.2.1.2. Contractors, asphalt producers, and government bodies also contributed meaningfully to this category with engineering and consultancy firms contributing the least (nearly 11%). This shows a large difference and indicates how strongly different actors perceive cultural challenges.

Market: Market barriers were also emphasized by research and knowledge institutions the most with nearly 29% of all related codes. This pattern suggests that research and knowledge institutes are more vocal about the broader system-level challenges, which means issues such as procurement criteria and market concentration. Government bodies and asphalt producers were vocal about this category to a similar level followed by engineering and consultancy firms. Interestingly, contractors had nothing to say about this category, which may imply that these barriers are not considered as immediate bottlenecks by this group, as they mainly respond to tenders and requirements by the client and do not really shape them.

Regulatory: Regulatory challenges were emphasized the most by government bodies with nearly 30% of all related codes, which is indicative of their central role in both shaping and navigating regulations that govern RAP reuse. Typical issues highlighted by them include fragmented regulations and lack of standardization constraints in the ownership of RAP, and restrictive and inconsistent regulatory standards, as described in section 4.2.1.3. Engineering and consultancy firms were next with 24%, closely followed by contractors and asphalt producers. Research and knowledge institutions emphasized this barrier the least with 9.5% codes, unlike cultural and market barriers, where they were the most vocal. This may suggest that their focus is not on day-to-day regulatory bottlenecks but more on system and cultural barriers.

Technical: Technical challenges were emphasized the most by engineering and consultancy firms with nearly 26% followed by contractors and asphalt producers with nearly equal percentages of codes related to technical challenges. This reflects that as these groups are involved in the design, production, and application of asphalt in roads thus they know the technical bottlenecks (uncertainty in the quality and performance of RAP, lack of standardized guidelines, and logistical challenges) firsthand. Hence their emphasis suggests that implementation-level actors (actors who are involved at the stages where technical decisions are translated into practice) are more aware about how technical uncertainties and challenges affect reuse of RAP. Government bodies contributed nearly 17% and lastly research and knowledge institutes contributed 10% to this category. This comparatively low contribution from research and knowledge institutes might suggest that they are more concerned about system level challenges, as explained under cultural challenges.

4.2.2.2 Stakeholder Group Centric View

This view reveals which group prioritizes which category of barriers compared to others. The second graph, Figure 7, takes a different lens and presents how each stakeholder group internally distributes its attention across the four barrier themes. It shows which barrier themes were emphasized the most within each group.

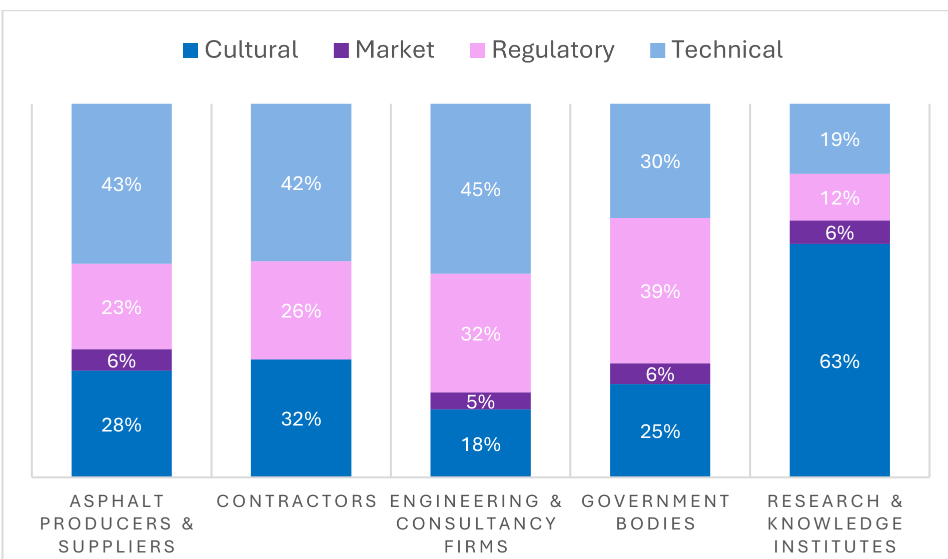

Figure 7 Stakeholder Perceptions: Stakeholder group centric view (author)

Government Bodies: Government actors emphasized regulatory barriers the most out of the four barrier themes with nearly 39% of their codes being about this theme. This was followed by technical (31%) and cultural (25%). This distribution is reflective of their role in designing, implementing, and adapting regulatory standards regarding RAP reuse practices. This also demonstrates their understanding and recognition of the challenges such as fragmented regulations, lack of standardization, ownership rules, and strict regulations that limit reuse potential of RAP. This is important as these actors can play a major role in changing and enhancing the regulatory environment, which can lead to increased reuse of RAP. Moreover, their substantial emphasis on technical and cultural barriers suggest that the public authorities are not solely focused on policy requirements. They also acknowledge that addressing technical uncertainties and enhancing inter-organizational collaboration is also necessary.

Contractors: Contractors put a high emphasis on technical barriers with around 42% of their codes being about this theme followed by cultural (31.5%) and regulatory (26%). Notably, there was no mention of market challenges from their side. This distribution suggests their implementation-oriented role within the asphalt value chain and hence they are acutely aware of the technical uncertainties that affect the reuse of RAP. The strong presence of cultural barriers reflects that communication, collaboration, and client expectations also shape their RAP adoption strategies. On the other hand, absence of market challenges might suggest their prioritization of more immediate obstacles that need to be tackled.

Asphalt Producers: Similar to contractors, asphalt plants also emphasized technical barriers the most, with nearly 43% of their codes being about this theme, followed by cultural (28%) and regulatory (23%) themes and market barriers were the least emphasized (5.7%). This distribution suggests that, just like contractors, these actors are more concerned about technical uncertainties as they deal with mix designs, supply-demand, storage, and processing challenges.

Engineering Consultancy Firms: This group put a lot of emphasis, more than the other groups, on technical challenges with nearly 46% of their codes being about this category. Following this they also raised regulatory barriers (31%) a lot and then cultural barriers (19%) and lastly market challenges (5%). The high emphasis on technical followed by regulatory barriers suggests that due to their highly technical role they recognize technical barriers more, however, they also acknowledged and raised regulatory challenges which further suggests that the restrictive nature of the policy environment affects reuse practices.

Research and Knowledge Institutes: Cultural barriers dominated the perception of this group, accounting for nearly 63% of their total barrier themed mentions. This suggests that this group views communication and institutional dynamics as the main bottleneck regarding the uptake of RAP reuse practices. Their comparatively lower emphasis on technical (19%) and regulatory (12%) themes reflects their belief that technical knowledge regarding RAP reuse already exists, but the real challenge lies in fostering a culture that promotes transparency and knowledge sharing across the value chain.

Combined synthesis of stakeholder perspectives across barrier themes

The comparative analysis of stakeholder perspective across barriers highlights convergence and divergence in how barriers are perceived. A clear point of convergence is the strong emphasis on technical & cultural barriers. These emerged as the most widely emphasized themes across all stakeholders, especially contracts, asphalt plants and engineering consultancy firms. This suggests that practical implementation challenges and systemic issues regarding communication and collaboration are considered the most pressing obstacles to RAP reuse. On the other hand, market barriers received the least attention across all the stakeholder groups, which suggests that they are considered secondary or indirect, which in turn highlights the need for a greater focus to be shifted towards these challenges.

Notably, the earlier frequency table pointed out that lack of information and knowledge sharing is the single most frequently mentioned barrier, which reinforces the finding that cultural barriers are one of the primary concerns in the reuse of RAP. Taken together, the synthesis shows that barriers are not perceived evenly but are filtered through the roles and responsibilities of each group in the value chain. Technical & Cultural barriers dominate because they are experienced directly in projects, while market and regulatory are emphasized primarily by actors whose roles lie at high governance levels. This uneven distribution of emphasis highlights the importance of multi-level coordination. This is because overcoming barriers to RAP reuse requires not only technical solutions but also governance arrangements that bridge the different priorities of actor's levels and roles.

4.2.3 Comparison with literature

This section compares the findings of literature and interviews regarding the barriers to the reuse of RAP and is organized under the four main barrier themes. Each includes three types of observation- barriers common to both literature and interviews, barriers found through interviews and barriers not confirmed in interviews. While the literature provided a foundational basis for understanding potential barriers, interviews allowed for their confirmation, refinement and in several cases, expansion of these insights. In many instances interviewees provided richer explanations about the barriers already mentioned in literature and offered deeper insights as to the reason behind why some barriers persist. For instance, in literature uncertainty in the quality of RAP variability in the source of material and historical use, interviews revealed that other than that it is also affected by diverse range of asphalt mixes across regions. Almost all of the barriers in literature were confirmed through interviews, which indicates their relevance and existence in practice. However, two challenges, namely: unclear roles and responsibilities and high initial investment costs, were not identified by interviewees. On the other hand, interviews uncovered six new and context specific challenges which were not mentioned in literature. This comparison is explained in the following section.

4.2.3.1 Technical Barriers

Technical barriers are associated with the technical limitations such as the availability, maturity, and performance of technologies and processes necessary for the effective reuse of RAP.

Confirmed in both literature and interviews: Uncertainty in the quality of RAP- Literature identified this barrier and linked it to variability in the source of material and historical use. Interviews revealed that beyond this, diverse range of asphalt mixtures across regions and contractors causes further inconsistency. Next is Lack of long-term performance monitoring. Beyond the lack of field trials for long term performance monitoring, interviews revealed the lack of standardized frameworks for testing long-term performance and validation methods as critical gaps. Milling and Processing challenges, literature identified non-selective milling and changes in gradation post milling as barriers. Interview findings add to this by uncovering constraints like limited milling time and post processing material losses. Logistical Challenges, while storage issues at the asphalt plants were mentioned in literature, interviews reveal challenges like limited availability of RAP, and lack of planning coordination among actors, in addition to storage challenges. Challenges in reusing RAP in surface layers and lack of standardized technical guidelines were identified in both literature and interviews.

Found through interviews: Emission concerns- Emissions like benzene and PAH associated with processing of RAP were cited as challenges by some interviewees, which was not mentioned in the literature reviewed.

Not confirmed in Interviews: All of the technical barriers identified in literature were confirmed through interviews.

4.2.3.2 Cultural Barriers

Cultural barriers refer to institutional, behavioral, or organizational attitudes and practices that impact the reuse practices related to RAP.

Confirmed in both literature and interviews: Lack of collaboration was identified in both literature and interviews, but interviews revealed a mixed view on this among the stakeholders. Some agree that collaboration can be enhance while others say that the current state of collaboration is working well. For example, an interviewee from an engineering firm and one representative from RWS explained how collaboration should be improved. While someone else from RWS, a contractor and another person from RWS explained that the current state of collaboration is working well. This highlights that this barrier is very context dependent. Lack of information and knowledge sharing, literature highlighted this challenge and noted lack of structured platforms for knowledge sharing (like lessons learned from successful/unsuccessful RAP implementation, new innovations in mix design) as the reason behind it. On the other hand, interviews provided a deeper understanding and reasoning behind this lack of information and knowledge sharing which attributed to- competitive pressure (to maintain a competitive advantage in the market), lack of platforms, avoiding reputational damage (risk that if a shared mix design is misused elsewhere, any resulting problems may be blamed on the original designer), and limited internal knowledge about materials and roads.

Found through interviews: Limited local capacity and strategic focus on RAP was found during interviews as some municipalities lack the capacity and expertise regarding RAP reuse and some of them don't prioritize RAP compared to other pavement materials. As a result, RAP is not prioritized compared to low-risk materials like pavement tiles and cobblestones. This contributes to risk-averse behavior and slows the uptake of RAP.

Not confirmed in Interviews: Unclear roles and responsibilities, literature mentioned vagueness in roles and responsibilities (about ownership, quality control, decision making) as a challenge, however, this was not mentioned during the interviews.

4.2.3.3 Regulatory Barriers

Regulatory barriers include constraints arising from legal frameworks, policies and governance structures that limit the potential of RAP.

Confirmed in both literature and interviews: Misalignment of goals, fragmented regulations and lack of standardization, and restrictive and inconsistent regulatory standards - all three of these challenges were identified in literature and then later confirmed and verified through interviews.

Found through interviews: Material Traceability Challenges: Interviews revealed this challenge which is about the lack of a centralized system that tracks the flow and quality of RAP for long term planning and availability. Constraints in the ownership of RAP: Interviews revealed that the lack of consensus on who should own the material and hence decide how the reuse of RAP should be carried out post milling, is a challenge. Constraints on RAP containing tar: Interviews identified this challenge about how old asphalt contains tar which introduces regulatory hurdles as it can't be reused in new mixes and hence cause loss of material.

Not confirmed in Interviews: All of the technical barriers identified in literature were confirmed through interviews.

4.2.3.4 Market Barriers

Market barriers are the economic and structural challenges within the asphalt market which affect the adoption of RAP reuse practices.

Confirmed in both literature and interviews: Procurement prioritizes cost and a monopolized value chain (few dominant players controlling the value chain) were identified in literature and then later confirmed during interviews.

Found through interviews: Inconsistent use of environmental incentives: Interviews revealed that environmental incentives in tenders like the MKI score are not consistently used across all organizations. RWS utilizes this in all their projects to give contractors the incentive to come up with more circular solutions, however, this is not followed by all the local actors. This leads to contractors facing inconsistent incentives, while national road projects reward circular innovations, many smaller municipalities still prioritize cost which reduces the overall drive for scaling up RAP reuse.

Not confirmed in Interviews: High initial investment costs: These include upfront investment for new machinery, adaptation of production facilities or validation procedures for new materials. This was mentioned as a general challenge for CE however, it was not agreed upon by the interviewees. RAP is considered as cheaper compared to virgin material used in asphalt and also the equipment and infrastructure for RAP is already established.

4.2.3.5 Summary

The comparison reveals that even though literature provided a good starting point to anticipate the barriers to RAP reuse, they often presented a generalized view. The interview findings helped validate those barriers and contextualize these challenges in the Dutch infrastructure sector. By confirming some barriers and revealing new ones this section emphasizes the value of combining literature review with empirical findings to develop a complete understanding of barriers to the reuse of RAP. An overview of barriers showing which ones were identified in literature and which ones were confirmed through interviews is presented in Table 3.

Table 3 Comparison of barriers to RAP reuse identified in literature and confirmed in interviews (author)

Barriers	Identified in literature	Identified in Interviews
Technical		
Uncertainty in quality of RAP	✓	✓
Lack of long-term performance monitoring	✓	✓
Lack of standardized technical guidelines	✓	✓
Challenges in reusing RAP in surface layers	✓	✓
Milling & Processing Challenges	✓	✓
Logistical Challenges	✓	✓
Environmental Concern		✓
Cultural		
Limited local capacity and strategic focus on RAP		✓
Lack of information and knowledge sharing	✓	✓
Lack of stakeholder collaboration	✓	✓
Unclear roles and responsibilities	✓	
Regulatory		
Misalignment of Goals	✓	✓
Fragmented regulations and lack of standardization	✓	✓
Restrictive and Inconsistent Regulatory Standards	✓	✓
Constraints in the ownership of RAP		✓
Material Traceability challenges		✓
Constraints in RAP containing tar		✓
Market		
Procurement prioritizes cost	✓	✓
Inconsistent use of Environmental incentives		✓
Monopolized value chain	✓	✓

High upfront investment costs	✓	

4.3 Wave 2: Project-level analysis of governance structures

This section presents the core findings from the second wave of semi-structured interviews which focused on the governance structures surrounding the reuse of RAP at the project level. The objective here was two-fold: first to verify and ground the barriers identified in the first wave to project level insights, and second, to examine how governance mechanisms within a project (both specific projects and general sector) shape these barriers. The analysis is based on two complimentary sources of insights- first being general sector, which describes how RAP reuse is usually governed in Dutch infrastructure projects, and second being project-specific, which describes insights from specific projects that the stakeholders were involved in. Together, these insights help to distinguish between sector-wide governance practices and project-specific practices. The analysis is guided by the MLG framework introduced in section 2.7.2. The section begins by first giving a description of the three case projects followed by an overview of the interviewees for this wave. Later, in section 4.3.1, a detailed description of the application of the four characteristics of MLG is given for all the three projects and general projects practices as well. It also interprets which type of MLG is dominant in which project. The section ends with a table giving an overview of the barriers observed at the project level, as well as the interpretation table.

Case Studies

Three projects were utilized as case studies in the second phase of this research. The information on the selected projects was obtained directly from stakeholders involved in these projects. For each project interviews were conducted from either the client side or the contractor side. Therefore, the details about the projects were shared by the respective stakeholders for each project. The key aspects of each project like its type, the parties involved and details about RAP used in the project are provided in Table 4. A detailed explanation of each project like the project scope, specific approach to RAP reuse and the technical details about the mix used is added to

Appendix H: Case Projects.

Table 4 Case Studies (Projects)

Project	Client	Contractor	Project Type	RAP Reuse Approach
Project A: Middnweg Project Amsterdam	Municipality of Amsterdam	BAM Infra	Road maintenance along the Middenweg	Base/Binder layers: 70% RAP Surface layers: 60% RAP
Project B: Rijkswaterstaat Groot Variabel Onderhoud (GVO) West Nederland Noord (WNN) Project	Rijkswaterstaat	BAM Infra	Large scale maintenance	Achieved 41% secondary material content in total

Project C: A1 Apeldoorn-Azelo Project Rijkswaterstaat	Rijkswaterstaat	Heijmans	Highway Expansion	Base/Binder layer: 60-70% Surface layers: 40-60%

Overview of Interviewees

A total of 6 interviews were conducted with 7 interviewees. The group is comprised of 4 representatives from the client's side (Rijkswaterstaat) and 3 representatives from 2 different contracting firms. Notably, the 6th interview consisted of two interviewees from the Rijkswaterstaat interviewed together, both contributing to the same project (Project B). The resulting list of stakeholders from this process is presented in Table 10 in Appendix I.

4.3.1 Application of MLG Lens to the Project-Level Insights

This section describes the results of the application of the MLG lens to the general sector and three case projects chosen for this research. The findings are presented under four main characteristics of MLG adapted from literature to be applied to this research. The adapted analytical framework is described in section 2.7.2. The four characteristics are: authority in decision-making, jurisdictional boundaries, coordination mechanisms, and adaptability of governance structures. Taken together, these characteristics help to examine how decisions are made, how which actors are included, how they coordinate and communicate, and whether these practices enable or reduce RAP reuse.

The results are presented under the four characteristics headings. For every characteristic, the analysis begins with the insights from the general project practices perspective which highlights how governance arrangements are in the Dutch road infrastructure projects. This is followed by evidence from the three case projects. For each project and characteristic, the discussion not only illustrates governance dynamics but also identifies whether they show predominantly Type I or II MLG. Wherever relevant, the discussion also connects to the findings of wave one, that means to the barriers verified to the reuse of RAP. Therefore, the project level insights not only verify some of the barriers identified in wave 1 but also provide a deeper explanation of how governance structures either reinforce or mitigate these barriers in practice. To keep the text concise and analytical detailed evidence in the form of quotes from interviews is provided in Appendix I: Interview Quotes: Project level analysis of governance characteristics.

4.3.1.1 Authority in Decision Making

This characteristic examines who holds the authority to make decisions related to the reuse of RAP in projects in the Dutch road infrastructure sector. It identifies whether the process is centralized, where few actors control decisions (Type I), or is it shared, where different actors jointly make decisions (Type II). Authority over RAP content and how it is going to be implemented in the project is an important indicator of governance structures. This is because it directly influences the extent of RAP reuse. In this section, this is done in context of the general project practices across the Dutch road infrastructure sector (referred here as the general project practices), and the three case projects.

General Project Practices

In infrastructure projects, the decision-making authority involving the reuse of RAP is predominately held by the client. So, the client sets the requirements regarding the reuse of RAP in a particular project. The contractor has to stay within the limits and requirements set by the client and use validated mixtures.

In general, contractors in the infrastructure sector have the technical capability to use higher percentages of RAP than what is typically allowed in projects. But many clients remain cautious due to the uncertainty about long-term performance of asphalt mixtures with high RAP. Therefore, the requirements of the client and their reluctance to increase the content of RAP beyond a certain threshold restrict contractors to increase RAP content in mixes. These project level insights support the findings of the first wave where lack of long-term performance monitoring of mixes with RAP was identified as a challenge. As a result, the, without evidence of durability, clients hesitate to allow high RAP content.

The decision-making process is also affected by the type of client or road authority. Different road authorities have different priorities regarding the reuse of RAP. For instance, for RWS the approval process of high RAP content mixes is very centralized. Once a mix has passed the technical validation process, then it can be used across all their projects without further approval. For municipalities, the process is a bit different, it varies from contract to contract. In some contracts they allow the reuse of RAP and in some they refuse to use RAP. So, in municipalities ad some provinces, the process is a bit fragmented and contract specific.

This confirms the regulatory barrier about fragmentation in regulations and lack of standardization, as described in section 4.21.3. As the findings here suggest, the validation procedure is not standardized, as Rijkswaterstaat follows a centralized approval process while municipal procedures are more fragmented. Such variations limit predictability for contractors as they may be allowed to use RAP in some projects while not in others, which limits consistent and widespread reuse of RAP.

Interpretation of Type of MLG

Decision making authority in Dutch road projects reflect predominately Type I MLG pattern, with centralized authority at the client level. While they rarely describe exact RAP percentages to be used, they set performance and safety requirements for the mix, like roughness value, skid resistance, and other technical criteria. For certain road authorities, like Rijkswaterstaat, a mix has to be validated through a centralized process before it is allowed in any projects. Furthermore, some municipalities and provinces don’t allow RAP at all in their projects. Therefore, the contractor’s ability to reuse RAP depends on what the contract allows.

Project A: Middenweg Project Amsterdam

In this project, the decision-making process was different compared to what usually happens in the sector. It involved both the client and the contractor, and subsequently the asphalt plant, during the discussion on the content of RAP in the mix to be used in this project. The contractor explained that the amount of RAP used in the mix was much higher than what is allowed by the RAW guidelines, and that unlike most projects, where the regulations and the client set the requirements and limits for RAP reuse, this case focused on technical possibilities.

This collaborative decision-making approach worked well for the project. It can be said that this highlights the regulatory barrier: fragmented regulations and lack of standardization, as described in section 4.2.1.3. This is in the sense that the project developed its own norms for approving the high RAP content mixture as there are no national norms or guidelines that do so.

Interpretation of Type of MLG

This project demonstrates a Type II MLG approach considering the authority in decision making. This is because there was a collaborative decision-making approach where all the major parties (contractor and the client) were involved in the decision-making process regarding RAP reuse. Also, the process was task-specific and adapted to the project's context which resulted in a high content of RAP in the asphalt mix.

Project B: Rijkswaterstaat GVO WNN Project

In this project, the decision-making process closely followed what generally happens in projects in the Dutch infrastructure sector as explained above in the general sector section. The decisions related to the reuse of RAP were based on the client's requirements and the contract. The contractor then was allowed to make decisions on their own about the content of RAP in the mix, but remaining within the regulatory limits set by the client.

From the client's perspective, control is primarily exercised through environmental performance indicators, particularly MKI value and reliance on already validated mixtures. This ensured that the contractor's decision aligned with national requirements but left little room for experimentation with high RAP percentages.

Interpretation of Type of MLG

This case mainly points towards a Type I MLG approach. This is because there was a centralized authority as the client set the requirements and validates mixes before they can be used in the project. Also, the contractor has autonomy in decisions regarding content of RAP in a mixture but only within the regulatory limits set by the client. However, the validation process involved the contractor, asphalt plant, and the client. This suggests a Type II pattern, where many parties were involved in decision making. Therefore, this project, even though it is predominantly Type I MLG, also shows patterns from Type II.

Project C: A1 Apeldoorn-Azelo Rijkswaterstaat

In the A1 project, the decision-making process was similar to what is followed in the general sector in the Netherlands. The decision-making authority is with the client, and they set requirements for the reuse of RAP in this project. Contractor had the flexibility to choose the mix design and RAP proportions but operate within the boundaries set by the client.

The client confirmed that the choice of mixture and the proportion of RAP was up to the contractor, and to ensure that the final mix met the specified standards and demonstrate compliance through validation. This arrangement illustrates the strong role of the client in safeguarding performance and quality.

Interpretation of Type of MLG

This case also points towards a Type I MLG approach considering the authority in decision making. This is because there was a centralized authority as the client set the requirements and validates mixes before they can be used in the project. Also, the contractor has autonomy in decisions regarding content of RAP in a mixture but only within the regulatory limits set by the client.

4.3.1.2 Jurisdictional Boundaries

This characteristic refers to how responsibilities for RAP management are distributed across different levels of governance. This is to identify whether these responsibilities are distinct or overlapping. In Type I, these boundaries are clearly defined with each level managing its own assets and resources. So, the jurisdictional boundaries are non-overlapping. On the other hand, in Type II these boundaries are more flexible and overlap. Which means, there are more joint projects, resource sharing (RAP, in this case). In this section, the general sector as well as the three case projects are analyzed considering this characteristic to identify which type of MLG is prominent.

General Project Practices

In the Dutch road infrastructure sector, findings from the interviews suggest that the jurisdictional boundaries for RAP reuse are clearly defined. There is a clear distinction between how each governance level operates within its own management area, i.e., National roads are managed by Rijkswaterstaat, provincial roads by provinces, and municipal roads by the municipalities. This separation reinforces the findings from the first wave about how there is lack of stakeholder collaboration, in section 4.2.1.3.

Because of these boundaries, there is hardly any collaboration in the sense of material and knowledge sharing across the governance levels. Interviewees explained budget allocation and complexity in the contractual agreements as the main reasons for this separation. Multi-level projects require a complex and detailed contract stating division of responsibilities, budget and so on, which requires a lot of money as well as time. This discourages actors from collaborating on such projects.

Differences in the types of asphalt used across governance levels is also a challenge. Rijkswaterstaat mostly utilizes porous asphalt (ZOAB) in its roads and municipalities utilize more dense asphalt mixtures. This becomes a barrier as then the milled material cannot be shared across different levels because the qualities and specifications are different.

Contractors confirmed how there is hardly any sharing of resources, specifically RAP material, between different levels of governance. Even when there is some cross-level collaboration, it is mostly regarding knowledge sharing and not in joint projects. These insights prove that the clear distinction between the governance levels has led to almost no collaboration between them. This is due to contractual complexities, budget controls, and different types of asphalt mixes used across the levels.

Interpretation of MLG Type

The insights from the general sector point toward predominantly Type I MLG pattern. This is because there are distinct and non-overlapping jurisdictional boundaries where each level is responsible for its own network of roads. As a result, there are hardly any joint projects and sharing of resources. The reason behind such distinction is highlighted as: clear budget allocation, complex and time-consuming contractual agreements, and the difference in the type of material used.

Case Projects

During the interviews it was uncovered that each governance level (national, provincial, and municipal) is responsible for their own road networks, as explained in the section above. Hence, for all three case projects, i.e. The Middenweg Project Amsterdam, RWS GVO WNN Project, and the A1 Apeldoorn-Azelo project, there was no involvement of multiple governance levels. Each project was executed entirely within its own jurisdictional boundary by the respective road authorities, with no sharing of RAP material or joint decision-making.

This illustrates that non-overlapping jurisdiction provides stability at the project level but contributes to barriers at the sector level. Contractors face inconsistent RAP requirements and rules when moving between different levels of governance. This reinforces the challenge of fragmented regulations for RAP reuse across the sector identified in section 4.2.1.3. Furthermore, these directly influence the coordination and collaboration between these governance levels. As there is less scope of joint projects, as every road authority has its own road jurisdictions, there is even less collaboration regarding RAP reuse. This also leads to variation in validation procedures and technical guidelines, which are again some of the barriers identified in the first wave.

Interpretation of Type of MLG

For each of the three projects there was strict separation of responsibilities, in the sense that each level of governance is responsible for road networks within its own jurisdiction. This points to Type I MLG because there are clear and non-overlapping jurisdictional boundaries.

4.3.1.3 Coordination & Communication Mechanisms

This characteristic looks into how actors coordinate and communicate both across governance levels as well within a project. This way, it helps to look into what kind of barriers to the reuse of RAP are reinforced or mitigated. Type I system represents hierarchical and top-down coordination and communication by following contractual rules and predefined roles. Type II, on the other hand, represents more flexible and multi-directional communication and allows for overlapping responsibilities and frequent interactions between actors.

General Project Practices

Interview findings indicate that coordination mechanisms in the Dutch road infrastructure sector are hierarchical in nature. Coordination between the client and the contractor within a project, specifically considering the reuse of RAP, follows contractual lines, leaving little room for adaptation once requirements are set. Communication on RAP specifically was described as minimal, with most of the coordination and communication takes place between the contractor and the production plants. This reinforces the barrier identified in the first wave about the lack of information and knowledge sharing.

The findings from second wave also add a new dimension to the barrier about constraints in the ownership of RAP. Under the current model, where contractors take the ownership of the material post milling (described in detail in section 4.2.1.3 under constraints in the ownership of RAP), there is hardly any incentive for coordination with the client. A different ownership model, for example, where the road authority retains the ownership of RAP, might require more coordination with the client around quality, logistics, and storage. This particular insight reinforces the barrier identified in the first wave about constraints in the ownership of RAP. It proved that there is no sector-wide consensus on how the ownership model should work.

Broader coordination across governance levels is limited at the project level, as already established. Whenever such communication occurs, it is facilitated through sector-wide platforms like CROW and National Platform for sustainable road pavements. As described in section 2.3, these platforms serve as forums for discussing technical standards, innovations, and common challenges. The challenge is that there are so many municipalities and provinces in the Netherlands, so not everyone has an expert on reclaimed asphalt reuse and hence they are not represented in these sessions. Therefore, only limited number of actors take part in these sessions. These platforms are considered very beneficial in sharing knowledge and lessons learnt from RAP projects and in aligning technical standards and terminologies across the sector. However, the underrepresentation of local and provincial levels and repeated representation of the same stakeholders indicates that their potential to foster more integrated RAP reuse strategies is not yet fully realized.

Interpretation of Type of MLG

The insights gathered regarding coordination and communication mechanisms in the Dutch infrastructure sector highlight Type I MLG. This is because coordination is more hierarchical and top-down rather than flexible and multi-directional between the client and the contractor at the project level. Also, communication between governance levels is minimal and mostly limited to knowledge sharing events. This further reinforces the presence of Type I MLG.

Project A: Middenweg Project Amsterdam

This project, contrary to the general sector, demonstrated a more collaborative approach. The contractor, from this project, explained that the project involved joint discussions with the client about setting new standards and reusing more RAP that is generally allowed.

Contrary to the hierarchical client-contractor communication that usually takes place in these projects, this project reflects more open and two-way communication. The client and the contractor jointly designed the technical framework for the project regarding RAP reuse and shared responsibility for implementation. This resulted in a much higher RAP content than allowed by the standards.

Interpretation of Type of MLG

Combining the insights from section 4.3.1.1 about the authority in decision making and the collaborative approach described in this section, it can be concluded that this project demonstrated Type II MLG. This is because, rather than a hierarchical top-down coordination where the client sets the boundaries and then the contractor operates within those boundaries, there was a greater level of coordination between the two parties.

Project B: Rijkswaterstaat GVO WNN Project

In this project, communication between the client and the contractor followed the typical structure that is followed in projects generally. That is, discussions about the reuse of RAP, its content and type was all discussed in the beginning and during the execution there was minimal contact with the client once the validation process was completed. As long as the contractor used the approved mix, there was no need for further communication.

This approach meant that most of the coordination largely took place between the contractors' own network like the asphalt production plant. This mirrors the findings from the general sector where, as explained in section 4.3.1.1, where operational level communication about RAP is internal to the contractor and doesn't extend beyond to the client once the technical requirements are met.

Interpretation of Type of MLG

In this project, coordination followed the general sector pattern with hierarchical and top-down communication. Discussions regarding RAP were concentrated in the early phases of the project, where requirements were set and mixtures were validated. Operational coordination was handled by the contractor and the asphalt production plant. This points to Type I MLG structure where communication is top-down and minimal.

Project C: A1 Apeldoorn-Azelo Rijkswaterstaat

In this project, the coordination between the contractor and the client was more intensive compared to the general sector approach because the mix used in the project had a Technology Readiness Level[14] (TRL) of 7 - 8. Because of this, the client (Rijkswaterstaat) assigned a material specialist from their GPO department who was responsible for following the project closely to ensure that the mix met all the requirements.

The client explained that this involvement from the client side was only project-specific, and this doesn't usually happen in a project. Therefore, communication between the client, the contractor, and the asphalt plant in this project was really back-and-forth. This was possible because the asphalt plant is partly owned by the contractor which led to aligned interests

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[14] TRL is a scale from 1-9 which is used to estimate the maturity of a technology. For asphalt mixtures, TRL 1-4 are early-stage lab developments, TRL 5-8 are involve real world test sections with increasing traffic intensity, and TRL 9 indicates that the mixtures can be applied to regular road networks.

and smoother cooperation. This close engagement with the client during execution ensured that quality checks were performed so that the mixture could progress towards TRL level 9 validation. This approach is in contrast with what usually happens in projects in the general sector, where communication regarding RAP related decisions usually happens in the planning phase and then it becomes minimal once validated mixtures are in use.

Interpretation of Type of MLG

Contrary to the general sector pattern, this project showed more intensive communication between the client and the contractor. This was because of the experimental use of TRL 7-8 mixtures, because of which a material specialist from the client's side was involved in the project during implementation. Considering the communication structure in this project, it can be deduced that this represents Type II structure.

4.3.1.4 Adaptability in Governance Mechanisms

This characteristic refers to the ability of the governance structures to be rigid or flexible. This examines whether the governance structures can adapt to the changing information and knowledge regarding RAP reuse, logistical issues, and innovative practices. In Type I structures, adaptability is limited because authority, jurisdiction, and coordination are rigid and predetermined. Type II is orientation provides more flexibility as it allows the system to accommodate new practices, asphalt mixes, and material flows as projects evolve.

General Project Practices

In the Dutch asphalt sector, the adaptability of governance structures is limited. This conclusion is drawn from the three characteristics about the general sector explained in previous sections. To begin with, the authority in decision making usually sits with the client as explained in section 4.3.1.1. They may or may not allow RP in a particular project and also set requirements about the mixtures containing RAP. This may result in less reuse of RAP in some projects. This reluctance of the client is attributed to lack of long-term performance data of the mixtures with RAP. This reluctance of the client to allow higher RAP content reflects a rigid governance structure which has been followed for a long time which suggests long standing of the practice.

Then, jurisdictional boundaries clearly reflect Type I governance with clear boundaries between national, provincial, and local governance levels. This reduces adaptability because materials flows, knowledge and other resources remain isolated in separate governance levels, as described in section 4.3.1.2. The absence of or limited number of joint projects and lack of cross-level material sharing means that RAP reuse strategies are bound to specific governance levels rather than adjusted flexibly across the sector. This links directly to the regulatory barrier of fragmented policies and lack of standardization described in section 4.2.1.3.

The coordination mechanisms described in section 4.3.1.3 describe hierarchical and top-down communication between the client and the contractor which restricts adaptive decision making once the project begins. This is because deviations are not often allowed once the requirements are set. For instance, the contractor cannot introduce a new RAP mix once the project begins.

Taken together, these patterns suggest that adaptability of the governance structure is limited due to rigid authority structures, strict jurisdictional boundaries, and hierarchical coordination mechanisms.

Interpretation of Type of MLG

When taking together the three characteristics: authority in decision making, jurisdictional boundaries, and coordination mechanisms, the general sector reflects less adaptability. This is because of rigid authority structures, strict jurisdictional boundaries, and hierarchical coordination mechanisms. This points to a Type I structure as it is described as rigid in nature.

Project A: Middenweg Project Amsterdam

For this project, RAP related decisions were taken jointly, as established in section 4.3.1.1 which led to an increase in the content of RAP reused in the mix for this project. However, this came at the cost of logistical challenges. Separate milling was required to keep the high-quality reclaimed asphalt from surface layers separate from base and binder material. The milled material from the old road (Middenweg) was stored separately at the asphalt plant for nearly four months. During this period, the storage area was unavailable for other uses which led to operational disruptions at the plant. The plant owner explained to the contractor that storing large quantities of material for one municipality meant less flexibility for other projects. If multiple clients require similar arrangements, it will require much more storage at the plant which they simply don't have the space for.

These insights reinforce the barrier identified during the first wave about logistical challenges in section 4.2.1.2, where storage limitations occur when material is in abundance. The Middenweg project is a case when there is too much material, and it causes storage issues and disruptions in other projects. This reflects that flexible governance enabled higher RAP reuse, but the logistical system of the asphalt plant struggled to adapt. This reinforces sector wide concerns about storage and planning challenges.

Interpretation of Type of MLG

In this project, the client, and the contractor jointly adapted governance arrangements to enable higher reuse of RAP. This selective milling, storing material for months specifically for this project, and designing the process specifically for this project. This points towards flexibility and a willingness to deviate from the standard practices, therefore it represents Type II structure.

Project B: Rijkswaterstaat GVO WNN Project

In this project, the contractor argued that RAP content could have been higher. But the main challenge that restricted this was material availability, especially the scarcity of PA Stone[15]

[15] Stone from porous asphalt that has been cleaned so there's no bitumen coating

which is essential for high RAP content in porous mixes. The contractor explained that part of achieving over 70% RAP in porous asphalt is by adding PA Stone to RAP. However, this material is scarce and needs to be stockpiled for continuous use, which was not possible in this project. Operational challenges further compounded this issue. Milling and paving processes occur at high speeds (around 1,000 tons per hour), while processing RAP into high quality material is a slow process (around 50 tons per hour). In this project, because of the short time frame for highway works, as they cannot be blocked for long, meant the milled asphalt could not be processed in time and reused on site. Therefore, it had to be disposed of which cost money.

These insights reinforce the logistical barriers like lack of storage, scarcity of material, and tight schedules, from section 4.2.1.1. This led to further cost implications as the milled material needed to be disposed of as the plant had to clear storage space for other projects' material. This reflects that rigid guidelines and timeframes can lead to unintended consequences, like extra cost burden for disposal, and reduce adaptability of the governance structure.

Interpretation of Type of MLG

This project demonstrates low adaptability which is more in line with Type I MLG. Although the contractor has validated mixture with high RAP content, rigid timeframes and operational requirements of national highway projects restricted their utilization. The short construction windows left little room to adapt material flows or processing schedules. This led to unused RAP being disposed of. This project illustrates rigidity and hence points towards Type I structure.

Project C: A1 Apeldoorn-Azelo Rijkswaterstaat

This project highlights rigidity in procurement mechanisms. The insights from this project confirm some of the market barriers identified under section 4.2.1.4. One key issue is the tendency of procurement process to prioritize cost over innovation. The client explained that Rijkswaterstaat consistently makes use of Best Price Quality Ratio (BPKV) in tenders, which allows sustainability factors to be weighed alongside cost (Rijkswaterstaat, n.d). Larger Municipalities like Amsterdam and Utrecht were also described as familiar with this approach. However, the interviewee noted that in smaller municipalities and some provinces, procurement still largely follows a lowest-price wins model. As a result, in such cases as long as technical requirements are met, contracts are awarded based on cost. Although this is not entirely because of cost, the performance and quality issues also come into play. However, this does confirm the market barrier about how procurement prioritizes cost over innovation identified in the first wave.

This creates a fragmented market culture, where circular options are supported in some contexts but overlooked in others. This also points to another issue that was identified in the first wave about the inconsistent use of environmental incentives across governance levels. It was noted that some road authorities utilize MKI as an incentive for the contractor to come up with circular asphalt mixes. However, this is not a standard practice across all road authorities, for example smaller municipalities don't utilize this practice. This is similar to what was described above about BPKV contracts. This variation leads to uneven adoption of RAP across the sector.

Interpretation of Type of MLG

In this project, the initial discussion regarding RAP reuse in the project and the procurement process closely followed what happens in the general sector. And hence, the structure remains rigid and points towards Type I MLG. However, the experimental use of TRL 7-8 level mixes for validation and because of which coordination with the client was more frequent, this points towards flexibility and a Type II structure. However, this flexibility is highly project specific and does not indicate a systematic shift in the governance. Taking it together, it can be said that this project demonstrates the features of both Type I & II together.

Overview

The analysis of barriers to RAP reuse must be studied through the governance characteristics discussed in this section 4.3.1. While many barriers were identified in the first wave of interviews and explained in section 4.2.1, not all were explicitly mentioned at the project level (for the projects analyzed). This does not imply that the barriers do not exist in practice, but the project level insights explain in detail how some of these barriers are shaped by governance characteristics. The barriers that were not verified here are discussed in the discussion chapter. In conclusion, the barriers to RAP reuse are not isolated but somehow intertwined with the governance structures across the sector. To avoid repetition, a detailed explanation how challenges from all 4 barrier category was observed at the project level and how governance characteristics shaped them is given in Appendix J: Cross-case overview of barriers. The overview of the barriers observed and confirmed in project level analysis is shown in Table 5.

Table 5 Overview of Barriers to RAP reuse observed in Project-level analysis and their link to Governance Characteristics (author)

Barriers	Observed in Projects	Governance Characteristics
Technical		
Lack of long-term performance monitoring	Confirmed for general sector practices and implied in projects as absence of long-term performance data makes clients reluctant to allow high RAP mixes.	It reinforces authority in decision making and is also linked to weak coordination for performance feedback across the sector
Lack of standardized technical guidelines	Implied in all projects as all of them followed different norms for RAP reuse.	It is linked to strict jurisdictional boundaries and client's authority in decision making
Logistical Challenges	Observed in Projects A & B (storage issues and planning uncertainties because of short timeframe)	It is reinforced by limited adaptability in governance structures
Cultural		
Lack of stakeholder collaboration	Limited cross-level collaboration on road projects, knowledge sharing platforms are not fully representative	Reinforced by strict jurisdictional boundaries across governance levels and weak coordination mechanisms
Regulatory		

Fragmented regulations and lack of standardization	Observed across all projects as different road authorities follow different procedures; approvals for RAP negotiated case by case	Reinforced by strict jurisdictional boundaries
Restrictive and Inconsistent Regulatory Standards	Observed as a general sector practice as well as across the three projects (not because less RAP percentage was allowed, but there are strict regulations for surface layers)	It is linked to authority in decision-making and absence of validated long-term performance data.
Constraints in the ownership of RAP	Observed in Project B, in a different view than wave 1. This is because, shifting of ownership of RAP to contractor leads to less communication and coordination with the client	Reinforced by coordination gaps between contractor and client
Market		
Procurement prioritizes cost	Observed in general sector, smaller municipalities and provinces sometimes prioritize cost in tenders.	Reinforced by low adaptability in governance structures
Inconsistent use of Environmental incentives	Observed in general sector, as smaller municipalities and provinces don't make use of MKI Value to reward circular solutions	Reinforced by low adaptability in governance structures

Summary of Interpretation of Type of MLG

Taken together, the analysis of the general sector and the three case projects through the lens of MLG reveals a predominantly Type I MLG in Dutch infrastructure projects. This is especially true when considering characteristics of authority in decision making, jurisdictional boundaries, and overall adaptability of the governance structure. The general sector operates within a rigid, hierarchical structure that centralizes decision making at the client level, isolates responsibilities across governance levels, and restricts opportunities for cross-level sharing of resources. However, within specific projects patterns resembling both Type I & Type II MLG emerge. Project A demonstrates how Type II features like collaborative decision making, joint discussions, and adaptive practices can be mobilized to achieve higher RAP reuse, though they were exceptional arrangements which led to some logistical issues. Project B showed the dominance of Type I rigidity, but with moments of Type II involvement during validation procedure for mixes. Project C further strengthened the idea of Type I and Type II together, as experimental use of mixes led to close collaboration between client and contractor, but procurement and jurisdictional boundaries reinforced Type I.

These findings confirm what Hooghe & Marks (2001) emphasize: the two types of multi-level governance are not mutually exclusive but frequently coexist in practice. Type II characteristics often emerge embedded within Type I structures, operating at the edges of otherwise rigid Type I structures. In this case, the Dutch infrastructure projects largely retain Type I structure with Type II structures emerging in pilot projects, and experimental practices. The persistence of Type I structures limits the institutionalization of flexibility which makes Type II patterns situational and not systematic. An overview of the interpretation of the three projects and the general sector through the lens of MLG is provided in Table 6.

Table 6 Interpretation of MLG Types (author)

Characteristic / Case	Authority in Decision Making	Jurisdictional Boundaries	Coordination & Communication mechanisms	Adaptability of governance mechanisms
General Sector	Predominantly Type I: centralized at client level with occasional Type II patterns in pilot projects	Type I: clear and non-overlapping jurisdictional boundaries	Type I: Hierarchical, top-down coordination and communication	Type I: Rigid structure with limited adaptability
Project A: Middenweg Project Amsterdam	Type II: collaborative decision making between client and contractor	Type I: strictly municipal	Type II: Frequent and multi-directional communication	Type II: flexible governance structures according to the needs of the project
Project B: RWS GVO WNN Project	Mixed: Mostly Type I, with authority centralized at client level, with some Type II patterns during validation	Type I: strictly national	Type I: Hierarchical, top-down coordination and communication	Type I: rigid structures, limited by time and storage constraints
Project C: A1 Apeldoorn- Azelo	Type I: centralized at the client level	Type I: strictly national	Type II: intensive back and forth communication between the contractor and the client	Mixed: rigid structure considering the decision-making process and procurement. Type II patterns emerge because of flexibility for innovation

Chapter 5. Discussion

This chapter discusses how the findings of the research can be interpreted. It begins by reflecting on the barriers across the four categories followed by rethinking governance structures for RAP reuse. Following this, the chapter then discusses how the barriers to increasing RAP reuse can be addressed through a combination of Type I & II features in section 5.2. It offers possible directions rather than definitive solutions. The discussion then explains the academic and practical contributions of this study in section 5.3. The chapter concludes by presenting the limitations of the research in section 5.4.

5.1 Interpretation of Results

This section describes what the findings of this research mean or how they can be interpreted. The previous chapter presented all the findings, this section goes beyond reporting and brings together those insights, highlights their interconnections and discusses what they mean for scaling up RAP reuse. Subsection 5.1.1 brings together barriers under the four categories distinguishing those most emphasized by stakeholders and observed in projects. Then, subsection 5.1.2 analyses what it means for governance structures for RAP reuse by discussing current structure, role of MLG in enhancing those structures and implications for the sector and three governance levels.

5.1.1 Barriers

Through the first wave, a broad set of barriers to the reuse of RAP were identified and allowed for analysis for their relative prominence across categories and stakeholder groups. The second wave added depth through the lens of MLG at the project level to show which barriers emerge due to governance structures. Taken together, these reveal which barriers were observed at the project level and which were raised during interviews but were not observed in the chosen projects in this research. It also reveals how the two types of MLG reinforce these barriers. The barriers that were most emphasized during the interviews are recognized by considering the frequency analysis (which barrier was mentioned by how many interviewees) and observability at the project level. These barriers across the four categories are:

- **Technical:** Lack of long-term performance monitoring of mixes with RAP, Lack of standardized technical guidelines regarding RAP reuse practices, Logistical challenges (including limited storage capacity, planning uncertainty, and material availability) , and Uncertainty in the quality of RAP (due to historical use, use of modifiers and rejuvenators, and presence of aged bitumen).
- **Cultural:** Lack of information and knowledge sharing, Lack of stakeholder collaboration, and Limited local capacity and strategic focus on RAP. The lack of information and knowledge sharing (due to competitive market advantage, avoiding reputational damage, lack of forums and platforms for sharing, and lack of internal knowledge about roads and materials) is one of the most mentioned barriers across the interviews, as described at the end of section 4.2.1.

- **Regulatory:** Fragmented regulations and lack of standardization, Restrictive and inconsistent regulatory standards, and Constraints in the ownership of RAP. These challenges are presented here because they were either mentioned the most across interviews or observed at the project level.
- **Market:** This category was the least represented or emphasized during the interviews. Within this category, the barriers that were observed at the project level are: Prioritization of cost in procurement procedures (by smaller municipalities and provinces) and closely linked to this is the Inconsistent use of environmental incentives as an awarding criterion across all road authorities.

Apart from these barriers, there were some other barriers that were identified through interviews, but they were not observable at the project level or not emphasized the most by stakeholders. These barriers include Environmental concerns, Constraints on RAP containing tar, Monopolized value chain, Misalignment of goals, Challenges in reusing RAP in surface layers, and milling & processing limitations. Interestingly some of these can be seen as dependent on other barriers. For instance, Challenges in reusing RAP in surface layers are deeply rooted in lack of long-term performance data and uncertainty in the quality of RAP. Similarly, milling and processing limitations can be linked to logistical challenges since inefficient separation and handling of RAP adds to storage and planning constraints.

5.1.2 Rethinking Governance for RAP Reuse

The previous subsection discussed which are the most crucial barriers to increasing the reuse of RAP based on interviews and case studies. This subsection shifts the focus from barriers themselves to the institutional arrangements that shape them. It starts with current governance structures followed by how MLG provides pathways to enhance them for RAP reuse. Then, it discusses the need for dedicated governance for RAP reuse, implications for the sector considering MLG types and finally the implications for the three levels of governance.

Current Governance Structures

This research shows that the scaling up of RAP reuse is not just a technical challenge but fundamentally a governance issue. Current governance mechanisms, though well-intentioned, face limitations such as institutional fragmentations and inconsistent rules. This reflects what was discussed in literature (Ruiz et al, 2025), where national ambitions are not consistently translated into local implementation. This results in fragmented implementation, for instance, a few projects that achieve high reuse but scaling up remains difficult. The outcome is that the reuse practice remains often pilot dependent or carried out by specific organizations and doesn't become a default mode of operation.

A central example is fragmentation in standards and practices across road authorities. Rijkswaterstaat operates with a centralized validation procedure for RAP mixes, while some municipalities don't even allow RAP in their projects. Different road authorities specify different asphalt requirements which creates uncertainty for the contractors and asphalt producers in terms of demand which might limit their willingness to invest in advanced recycling technologies. This mirrors what MLG describes as coordination dilemma where the decisions of one level of governance often have a spillover effect or externalities on others (Hooghe & Marks, 2021). However, the absence of coordination mechanisms across levels creates socially suboptimal outcomes.

The project cases further illustrate how governance mechanisms across levels are different. In the RWS project, decision making authority followed a centralized and hierarchical logic, with little room for flexibility, showing Type I features. Challenges in its projects were less about regulatory rigidity and more about less adaptability in structures which led to logistical issues. In contrast, Municipality of Amsterdam's project showed more Type II features with joint decision making, and more coordination and collaboration between client and contractor. This allowed for higher RAP reuse in surface layers as allowed by standards. While these differences cannot be generalized to all projects, as this study looked into only three projects, they highlight how institutional variation between agencies can tilt projects toward more Type or Type II governance dynamics.

These observed differences between the two road authorities reflect their institutional position within the Dutch multi-level governance system. As the national road authority, RWS manages national roads and highways with strict accountability requirements. This institutional setting favors centralized validation, and standardized procedures which align with Type I. On the other hand, municipalities operate on a smaller scale, where project-specific flexibility and experimentation are more feasible. While the evidence in this study is limited to the selected projects, these institutional characteristics help explain why the RWS project emphasized procedural stability, whereas the Amsterdam project demonstrated greater adaptability in enabling higher RAP reuse.

Enhancing Governance Mechanism for RAP Reuse

Multi-level Governance offers pathways to overcome the coordination dilemma described above. To begin with, coordination is more sustainable when it Is guided by shared norms and trust (Hooghe & Marks, 2021). In the Dutch context, this means creating sector-wide databases, clear and specific guidelines for reuse practices that consistent across all levels, and long-term monitoring of roads with RAP mixes. Unified multi-actor coordination is critical for high RAP reuse. A good example is the Northern Netherlands sustainable asphalt covenant where road authorities, contractors, and producers agreed on a unified regional approach. By reducing the number of asphalt mix types and committing all parties to higher RAP reuse, they created a stable market demand (Circle Economy, 2025). Without such agreements, one progressive agency might advance high RAP mixes but as long as others don't join and keep relying on virgin materials, overall scaling of RAP will remain limited. Regional and national coordination platforms are therefore important to create consistent rules and reduce uncertainty for market actors.

Risk sharing mechanisms are another area where governance can make a difference. Mixes with high RAP content are perceived as riskier until their long-term performance is proven. In a purely Type I system, this creates cautious approval and validation procedures and risk averse nature. Governance can help solve this through performance warranties, shared insurance mechanisms, and innovation funds as these sector-wide instruments would reduce client hesitation and accelerate adoption of RAP. Then, MLG stresses the value of functional specialization and network-based approaches, in other words Type II governance structures (Hooghe & Marks, 2021). RAP reuse will benefit from dedicated task-specific arrangements like regional material banks, joint pilot programs and validation procedures. These will help enable targeted problem solving without changing existing jurisdictional boundaries. Beyond this, provincial and national governments can play a capacity building role to help smaller municipalities and other local road authorities with expertise, experiences, templates, and pooled resources.

Need for Dedicated Governance for RAP Reuse

Based on the findings of this research, it can be said that current governance structures for asphalt projects are primarily designed for project delivery, and regulatory compliance, and not for fostering cross level coordination or long-term innovation. Therefore, dedicated governance arrangements for RAP reuse or any secondary material reuse are needed. As discussed in section 2.5, previous studies have noted that governance for road projects is designed mainly for project delivery, often splitting responsibility for construction & maintenance (Ruiz et al. 2025). This study confirms that such mechanisms disadvantage RAP reuse, further supporting the need for dedicated governance. These arrangements could take form of a regional material bank, permanent knowledge sharing platforms, or covenants like the one Northern Netherlands. Their value lies in creating continuity beyond plot projects to ensure that successful practices are mainstreamed rather than remaining isolated. Without dedicated governance, the reuse of secondary materials risks remaining vulnerable to cautious defaults of the existing structure. Studies on circular economy transition show that without institutionalized governance, successful practices often remain isolated and fail to scale beyond pilot projects (Ruiz et al. 2025).

MLG provides a useful lens to determine how such governance should look like. The findings indicate that neither purely Type I nor purely Type II governance is sufficient on its own. Type I governance tends to lock in risk-averse nature and case-by-case approvals, while in Type II, the impact remains local and fails to be embedded in formal standards. The implication is to design complementarity between the two types. This can be done by retaining Type I where the dominance of legal accountability and safety is required (authority in decision making, and jurisdictional boundaries). Institutionalizing Type II where learning, coordination, and adaptability is needed like cross-actor coordination, capacity building and pilot projects.

Implications for the Sector Considering MLG Types

When reflecting on the four governance characteristics it becomes clear that not all aspects of the system can or should be transformed. Some features are inherently suited to remain Type I, while others can become more Type II:

- Decision making authority should remain Type I, centralized with the client. As the legal project owner, the client must retain final authority over safety, quality, and compliance standards.
- Coordination & communication mechanisms should become more Type II structured with more frequent and structured discussions between the client and the contractor regarding RAP reuse potential and practices for the project. This also involves enhancing communication channels between road authorities at different governance levels. Such arrangements can go beyond rigid top-down communication and by enabling joint-problem solving and feedback loops. This can help enhance the quality and consistency of RAP-related decisions, even when final authority rests with the client.
- Jurisdictional boundaries cannot be changed and hence Type I remain structured. Responsibilities between national, provincial, and municipal levels are clearly allocated, and these divisions are institutionally durable. Attempting to dissolve or overlap these boundaries can create confusion rather than solving governance challenges.
- Adaptability in governance structures is where Type II experimentation can be most valuable. In practice this means creating more space for pilot projects for gaining results (for example- long term performance monitoring data), strengthening knowledge sharing platforms, and building capacity at the local level.

The sector is already halfway there with Type I structures already in place as they provide necessary stability. The requirement is for systematic embedding of Type II features to enhance multi-actor and multi-level coordination across the sector, create feedback loops, reduce uncertainty, and mainstream the uptake of RAP.

5.1.3 Implications for the Three Levels of Governance

The implications of the findings are best understood through the three levels of governance in the Netherlands. At the national level, authorities such as Rijkswaterstaat (national road authority) and Ministries hold the power to set standards, establish monitoring frameworks, and maintain regulatory clarity. This can be done with the help of research and knowledge institutions and platforms like CROW & NPDW as they serve as tools to provide a knowledge base and sector wide learning mechanisms. The role of the national level is to provide stability (Type I) while also encouraging experimentation by funding pilot projects and embedding successful results into national standards.

At the provincial level, governments are well positioned to act as coordinators capacity builders. They can bridge national ambitions into implementation at the local level, fostering regional collaboration, and supporting knowledge sharing platforms, which aligns with Type II features. At the municipal level, specifically smaller municipalities, the findings indicate a need for enhanced capacity and more consistent practices. MLG stresses the importance of horizontal coordination alongside vertical coordination. Municipalities can therefore benefit from collaborating with each other by sharing lessons, joint projects, adopting standardized procurement approach and developing collective approaches to RAP reuse. Horizontal coordination also extends to engaging private sector actors like contractors, asphalt plants, and engineering consultancy firms. Their involvement is essential in translating policy ambitions in practice, pooling technical expertise and to ensure project innovations tested in projects are replicated across the sector.

Taken together, this shows that RAP reuse requires a balance where national authorities provide stability and consistency, provinces provide support and coordination, and local authorities operationalize practices on the ground while learning from each other and more experienced municipalities. In terms of governance, this division of roles illustrates why purely Type I or Type II structures are not enough to increase the potential of RAP reuse. Hence, a hybrid structure with features of both arrangements is required.

5.2 Addressing Barriers: Possible Directions

Multi-level governance (MLG), as conceptualized by Hooghe & Marks, provide a useful lens to figure out potential directions towards increasing the potential of RAP reuse in the Netherlands. As a result, this section provides possible directions towards resolving some of the barriers to RAP reuse by combining insights from Type I & Type II structures. In the first wave, a wide range of barriers were identified across the four categories- technical, cultural, regulatory, and market. However, it was not feasible within the scope of this research to address all of them. Instead, insights from the second wave were used to filter out some of the barriers - combining those that were most emphasized by stakeholders and observable across projects. These core barriers form the focus of this section.

5.2.1 Technical Barriers

The most emphasized technical barriers, namely lack long-term performance monitoring, lack of standardized technical guidelines, logistical issues, and uncertainty in quality, can be addressed through a combination of Type I and Type II features of MLG. This is because Type I solutions provide stability, such as standardization at the national level, national monitoring, and contractual alignment. While Type II provides flexibility through pilot projects, resource pooling, and collaborative implementation of projects.

From a Type I perspective, the following directions can be followed to try and address the technical barriers:

- Establishing a national, mandatory performance monitoring program to close the long-term performance evidence gap. This will help reduce the risk-averse nature of the clients and may allow for higher RAP content.
- Issuing standardized validation protocols (for RAP mixes) so that contractors don’t have to follow different procedures for different road authorities project-by-project.
- Introduction of logistic requirements in the contracts (specifically for RAP) like minimum notice for milling process, stockpile management rules and enable time allowances where RAP reuse is being utilized at scale.

From a Type II perspective, the following directions can be followed to try and address the technical barriers:

- Creating more pilot projects and TRL validations with joint client-contractor oversight and publishing the results and lessons learned. This will help accelerate learning across the sector about reuse practices.
- Create regional pooling mechanism to share resources. This will help smooth volatility in supply of RAP. For instance, a regional pool in the province of Noord Holland can be shared by all the municipalities in that province.

5.2.2 Cultural Barriers

The most emphasized cultural barriers explained are lack of information and knowledge sharing, lack of stakeholder collaboration, and limited local capacity and strategic focus on RAP. These are inherently harder to resolve because they don't need engineering or technical solutions but rather a change in the attitude, mindset, and patterns in the sector which are long standing. A combination of Type I and Type II structures can still provide a starting point by creating continuity and obligatory mechanisms and capacity support.

From the point of view of Type I structures, the following measures can help address some of the cultural barriers:

- Assigning an RAP lead person from the client's side in projects to ensure continuous coordination between the client and contractor in projects. This will provide a single point of contact between and across multiple projects for knowledge sharing.

From the point of view of Type II structures, the following measures can help address some of the cultural barriers:

- Existing knowledge sharing platforms (CROW & NPDW) should be strengthened through more balanced representation and incentivized participation for smaller municipalities and provinces. This could accelerate learning about RAP reuse practices across the sector.
- Capacity building in smaller municipalities through mentoring, providing templates and checklists about procedure for RAP reuse. This can help raise baseline competence at the smaller municipalities that have not prioritized RAP in their projects.

5.2.3 Regulatory Barriers

The most emphasized regulatory barriers are fragmented regulations and lack of standardization, restrictive and inconsistent regulatory standards, and constraints in the ownership of RAP. They can be addressed through a combination of type I & II features. Type I features can provide stability by creating a unified national rulebook/standard which could help remove some fragmentation across road authorities in the sector. Type II provides flexibility and task-specific solutions like conducting pilots or field trials whose results can help enhance the national guidelines and facilitating targeted discussions for ownership constraints.

From the perspective of Type I features, the following directions could be considered:

- National level clarity and harmonization in reuse practices of RAP by creating one clear rulebook for unified interpretation of the RAW standards and clear pathways for surface layer applications. This will help remove fragmentation in regulations and case-by-case validation.
- Separate guidelines for specifically RAP reuse practices (or in general for secondary materials). It is not that currently no guidelines exist for RAP; they do but they form a small part of the broader guidelines for civil engineering works.

From Type II perspective, the following directions could be considered:

- Creating more pilot projects or specific field trials to test high RAP mixes under enhanced monitoring and time-bound performance testing. This could help gain results and enhance the national guidelines for RAP reuse.
- Facilitating discussions between key actors in the value chain to evaluate the effectiveness of the current ownership model of RAP (where ownership shifts from client to contractor post-milling). This is to acknowledge that some stakeholders think its adequate while others think it is restrictive.

5.2.4 Market Barriers

The most emphasized market barriers are prioritization of cost in procurement procedures and inconsistent use of environmental incentives. The only concrete direction that this research can provide based on the findings is the standardization of procurement procedures across the sector. Even though market barriers were the least emphasized, still the procurement issue remains significant enough to grant attention. The direction provided links to Type I structure as it points moving towards creating a standardized procedure for procurement across road authorities at different levels. It also links to type II features as it requires capacity building at the local level to implement such procedures. The directions provided to address market challenge are:

- Creating standard procurement guidelines across the sector for road projects involving RAP reuse. This can be done by extending Best Price Quality Ratio template and using MKI as an awarding criterion in tenders. It is not that this is not being done, Rijkswaterstaat and many municipalities and provinces make use of these mechanisms consistently. However, some smaller municipalities and provinces don’t have experience in implementing such mechanisms. This not only harmonizes procurement practices across the sector but is linked directly to capacity building at the local level.

Conclusion

It is important to note that the directions outlined in this section should not be understood as definitive solutions that can eliminate all the barriers to RAP reuse. Rather, they represent starting points derived from the empirical findings of this research which are grounded in literature and stakeholder interviews. Their value lies in demonstrating how a balance of Type I and Type arrangements can be utilized to begin addressing some of the most crucial barriers to RAP reuse in the Netherlands.

5.3 Contributions of the Research

This section places the research findings in existing literature. This is done by explaining the academic as well as practical contributions of this study.

5.3.1 Academic Contribution

Theoretically, this research extends the application of multi-level governance theory into the domain of circular economy and the reuse of secondary materials in the road infrastructure sector. Type I & II concepts when applied to RAP offered a novel explanation as to why certain barriers persist in the sector. For instance, jurisdictional boundaries coupled with hierarchical and top-down coordination leads to limited information and knowledge sharing across governance levels and the sector regarding RAP reuse practices and lessons learned. It builds a bridge between circular economy transition (more specifically increasing the potential of RAP) and governance studies by providing an adapted framework that was applied to the Dutch road infrastructure sector. The adapted framework contributes to theory in three ways: First, it shows that technical, market, cultural, and regulatory barriers don't exist in isolation, rather they are a result of governance effects. Secondly, it provides empirical evidence that Type I and Type II MLG structures coexist creating a hybrid dynamic that can help increase the potential of RAP reuse. Lastly, it offers a transferable analytical tool to analyze similar problems, like other recycled construction materials or circular economy initiatives in multi-level settings. This can be considered a conceptual advancement as it broadens the applications of MLG.

5.3.2 Practical Contributions

On the practical side, the integration of barrier identification with MLG framework has direct implications for policymakers and industry experts. By revealing the governance roots of the most emphasized and observable barriers to RAP reuse, the research helps to shift the focus from technical fixes to systematic governance solutions. For instance, Fragmented regulations and lack of standardization can be understood as a result of coordination failure across governance levels. The remedy is not only to change standards but to establish multi-level coordination mechanism so learning and knowledge can be shared. Beyond revealing these governance roots, the study also discusses where change is most feasible, meaning which aspects should remain Type I and which need to shift more towards Type II. Importantly it highlights the need for dedicated governance for RAP reuse which can help ensure successful practices are mainstreamed across the sector. It also provides directions that can be taken towards increasing the potential of RAP reuse in the Netherlands. This makes the research practically useful as a starting point for targeted interventions. Policymakers and practitioners can build on this to design governance responses like strengthening multi-level and multi-actor coordination mechanisms, developing clearer and standardized national standards or creating space for long-term gathering of performance data through pilots. Lastly, the research documents projects where voluntary Type II features were demonstrated (like frequent multi directional communication or joint decision-making regarding RAP reuse). This way the research shows how such arrangements can generate practical lessons for improving coordination and allow for increased RAP reuse.

5.4 Limitations

This study, just like many theses, faced certain limitations which probably influenced the outcome of the research. To begin with, in terms of scope, the research focused on the Dutch road infrastructure sector which restricts the generalizability of the findings to other contexts. The study doesn't consider the perceptions and experiences of smaller municipalities and contracting firms, particularly those without their own asphalt plants. This narrows the picture because these actors may face different constraints in terms of resources, capacity, and access to RAP. Similarly, the selection of case projects only considered projects that successfully incorporated RAP in the mix. By not considering the projects with failed attempts at RAP incorporation, this study misses an opportunity to gather lessons from projects where barriers proved to be insurmountable.

In terms of methodology, the study is purely exploratory and qualitative in nature. Therefore, the reliance on semi-structured interviews means that findings reflect stakeholder perceptions which can be influenced by individual experiences or organizational agendas. Furthermore, some organizations were only represented by a single interviewee during the interviews. This limited representation may not fully capture the diversity of views and can introduce the risk of bias if only a single perspective from the organization is included. In addition, the literature review was selective and not systematic. While it drew on key Dutch and European studies regarding RAP and CE transitions, not all works on barriers to RAP were included. This may leave gaps in how comprehensively the findings are situated within the broader academic debate.

A major conceptual limitation concerns the categorization of barriers in this study. In this study, the five categories of barriers identified through literature were reduced to 4 by merging information sharing and institutional & governance categories under Cultural category. While this was in line with the Kirchherr et al 92018) barrier framework utilized, it is important to acknowledge that this decision is not uncontested in literature. On one hand, some studies (Henrysson & Nuur, 2021; Rajčić et al. 2024) highlight how issues of trust, transparency, and collaboration are rooted in organizational norms and behaviors. From this perspective, problems of weak information sharing, lack of collaboration, and limited organizational capacity can reasonably be viewed as cultural. On the other hand, some studies treat institutional and governance challenges as distinct from cultural. For example, Munaro & Tavares (2023); Grafström & Aasma (2021), distinguish institutional barriers such as unclear roles, regulatory fragmentation, and weak enforcement from cultural barriers, which refer specifically to values, attitudes, and behaviors. Therefore, while the four-category framework utilized in this study offered coherence and fit the RAP context in the Dutch sector, it may blur analytical distinctions that other studies considered significant. This is a limitation of this study, as the chosen categorization though justified, reflects one interpretation. Different categorizations, like treating institutional and governance separate to cultural may lead to different emphases and by merging categories some nuances of governance-specific challenges may have been downplayed.

Finally, the application of MLG as an analytical framework has its own limitations. The framework applied in this research was adapted from literature and operationalized based on observable features, which depended on the researcher's interpretation. Moreover, MLG models are abstract in nature and inherently reductive as they oversimplify the complex dimensions of governance into a limited set of characteristics. This makes it difficult to fully capture the diversity of empirical context. That's why the findings should be seen as indicative but not exhaustive.

Chapter 6. Conclusion

This study set out to identify and understand the barriers to increasing the reuse of RAP in the Netherlands and analyze how governance mechanisms influence or shape them. This final chapter brings together all the findings of the research by presenting the main conclusions of the study. The chapter first discusses the answers of the main and sub research questions and then presents recommendations for future research.

6.1 Conclusion of the Research Questions

This section summarizes the findings of the four sub-research questions of this study followed by the conclusion to the main research question. The conclusions are drawn based on the findings of literature review and the two waves of stakeholder interviews.

SRQ1: What barriers to the reuse of RAP exist according to literature?

The literature review process was conducted involving the analysis of some of the major studies regarding berries to CE transition and the challenges associated with reusing RAP. The process was not aimed at performing a systematic review of all the studies but to establish a baseline of barriers to increasing the reuse of RAP that can later be verified or contested through stakeholder interviews. To do this, the study combined generic CE transition barriers with RAP specific challenges to ensure that both sector -wide governance and material specific challenges were included.

The resulting baseline inventory of barriers includes a wide range of barriers. These span 5 main themes: Regulatory, Institutional & Governance, Technical, Market, and Information & Knowledge Sharing Barriers. These themes capture the multi-faceted nature of RAP reuse challenges and served as a reference point against which empirical findings of the study could be compared. A detailed description of all the challenges under the 5 main themes is presented in section 2.4 and the resulting overview of the barriers is presented in Figure 2.

SRQ2: What barriers to the reuse of RAP exist in practice according to key stakeholders in the asphalt value chain and how are they perceived differently by different stakeholders?

This question was answered through stakeholder interviews with actors across the asphalt value chain. The findings show that the barriers to the reuse of RAP can be grouped under 4 main themes: Technical, Regulatory, Market, and Cultural (combining institutional & governance and information & knowledge sharing themes from literature review). This classification is based on the one followed in Kirchherr et al (2018) and it also provided a practical coding structure for thematic analysis.

In practice, technical barriers include technological limitations like quality and performance issues, logistical challenges, and the lack of standardized technical guidelines for scaling the reuse of RAP. Cultural barriers are concerned with the mindset, behavioral, and organizational patterns. These include challenges like limited state of information and knowledge sharing across the sector and stakeholder collaboration, and limited capacity at the local level for scaling up RAP reuse. Regulatory barriers refer to the challenges related to government policies, laws, and incentives that can enable or hinder the reuse of RAP. These include challenges like fragmented regulations and lack of standardization, inconsistent and restrictive policies, constraints in ownership of material and RAP containing tar, and tracking of material. Market barriers are concerned with the market and economic considerations that can affect uptake of RAP. These include challenges like cost prioritization in tender procedures and inconsistent use of awarding criteria across road authorities. A detailed description of all the challenges is given in section 5.2.1 and an overview of the identified barriers to the reuse of RAP is presented in Figure 4.

Coming to stakeholder perceptions, this research found out that stakeholder groups emphasize barriers differently based on their roles in the asphalt value chain. When grouped into the 4 themes, the study reveals that technical and cultural barriers remain as the most emphasized barriers followed by regulatory barriers. On the other hand, Market barriers were the least emphasized. Contractors, asphalt plants, and engineering consultancy firms emphasized technical barriers the most, which is reflective of their implementation roles in projects and operational involvement. Government bodies emphasized regulatory barriers the most, which is consistent with their responsibility for standards and rules. Research & Knowledge Institutions emphasized cultural barriers, like lack of information and knowledge sharing and collaboration, the most emphasizing them as systematic bottlenecks in increasing the reuse of RAP in the Netherlands.

Lastly, a comparison with the literature studies reviewed during the desk research reveals that while literature provided a useful baseline to anticipate barriers it often presented them in generalized terms. The interviews validated most of the barriers identified in literature but also added depth by contextualizing them into the Dutch road infrastructure sector. Barriers like unclear roles and responsibilities (considering RAP reuse) and high upfront investment costs were not recognized in practice. This suggests that they may be relevant barriers in CE transitions but same may not be the case for the reuse of RAP. At the same time, six new barriers were identified during interviews, for example- limited local capacity and strategic focus on RAP, constraints in the ownership of RAP, inconsistent use of environmental incentives and so on. A detailed explanation about which barriers were newly uncovered, and which were not verified in practice, is given in section 5.2.3.

SRQ3: To what extent do governance structures shape these barriers at the sector and project level?

The analysis of governance dynamics through the lens of multi-level governance theory at the project level reveals that the barriers to RAP reuse are closely shaped by governance structures. The underlying structures of decision-making authority, jurisdictional boundaries, coordination mechanisms, and adaptability in the Dutch road infrastructure projects help to explain why certain barrier emerge. For instance, centralized decision-making authority with the client ensures stability and reliability but leads to risk aversive behavior. This is because of lack of long-term performance data which leads to clients being reluctant to allow a higher percentage of RAP in a project due to uncertainties in the quality as well. Jurisdictional boundaries across the three levels of governance (national, provincial, and local) are clear and non-overlapping. This means there are hardly any joint projects, which leads to fragmented regulations and inconsistent standards being followed across projects involving reuse of RAP. Coordination, when limited to hierarchical top-down communication restricts the flow of information and knowledge (like lessons learned from pilot projects, advance in mix design etc.) across the sector. This reinforces cultural barriers like lack of collaboration and information sharing. Lastly, limited adaptability in governance structures explains why experimental and pilot projects are slow to translate into nationwide standards, leaving uncertainty in quality and performance of RAP unresolved.

Viewed through the lens of MLG, the sector represents predominantly Type I features: centralized decision-making, strict jurisdictional boundaries, limited coordination across levels, and rigid governance structures. Type II features: joint decision-making, frequent multidirectional communication, and flexible governance structures, only emerge in project specific contexts. This dynamic shows that while Type I structures bring stability and clarity needed for road safety and quality, Type II features provide flexibility for innovation but lack pathways to scale.

SRQ4: How can insights gathered through barrier identification and governance dynamics be synthesized to identify ways to increase the potential of RAP?

Even though a wide range of barriers to RAP reuse were identified, certain barriers stood out by combining the wide range of barriers identified from the first wave of interviews and the depth of project-level governance analysis from the second wave. These barriers are a combination of those emphasized the most by stakeholders and observed at the project level. Technical core barriers are Lack of Long-term performance monitoring, Uncertainty in quality of RAP, Logistical issues regarding storage, planning and material availability, and Lack of standardized technical guidelines. Cultural core barriers are Lack of information and knowledge sharing, Lack of stakeholder collaboration, and Limited local capacity and strategic focus on RAP. Regulatory core barriers are: Fragmented regulations and lack of standardization, Restrictive and inconsistent regulatory standards, and Constraints in the ownership of RAP. Market barriers were the least emphasized across both waves of interviews, but the market barriers that emerged at the general project context are Prioritization of cost in procurement procedures, and Inconsistent use of environmental incentives.

The other barriers to the increased reuse of RAP that were identified in this study are not less important. Rather, they are considered secondary in nature. Some of them are considered to be derivative of one or more core barriers. For instance, Challenges in reusing RAP in surface layers can be considered derivative of lack of long-term performance monitoring data and uncertainty in the quality of RAP.

Applying the MLG lens to the specific projects as well as general project practices shows that addressing these barriers requires features of both Type I and Type II structures. Certain elements are best retained as Type I, like centralized authority in decision-making and strict jurisdictional boundaries, to ensure stability and accountability. Type I features like national standardization, mandatory monitoring frameworks, and harmonized procurement rules can provide stability and clarity across the sector. While, coordination and adaptability need to evolve towards Type II, which includes strengthening vertical and horizontal coordination and cross-actor collaboration. Type II features like more collaborative pilot projects, regional resource pooling, and capacity building at the local level can help create flexibility and experimentation required for generating evidence of quality and performance and sharing knowledge. Together these insights reveal that increasing the potential of RAP is not only about technical fixes. It also requires governance arrangements where project level experimentation can help inform national guidelines. In this sense, this research does not provide definitive solutions to increase the reuse of RAP in the Netherlands but rather provides starting directions.

MRQ: How do governance structures shape the barriers to the reuse of Reclaimed Asphalt Pavement (RAP) in the Dutch road infrastructure sector and what does this imply for addressing them?

This research shows that the barriers to increasing the reuse of RAP in the Netherlands is multi-dimensional spanning across Technical, Cultural, Regulatory, and Market themes. Building up on literature, the interviews provided a nuanced picture of which barriers matter the most in practice and how they are reinforced by governance arrangements. The findings indicate that current governance structure, while effective for ensuring stability and compliance in road projects are not specifically designed to support the scaling up of RAP reuse. The way forward is not to replace Type I with Type II features, but to strengthen the link between them. Type I structures must continue to provide stability, safety, and uniformity while also becoming more responsive to lessons generated through Type II features. In practice, this means institutionalizing feedback loops so that findings from pilot projects are translated into updated rules, standards, and protocols.

The findings therefore suggest that RAP reuse would benefit from dedicated governance arrangements like regional covenants for resource pooling and learning, strengthened and more inclusive knowledge sharing platforms, and better overall coordination across the sector. In conclusion, the barriers to the increased reuse of RAP are as much shaped by governance structures as by technical and market conditions. To address them, it is necessary to understand the interplay between them and deliberately designing governance structures that combine the stability of Type I and flexibility of Type II. This research contributes by identifying which barriers are most crucial, which governance characteristics reinforce them, and pointing towards governance-based strategies that can enhance the potential of RAP in the Netherlands.

6.2 Recommendations for Future Research

This thesis has provided insights into the barriers to the increased reuse of RAP in the Netherlands and how governance structures shape them through the lens of MLG. However, some aspects of the findings and the limitations provide avenues for future research. This section describes where further research is required to strengthen understanding and support more effective practices.

One key finding of this study is that lack of long-term performance data is a key technical barrier and central reason for client's risk averse behavior in projects in allowing higher RAP percentages. For instance, it was mentioned during the interviews that if a road that was supposed to last for more than 15 years fails within 8-9 years, the responsibility shifts to the asset manager long after the contractor has exited the project. Future research should therefore investigate contracting models and monitoring frameworks that credibly allocate long-term risks while also generating long term robust data. This would help overcome the current cycle of uncertainty and caution.

One of the limitations of this study is that the perspectives of smaller municipalities and contractors were not captured during the interviews. Yet, findings suggest that there is limited capacity in small municipalities and provinces to incorporate the reuse practice of RAP in their projects. Further research could focus on these actors to understand the challenges they face in the reuse of RAP. This could reveal some other barriers that this research could not identify and also figure out what capacity building mechanisms might be helpful in overcoming those barriers.

Another thing is that this study only considered three projects in the second wave. While it was valuable, this limited scope cannot capture the diversity of outcomes across the sector. Future studies should involve a comparative case study design involving a broader set of projects selected on clear criteria including both successful RAP incorporation and failed attempts. Studying projects that failed to incorporate RAP would add important insights into the institutional and technical bottlenecks that remain hidden when only good practice examples are examined.

Lastly, this study found early indications that road authorities at different levels, like Rijkswaterstaat and the Municipality of Amsterdam, exhibit distinct governance characteristics in their projects considering RAP reuse. While RWS projects showed more Type I features, Municipality of Amsterdam's project showed more Type II features. These differences may partly explain the variations in how RAP is reused in projects across different levels. However, since this conclusion is based on the analysis of only three projects, further research is required to systematically test whether such differences are consistent across other authorities and contexts. A comparative case study design focusing on projects led by different road authorities at the national, provincial, and local levels could provide valuable insights into how governance structures across these levels influence RAP reuse. This is especially relevant because of the considerable difference in size, organizational structures, and responsibilities between road authorities at different levels, which are likely to shape their governance practices and responsiveness to innovations like RAP reuse.

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Appendices

Appendix A: Characteristics of the two Types of MLG

Two Types of MLG according to Hooghe & Marks (2001)

Type I: This type is characterized by stable, general-purpose jurisdictions that include various functions and responsibilities. The jurisdictions are organized in a nested and non-overlapping hierarchy and include territorially defined entities such as national government, provinces, and municipalities. Dabrowski (2022) characterizes this type as a vertical dimension as it refers to the increased interdependence of authorities working at different governance levels. Type I MLG systems are long-lasting and operate in a decentralized hierarchy. The key characteristics of this type are:

- General Purpose Jurisdiction: which means that each level handles many different functions and policy responsibilities.
- Nonintersecting memberships: which means that there are no overlaps between these jurisdictions (governance levels)
- Limited number of jurisdiction levels: which means that authority is organized between only a few levels (typically- national, regional, and local).
- Systemwide, durable architecture: which implies that the system is stable and long-lasting.

Type I governance aims to minimize coordination issues by maintaining a clear division of authority between the different levels with just a few actors. An example of this type of MLG is European Union's formal institutional structure.

Type II: This type includes a large number of task-specific jurisdictions that are designed to address particular policy problems or deliver specific services. It is characterized by flexible, overlapping, and task specific governance arrangements and are often temporary and created for specific policy objectives. Dabrowski (2022) describes this type as a horizontal dimension as it involves not only government actors but also the private sector, civil society, and other non-state actors. Type II MLG often includes public-private arrangements or multi-actor arrangements and are designed to be temporary, adaptable, and problem-focused. The key characteristics of this type are:

- Task-specific jurisdictions: which means it is designed for specific tasks and hence each jurisdiction fulfils distinct and specialized functions.
- Intersecting memberships: which means that there are no set boundaries for each jurisdiction and hence actors can belong to multiple jurisdictions at the same time.
- No limit to the number of jurisdiction levels: which means there are no fixed number of jurisdictions or levels.
- Flexible design: which means that arrangements can be created and dissolved as and when needed.

In this type, participation is often voluntary and actors and join or leave arrangements depending on their needs and interests which makes it well suited for situations requiring experimentation, innovation and cross-boundary problem solving. Examples are public-private partnerships for projects etc. An overview of the characteristics of the two Types of MLG is presented in Table 7

Table 7 Characteristics of the two types of MLG (Cairney, 2019; Adapted from Hooghe & Marks, 2001)

Key Questions	Type I	Type II
Should the jurisdictions be designed around communities/levels of government or policy problems/tasks?	General-purpose jurisdictions	Task-specific jurisdictions
Should jurisdictions bundle competencies or be functionally specific?	Separate functions, ensure non-intersecting memberships	Bundle competencies, encourage intersecting memberships
Should jurisdictions be limited in number or proliferate?	Limit the number of jurisdictions	Do not limit jurisdictions
Should jurisdictions be designed to last or be fluid?	Produce system wide architecture	Maintain a flexible design

Adapted MLG Framework applied in this study.

The four characteristics adapted from Hooghe and Marks (2001) and actually used to apply in this study along with their indicators and how to interpret them is explained in the following section:

1.Authority in Decision Making: This characteristic is concerned with the distribution of authority over decisions related to the reuse of RAP, for instance, how much RAP is allowed in the new mix, what type of mix and so on. It is to see if there is a single and clearly identified decision maker or whether the authority is shared between multiple actors. It is adapted from Hooghe & Marks (2001) distinction regarding the location of authority in governance structures. Type I is characterized by centralized decision-making where a single party is responsible for making these decisions, for instance, if a single road authority makes all the decisions and the contractors have to operate strictly within those parameters. On the other hand, Type II is characterized by collaborative decision making where road authorities, contractors and sometimes other actors take decisions about RAP reuse together.

2. Jurisdictional Boundaries: This characteristic is concerned with how the responsibilities regarding the reuse of RAP are distributed amongst different levels and actors, are they distinct or overlapping. This is adapted from Hooghe & Marks (2001) distinction between territorially defined jurisdiction structure (Type I) or overlapping jurisdiction (Type II). If the responsibilities for RAP management are distinct and contained withing different levels of governance, for instance National authorities manage RAP arising from national roads, provinces manage their own, and municipalities manage their own, with little crossover in ownership and operational management of the material, it represents Type I governance.

While, if these boundaries are less rigid and these levels potentially share authority or collaborate for RAP related decisions and projects, then it represents Type II governance.

3. Coordination Mechanisms: This characteristic is concerned with the structure of communication and coordination between different actors by exploring how information flows occur. It is adapted from how MLG implies different coordination structures- hierarchical (top-down) and networked (multi-directional). This reflects Cairney's (2019) emphasis that governance is not just about structures but also about the process of coordination. If the communication is hierarchical (top-to-bottom) and information flows through predetermined reporting lines, it represents Type I. while, if there is open, frequent, and multi-directional communication and information flows then it represents Type II governance.

4. Adaptability of governance mechanisms: This characteristic is concerned with to what extent the governance arrangements can adjust to changing circumstances, technical developments, or innovating project opportunities. This is adapted from the stability vs. flexibility dimension from Hooghe & Marks (2001). In the context of RAP, assessing this dimension involves identifying if governance structures allow for experimentation and quick adjustments, or if there are rigid frameworks that limit adaptation. Type I governance shows stable and long-standing arrangements, and it provides consistency, but it can also limit responsiveness to emerging opportunities. Type II is flexible where arrangements can be tailored based on specific projects.

Appendix B: Overview of Stakeholder Groups interviewed in Wave 1

Government Bodies- This group consists of three major levels of governance- national (Rijkswaterstaat), Provincial, and Municipal.

- **Rijkswaterstaat:** As the executive agency of the Dutch ministry of infrastructure and water management, Rijkswaterstaat (RWS) has the responsibility to design, construct, manage and maintain the Netherland's main infrastructure. Their leadership and involvement in national infrastructure projects makes them an influential stakeholder in the implementation and scaling up of RAP reuse strategies. The three departments of RWS targeted for this research are- Grote Projecten en Onderhoud (GPO) which oversees large scale infrastructure projects including highways and national roads, Programma's, Projecten en Onderhoud (PPO) which handles ongoing infrastructure works including road maintenance and upgrades where recycled material can be reused, and Water, Verkeer en Leefomgeving (WVL) which supports strategic innovation, environmental planning and sustainability frameworks.
- **Provinces:** They act as an intermediate level between the national and local levels and have the responsibility for the design, construction, and maintenance of provincial roads. Their involvement ensures that the regional perspective is also considered during the mapping and understanding of various challenges associated with RAP reuse.

- **Municipalities:** Municipalities play an integral role in the implementation of circular practices at the local level and are responsible for planning and maintaining regional and urban road networks, which makes their participation crucial in adopting and promoting the reuse of RAP. Understanding the role of the municipalities will help get insights into the challenges and opportunities for implementing RAP at the local level.

Contractors: Large contractors are majorly involved in and responsible for implementing RAP reuse practices. They can provide information and perspectives about how practices of RAP reuse are affected by different uncertainties and challenges from an execution point of view.

Asphalt Producers: They understand technical challenges like material compatibility and processing techniques, regulatory challenges about standards and specifications and market dynamics like demand for sustainable materials and cost considerations. They can give insights into innovative practices, operational experiences, and collaboration efforts.

Engineering & Consultancy Firms: They play a crucial role in designing infrastructure projects, advising on procurement, ensuring regulatory compliance, and innovating technical solutions. They can provide information about Material Performance Uncertainty, procurement constraints, inflexible standards and guidelines for RAP reuse, experiences in working with other stakeholders to implement circular practices and the challenges faced therein.

Research & Knowledge Institutes: TU Delft & CROW were considered under this category as they play a crucial role in advancing knowledge and innovation in the field of circular infrastructure, with TU Delft providing research perspectives on the barriers and CROW being a knowledge sharing and standard guidelines setting platform. The relative ease of setting up contacts with these institutes, besides their major relevance in the research, was also the reason why other institutes were not considered.

Appendix C: Interview Guide: Wave 1

Questions common to all stakeholders

Opening Questions

- In your work, have you encountered or are you engaged with practices involving reuse of Reclaimed Asphalt Pavement (RAP) in road construction?
- In your perspective, what are the biggest challenges or barriers that limit the reuse of RAP? Can you describe from your experience any of these challenges?

(Showing the diagram with the list of identified barriers and stakeholders)

Core Questions

- Based on what we've discussed and the list of barriers I've compiled through literature review, do you feel that these reflect the challenges relevant in the Dutch context, especially from your perspective at RWS? Are there any barriers you would add, remove, or prioritize differently based on your experience?

- Who do you consider the most important stakeholders when it comes to enabling or blocking circular RAP use?
- To what extent can your organization influence circular practices, specifically those related to utilizing RAP?
- What role can your organization play in ensuring that there is a solid supply chain of RAP and that it reaches its full potential?
- In your experience, how is the ownership of RAP typically defined in projects you work on?
- In what way does collaboration and communication between different actors (like RWS, Municipalities, contractors, suppliers etc.) affect circular practices in your projects?
- What is the influence of procurement rules, tender criteria and incentives affecting your (organization's) ability to use RAP in practice?
- Do you feel there is enough flexibility or incentive in current project processes to propose or implement reuse of RAP?
- To what extent is the is the knowledge, data and expertise required for circular road construction and more specifically utilizing RAP accessible? What are some gaps, if any?

Ending Question

- What could be a solution, in your opinion, to help overcome some of these barriers? What would need to change to make RAP reach its full potential both in your organization and in the broader system?

<u>Specific Questions for specific stakeholders</u>

Rijkswaterstaat

- In what ways does RWS support or influence municipalities (like Amsterdam) in adopting circular practices? Are there any formal mechanisms in place for this?
- Are there any collaboration initiatives between RWS and local government bodies on infrastructure circularity? If yes, then what has worked well and what has been difficult in those collaborations?
- Does RWS maintain data on reclaimed materials like RAP? How is this information used, and is it shared externally?
- How are sustainability criteria included in RWS procurement for road works? Do current procurement rules help encourage RAP use, or do they need changes?
- From a national perspective, what changes (in policy or practice) would most help boost circular reuse of RAP at all levels? For example, would you consider mandating certain recycled content, or creating a national platform for material exchange?

Municipality of Amsterdam

- To what extent does Amsterdam's circular economy policy influence road construction projects at the local level?
- What has Amsterdam's experience been using RAP on its roads?
- Are there current local policies or guidelines that promote RAP usage? If yes, what are they?
- Do you coordinate with Rijkswaterstaat on matters of material reuse? To what extent?
- Would having access to RAP from RWS or nearby municipalities improve your ability to build circular roads?
- What are the main challenges you face in using RAP in municipal road projects? (E.g., material quality, logistics, contractor capabilities?)
- What kind of support or policy from the national level would help Amsterdam increase circular practices?

Contractors:

- Do current technical standards constrain the use of RAP or other recycled materials? How and to what extent?
- What innovations or new techniques are there that could improve the quality or usage of RAP?
- What do you do to ensure the quality of RAP in practice? Are there any testing protocols or requirements that are cumbersome or insufficient?
- Have you worked on a project with high RAP content? What were the lessons learned from that technical experience?
- Do you think it's technically and logistically viable to use RAP from RWS projects in city projects or vice versa? What issues would need to be solved to make that happen smoothly?

Technical Experts:

- What are the biggest risks associated with using RAP in high percentages? How are these managed?
- Is there any standardization in how RAP is processed, stored, and tested across the Netherlands?
- What technical changes like specifications, testing methods or design tools would most help improve trust in circular reuse of RAP?

Research Institutions

- What are the most critical technical challenges you see when it comes to integrating high levels of RAP in new asphalt mixtures?
- Are there gaps between what research shows is possible and what actually happens in practice on the ground?
- In your view, is there any standardization in how RAP is processed, tested, and applied across different projects or regions in the Netherlands?
- How do research institutions like TU Delft collaborate with governments or contractors to influence real-world adoption of circular practices? What barriers exist?
- Do you think the knowledge generated in pilot projects like Circular Road is being shared and scaled effectively across municipalities?
- What would you recommend to better connect research-based insights with implementation actors (e.g., RWS, municipalities, engineering firms)?

Appendix D: Interview Guide: Wave 2

Opening Questions

- Are there recent projects that involved the reuse of RAP that you were a part of?
- Would you be open to sharing more about such a project, so it could be studied as part of this research?

Core Questions

- Who usually determines the percentage of RAP in a mix that can be reused in a project?
- To what extent are private actors like contractors, consultancy firms, and asphalt plants involved in these decisions?
- Do you experience situations where responsibilities regarding the reuse of RAP are unclear or overlapping? If yes, how do you resolve them?
- Have you noticed differences between how RWS and municipalities define or enforce RAP reuse policies? What are they?
- Have you worked on projects where different governance levels (e.g., RWS and municipality or a province) were involved? If so, how was that coordination structured?
- Is there usually a single lead actor in RAP reuse projects, or is responsibility shared between multiple parties?
- In your recent RAP projects, how would you describe communication with the public client (or the contractor, in case of clients)?
- Are there regular back-and-forth during design and execution? Or is it mostly the one way?
- Are there platforms or meetings where public and private actors (contractors, consultants) jointly discuss technical standards and innovations relating to RAP?

Appendix E: Informed Consent Form

Delft University of Technology
HUMAN RESEARCH ETHICS
INFORMED CONSENT TEMPLATES AND GUIDE
(English Version: January 2022)

Opening Statement

You are being invited to participate in a research study titled 'Bridging national and local governance for enhanced circular reuse of pavement materials in road construction'. This study is being done by Soumya Shukla from a master's student in the Construction Management and Engineering program at the TU Delft along with Witteveen+Bos.

The purpose of this research study is to explore how collaboration between national and local governments can enhance the circular reuse of pavement materials and reduce resource depletion, specifically Reclaimed Asphalt Pavement (RAP), in road construction, and will take you approximately 60 minutes to complete. The results of this study will contribute to the researcher's thesis, which will be published and made publicly accessible via the TU Delft repository. The interview will explore your experiences, perspectives, and knowledge related to governance, circularity, and the reuse of road construction materials.

During this study, the following data may be collected –

- Professional views and opinions on policy, procurement, technical practices, and collaboration in road construction.
- Contextual information about projects you've been involved in, without naming the project in the final report.
- Audio or video recording of the interview (if you consent), for the purpose of transcribing and then will be deleted at the end of the research.

Data Storage and Protection-

- Only anonymized transcripts will be retained; all audio/video files will be deleted at the end of the research
- Transcripts and related research notes will be stored securely on TU Delft's servers and the password-protected work laptop of the researcher at Witteveen+Bos
- All data will be anonymized in analysis and publications. Projects will be referred to using generic codes (e.g., Project A, B, C).
- Data will not be shared outside the immediate research team (the researcher and supervisor). Only the researcher and the direct supervisors at TU Delft will have access to raw data, including transcripts, recordings of interviews and PII and the student's direct supervisors at Witteveen+Bos will have access to transcripts and PII.
- The final thesis will be made publicly accessible through the TU Delft repository

The results of the research, including the anonymized transcripts of the interviews, will be made available to the members of the PMC– Circular and Net Zero Solutions at Witteveen+Bos. These transcripts will be fully anonymized before sharing, ensuring that no individual participant can be identified. The data shared will be used strictly for internal learning and project development within the PMC and will not be published or distributed outside of this context. The organization's role is limited to supporting the researcher's master thesis. Only the student's direct supervisors at Witteveen+Bos will have access to the contact details of interviewees and the transcripts of their interviews and only in cases where the interviewees were referred or provided directly by them. This access is solely for coordinating the interviews and will not be used for any other purpose.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by withdrawing answers to our questions in case you don't want them to be published.

Appendix F: Open, Axial, & Selective Codes for Wave 1 Results

Table 8 Open, Axial & Selective Codes for Wave 1 (author)

Open Codes	Axial Codes	Selective Codes
RAP reuse is affected by contamination, degradation and change of mixture in projects	**Uncertainty in the quality of RAP**	**Technical**
Different sources RAP lead to variability		
Too many varieties of asphalt mixtures is a challenge		
Uncertainty in the quality and performance of RAP is a challenge		
Standard asphalt reclamation leads to quality issues in the material		
Variability in the material affects its quality		
Quality concerns in recycled materials		
Lack of knowledge about the long-term performance of RAP	**Lack of long-term performance monitoring of mixes with high RAP content**	
Life-span concerns over mixtures with RAP vs without RAP		
Need for long-term performance monitoring		
Lack of standardized technical guidelines	**Lack of standardized technical guidelines**	
RAP needs processing to match the composition of the mixture to be reused again	**Milling and Processing Challenges**	
Milling of asphalt leads to changes in gradation of the material		
Reusing RAP in the same road it was milled from can be inefficient and lead to material loss		
Milling of all the layers together leads to loss of quality of the material		
Selective milling of asphalt is time consuming		
Selective milling of RAP should be done for better quality of the material		
Fine RAP fraction as technical bottleneck		
RAP needs processing to match the composition of the mixture to be reused again		
Underutilization of RAP in surface layers	**Challenges in reusing RAP in surface layers**	

Mixture sensitivity of porous asphalt		
More RAP can be used in SMA /AC and not that much in porous asphalt		
Not many barriers for reusing RAP in base layers		
Logistical challenges in RAP supply and planning	**Logistical Challenges**	
Supply and demand of RAP is volatile		
Need for investment in updated infrastructure		
Storage capacity issues		
Limited RAP available for reuse		
Emissions concerns in RAP processing	**Environmental Concerns**	
Resource constraints in small municipalities	**Limited Local Capacity and Strategic focus on RAP**	**Cultural**
Limited RAP knowledge in municipalities		
Municipalities follow prescriptive standards		
Risk aversion as barrier		
Municipalities are not prioritizing RAP		
Municipalities are focusing on materials other than Asphalt		
Information asymmetry between stakeholders	**Lack of information and knowledge sharing**	
Lack of centralized road condition data		
Lack of knowledge sharing for competitive advantage		
Lack of a centralized knowledge sharing platform		
Sharing lessons learnt is not a priority at the moment		
Need for information and knowledge sharing		
Municipalities often lack information about the roads they have		
Contractors don't share information with each other for competitive edge		
Fragmented data availability regarding material - source, quality, condition		
Lack of experience and lessons learnt sharing inhibits higher percentage of RAP in surface layers		
Limited stakeholder collaboration	**Lack of collaboration**	

Road authorities do not collaborate on road projects		
Less collaboration due to organizational differences		
Lack of alignment in sustainability targets	**Misalignment of goals**	**Regulatory**
Regional mismatch in sustainability goals		
No unified guidelines for using RAP leads to municipalities excluding RAP		
Lack of standardization in regulations regarding RAP	**Fragmented regulations and lack of standardization**	
Validation required for high RAP		
No standardization in RAP processing & Handling		
Validation required for RAP in porous asphalt mixtures		
Time-consuming validation processes		
Strict regulations and standards restrict RAP reuse	**Restrictive and Inconsistent Regulatory Standards**	
Strict regulations for porous asphalt		
Regulations for polishing value of the tones		
Strict material requirements		
Lack of clear RAP surface-layer standards		
Reuse challenges for porous asphalt		
Ownership of material is a barrier to circularity	**Constraints in ownership of RAP**	
Fragmented ownership of the material		
Government shouldn't give away RAP to the contractor post milling		
Ownership of RAP with the road authority leads to better decision-making		
Unsure about whether RAP ownership should be with contractor or road authority		
Ownership of RAP should remain with the road authority		
Material traceability via centralized data systems	**Material Traceability Challenges**	
Absence of central quality oversight of RAP		
Need for centralized RAP tracking		
Environmental compliance for RAP handling	**Constraints on RAP containing tar**	

RAP containing tar cannot be used due to environmental issues		
Cleaning up RAP is expensive		
Procurement prioritizes cost	**Procurement prioritizes cost**	**Market**
Monopolized value chain	**Monopolized value chain**	

Appendix G: Interview Quotes- Barriers to RAP Reuse

In this section, detailed quotes from the interviews conducted in the first wave are provided. The section is divided into the four main barrier categories and within each of them the quotes specific to each challenge is provided under respective subheadings. Firstly, an overview of the stakeholders interviewed is given in Table 9.

Table 9 Overview of the stakeholders interviewed: Wave 1(author)

Number	Role	Organization	Abbreviation
1	Sustainability Advisor- Sustainable Pavement Innovation	Government Body- Rijkswaterstaat	SA_GB
2	Circular Economy Advisor- Road Pavements	Government Body- Rijkswaterstaat	CEA_GB
3	Material Advisor	Government Body- Rijkswaterstaat	MA1_RWS
4	Material Advisor	Government Body- Rijkswaterstaat	MA2_RWS
5	Technical Specialist- Road Pavements	Governing Body-Municipality of Amsterdam	TS_GB
6	Asset Manager_ Pavements Maintenance & Materials	Governing Body- Province of Gelderland	AM_GB
7	Civil Engineer- Specialising in Asphalt Construction	Contractor-BAM	CE_CON
8	Sustainability Manager	Contractor-Dura Vermeer	SM_CON
9	Research & Development	Asphalt producer and supplier- Asfalt Nu	R&D1_APS
10	Research & Development	Asphalt producer and supplier- Asfalt Nu	R&D2_APS
11	Business Unit Manager - Mobility & Pavement Design	Engineering Consultancy Firm- Witteveen+Bos	BUM_ECF
12	Pavement Engineer	Engineering Consultancy Firm- Witteveen+Bos	PE1_ECF
13	Pavement Engineer	Engineering Consultancy Firm- Witteveen+Bos	PE2_ECF
14	Sustainability Consultant- Infrastructure	Engineering Consultancy Firm- Haskoning	SC_ECF
15	Sustainability Researcher	Research & Knowledge Institutions- TU Delft	SR1_RKI
16	Sustainability Researcher	Research & Knowledge Institutions- TU Delft	SR2_RKI
17	Material Advisor	Research & Knowledge Institutions- CROW	MA_RKI

Technical Barriers

Uncertainty in Quality of RAP

This challenge is concerned with the inconsistent quality and composition of RAP which is influenced by variability in the source, additives, and milling and processing procedures. For instance, a civil engineer at a large contracting firm (CE_CON) clearly stated the issue: *"The* *main challenge in increasing the percentage of RAP reuse is discontinuity in the material. The material comes from various projects and creates variability, and it can't be mixed without ensuring that the quality is good and consistent."*

Stakeholders also highlighted inconsistent quality rules and excessive diversity in mixtures across projects and regions as reasons for uncertainty. A municipal representative said (TS_GB), *"In urban areas, there is a wide variety of asphalt mixtures of different quality. Due to the lack of quality rules for asphalt granulate, there is no continuous quality of the asphalt with a high percentage of asphalt granulate."*

Also explained by a material advisor from RWS (MA2_GB), *"Right now, each town has its own specific requirements...... that leads to a huge variety in asphalt types. If we reduce that variety, it becomes much easier to monitor quality and share knowledge....... Fewer mixtures would make it easier for the people working in the sector to manage and understand the materials being used."*

Lack of long-term performance monitoring of mixes with RAP

The next technical challenge is the lack of reliable data and validation methods to guarantee the long-term performance of asphalt mixtures with high RAP content. This is supported by many stakeholders, for instance an asset manager from one of the provinces (AM_GB) stated, *"The biggest challenge is to produce and process asphalt mixtures with RAP without compromising the lifespan compared to the same mixture without RAP."*

A sustainability researcher in a research and knowledge institute noted, *"There's a clear knowledge gap in terms of how functionality is affected when recycled content increases.... To find out, you have to monitor long-term 10 to 15 years."- (SR1_RKI)*

A material advisor also explained how there is an absence of monitoring and sharing of data, *"There are several projects that utilize very high percentages of RAP but there is no monitoring of what happens, long-term performance, and there is no sharing of any findings."- (MA_RKI)*

Lack of standardized technical guidelines

The next barrier is the lack of uniform technical guidelines for the use of RAP. Stakeholders from both government and industry pointed to the need for technical guidelines for mixture composition, application, and performance tracking and validation. A material advisor from RWS (MA1_GB) stated, *"If you track those life expectancies, you can move from validation to standardization, instead of every contractor doing it its own way. At some point, you need technical guidelines, so everyone follows the same procedure."*

Also a sustainability advisor from RWS noted how the lack of technical guidelines creates issues for municipalities that want to start utilizing RAP but don't have a starting point, *"Many municipalities want to use RAP, but they don't have guidelines, they don't know when or how to start."- (SA_GB)*

Milling and Processing Limitations

Stakeholders emphasized how milling and processing practices affect the quality and reusability of RAP. For instance, a material advisor at RWS (MA2_GB) explained, *"To minimize traffic congestion, we only allow work at night and on weekends. That narrow time window creates a problem for reclaimed asphalt, especially if you want to separate and harvest just the surface layer. There is not enough time for that."*

A representative from an asphalt plant explained how milling changes the gradation of the material and what effect it has, *"After the milling process, the material becomes finer. Stones break, and you lose the original structure. So, if you want to reuse that material in the same type of mixture, you'll need to add more coarse material and reduce the fine particles."*- (R&D2_APS)

Another challenge is the loss of material during post-milling processing of RAP as explained by a representative from an asphalt plant, *"During processing about 30-40% of the reclaimed asphalt gets thrown out. You lose that material."*- (R&D2_APS)

While RAP is typically processed into 8-16mm, 5-8 mm, and 0-5 mm fractions, further complications to reuse are posed by the 0-5mm RAP fraction, as it is difficult to reincorporate at high percentages due to its very small particle size. A material advisor from RWS (MA1_GB) pointed out this challenge, specifically in the case of ZOAB also known as porous asphalt, when milled, it produces a large fraction of fine particles (0-5 mm) which are harder to reuse. *"In a 60% RAP mix, you get about a 20% 0–5 mm waste stream, which is only used in small amounts in base layers; the rest goes to foundations or is managed as waste.... That 0–5 mm ZOAB fraction is our biggest waste-stream problem."*

Challenges in reusing RAP in surface layers

Stakeholders highlighted that while its common practice to use RAP in base and binder layers, its integration in the surface layers is limited. For instance, a material advisor from RWS mentioned (MA2_GB), *"You can use much more reclaimed asphalt in Stone Mastic Asphalt (SMA) and Asphalt Concrete (AC) surface layers than in porous asphalt. So, in surface layers, I'd say we see reclaimed asphalt percentages ranging from 0% to 40%."*

Porous asphalt is more susceptible to inconsistencies in gradation as emphasized by someone from an asphalt plant (R&D2_APS), *"...in porous asphalt, sand is a sensitive fraction...if the reclaimed material contains too much sand, you can't create a compliant new mix..."*. This sensitivity stems from the fact that even a small deviation in the fine fraction, like excessive sand content or altered bitumen, can compromise the mechanical stability of the mix (Modarres et al. 2014). Additionally, porous mixes often require performance-based mix design with specific skid resistance, permeability, and noise performance standards. These targets are difficult to meet with RAP, especially when the source of the material varies.

Logistical Challenges

Stakeholders highlighted three interrelated themes for logistical challenges: limited supply of RAP compared to demand, storage capacity issues and planning uncertainties. Firstly, the limited availability of RAP is a significant issue in relation to the growing demand for circular road construction. As one advisor at RWS (CEA_GB) noted, *"There is not that much reclaimed asphalt available. We still produce more asphalt than we reclaim. So, there is a limit to how much reclaimed asphalt can be used."*

A representative from an asphalt plant explained that planning is also an issue as reuse requires knowing when, where, and what type of RAP will become available, *"Planning is difficult because you need to know which material you will have available in time, you need planning for when the RAP becomes available."- (R&D1_APS).* A sustainability consultant from an engineering consultancy firm explained that further complications occur when multiple projects are running in parallel, *"When there are many projects running simultaneously and the demand for recycled asphalt is high, it can be difficult to get enough recycled material because the supply is limited."_ (SC_ECF).*

Another challenge is the limited storage space available in asphalt plants, a representative from an asphalt plant emphasized these limitations, "Storage is a major problem...you need storage space to collect all that milled material and bring it to the plant..So you need to store it maybe for a week or a month and then use it in another project. But storage is expensive. So, lack of storage is a big barrier." To add to this, efforts to separate RAP by type to maintain quality, further increase requirements for space as explained by a material advisor at CROW (MA_RKI), *"If you're going to separate all the different asphalt mixtures when milling, then at the asphalt factory you'll need a lot more space for all the different stockpiles."*

Environmental Concerns

A new challenge emerged during the interviews- environmental constraints around emissions during processing of RAP. A sustainability consultant at an engineering consultancy firm mentioned, *"There are also environmental concerns, such as benzene emissions. It's a significant issue. We need to address the benzene emissions from asphalt recycling plants....... other emissions such as greenhouse gases... and polycyclic aromatic hydrocarbons (PAHs) also pose challenges."* Benzene is a hazardous substance found in crude oil which is used in manufacturing of asphalt. Besides its environmental effects, benzene is also carcinogenic in nature (IGD, 2023). It is released in an asphalt plant specifically in drying and heating phase of the production process when RAP is used (VBW, 2021). PAHs are pollutants released due to incomplete combustion of fuel and are present in bitumen fumes during high-temperature processing of bitumen. They are also carcinogenic in nature. RAP is linked to the excessive PAH and benzene emissions and several asphalt plants who have not been able to comply with the emission limits set by legislation were forced to close their operations (RTV, 2022; GLD, 2021)

Cultural Barriers

Limited Local Capacity and Strategic focus on RAP

The view of the national level and the market parties is that there is a lack of prioritization of asphalt and capacity and experience for RAP utilization at the local level. A Circular Economy advisor at RWS (CEA_GB) mentioned, *"Collaboration can be enhanced when* *municipalities prioritize it (RAP). Right now, I don't think it's on their priority list, their focus is more on reusing other elements, like pavement tiles and cobblestone."*

This is further linked to a knowledge and capacity gap at the local level regarding RAP reuse. A material advisor at CROW explained that circularity advisors in municipalities are responsible for many asset types which leaves little room to focus specifically on asphalt, *"It's very hard to find the right people with the right knowledge in municipalities.....for a project owner at a municipality they're responsible not only for the asphalt....They're dealing with too many things at once. They don't have the capacity to focus specifically on reclaimed asphalt."- (MA_RKI).* This was agreed upon by a Circular Economy Advisor from RWS (CEA_GB), *"The average municipality might have one person focused on sustainability in infrastructure, which is already a large task."* This capacity constraint leads to risk-averse behavior and a tendency to rely on existing norms and standards rather than experimenting with high-RAP content mixes.

The municipal perspective on this, specifically the Municipality of Amsterdam, is that they acknowledged the potential of increased access to RAP but pointed out limitations in supply and quality assurance. *"Calculations have been made that show that not enough RAP is released to build 100% circular roads. New material must always be added to the chain."- (TS_GB).* These insights suggest that not all municipalities are resistant to RAP reuse but that they require institutional support, information structure, and guaranteed performance to engage with RAP more confidently.

Lack of information and knowledge sharing

One persistent cultural barrier is the lack of sharing of information and knowledge. Contractors, in particular, are reluctant to share data on RAP mixtures, techniques, and innovations as they might lose their competitive edge in the market. As a material advisor from RWS noted, *"Some contractors treat their mixture development as their business model. They don't want to share all their information because it gives them a competitive advantage. That limits transparency."- (MA2_GB).* One pavement engineer from an engineering firm also agreed, *"Contractors don't like to share their knowledge. If they have a good idea, they won't tell it to the others. That's a problem."- (PE2_ECF).*

A representative of an asphalt plant emphasized that the development and validation process of a new mixture, with high RAP content, is a long and resource intensive process, which further discourages transparency. *"When we validate a mixture, the entire process takes two to three years. That's a lot of time and effort, so why would we give it away to others? And then, if something goes wrong, it damages the reputation of the product we worked so hard on."- (R&D2_APS)*

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worked so hard on."- (R&D2_APS). This protective behavior is further emphasized by how contracts are structured. Sustainability performance is linked to project awards, as contracts may reward higher RAP percentages incentivizing innovation but disincentivizing open sharing. As explained by someone from CROW (MA_RKI), *"Many contracts now offer incentives to score higher on sustainability. So, contractors are encouraged to increase their RAP use to win projects. But once you win with that data you don't want to share it, because it could help you win the next project too. So, sharing data becomes risky."*

Stakeholders also emphasized the lack of centralized systems for data sharing. For instance, a researcher (SR2_RKI) explained, *"Project-level data on the quality, performance, and lifecycle benefits is fragmented and not easily accessible. As a result, valuable information remains siloed with contractors or suppliers, with no uniform system for storing or sharing it."* Similar statements were made by a contractor (CE_CON) who said, "*Even though there is enough information sharing, the market can be improved by sharing current practices publicly. It would be helpful to have a standardized platform where such information can be exchanged."*

Another issue is the lack of fundamental knowledge about road assets. A material advisor from RWS (MA2_GB) explained, *"We use many different systems to store data, not one single system. So, if you want to know what's in an older road what kind of stones or asphalt were used it's very difficult. Once it's milled, you don't always know what kind of reclaimed asphalt you have.*

Lack of Stakeholder Collaboration

Stakeholders expressed contrasting views on the nature of collaboration regarding RAP reuse. A sustainability expert from an engineering and consultancy firm (SC_ECF) described the systematic disconnect across governance levels, *"The world of Rijkswaterstaat (RWS) and the world of municipalities and provinces follow different rules. They don't work together. Another important thing is that RWS uses a different type of asphalt than the municipalities and provinces."* Others emphasized the need for inter-governmental collaboration, as highlighted by a representative from an asphalt plant (R&D1_APS) who explained the benefits of improved coordination among road authorities, *"If road owners worked more closely together and thought about how to use RAP regionally, then there would be more available and better insight into when RAP is available. So yes, collaboration isn't common practice right now, it could be better."*

Furthermore, a material advisor from RWS also stressed that without a shared national roadmap and consistent collaboration between neighboring authorities, circular initiatives, those involving RAP reuse, will remain isolated and limited (MA1_GB), *"Fragmented collaboration is a key issue, if RWS drives sustainability but its neighbor doesn't, the overall impact is minimal."*

At the same time, not all interviewees agreed with this point. For instance, a Circular Economy Advisor from RWS presented a more optimistic view as he mentioned, *"I think you can say there's a lack of collaboration because it could always be better, but if you ask* *anyone, they'd say, "We're already doing quite a lot."* This view was further supported by a contractor (SM_CON), *"The asphalt sector is one of the only sectors where all stakeholders really work together to get the maximum sustainability out of the product. If lack of collaboration existed, it would be clear that RAP wouldn't be used, but that's not the case."*

These diverse perspectives reveal a nuanced picture: while collaboration exists through formal platforms and long-standing practices, its effectiveness is uneven and heavily dependent on governance level and regional context.

Regulatory Barriers

Misalignment of Goals

One recurring theme during the interviews was the misalignment in sustainability goals and priorities. For instance, one sustainability advisor from RWS (SA_GB) mentioned, *"Municipalities use standard specifications that often exclude RAP. We're transitioning, but there's no unified guideline on when and how to start..... Many municipalities want to use RAP, but they don't have guidelines, they don't know when or how to start."* This was echoed by a material advisor from RWS (MA1_GB), who explained, *"Because each municipality sets its own goals, contractors face a patchwork of requirements: one municipality wants X durability, another wants Y. So yes, there is misalignment in end-goals, even if everyone nominally seeks the same outcomes."* This challenge is compounded by the large number of municipalities in the Netherlands who have their own capacity and priorities. This reflects the absence of a unified direction across governance levels regarding RAP reuse.

Fragmented regulations and lack of standardization

A major concern mentioned during the interviews is that even though standard guidelines for asphalt exist in the Netherlands. This was highlighted by a material advisor from RWS (MA1_GB), *"European norms don't specify which types of RAP or what requirements must be fulfilled, or how often checks should happen. They treat it as a low-value material usually used in base layers, and they don't extend standards to surface layers."* This leads to each party effectively creating their own standard. An asphalt plant representative (R&D1_APS) reinforced this, *"There are no official standards for using RAP in surface layers. So, we made our own. What we try to do is make our own standards the standard in the Netherlands."*

Another issue is the lack of standardized validation methods. A material advisor from RWS (MA2_GB) explained, *"The validation process includes laboratory testing, test sections without traffic, and later with traffic. It's a long process. Some contractors have validated such mixtures for porous asphalt, but others haven't."* This project-by-project validation procedure is very time and resource consuming and also results in unequal reuse opportunities.

Restrictive and Inconsistent Regulatory Standards

Unlike the general absence of clear standards, RAP reuse in surface layers faces a specific challenge, which is strict regulations. As described by a sustainability consultant at an engineering consultancy firm (SC_ECF), *"In the Netherlands, there are strict regulations* *about how much recycled asphalt can be used in the top layer of roads. The regulations limit the percentage of recycled asphalt that can be used in the top layer, even though you might be able to use more in the base or subbase layers. So, we need to work within these standard requirements."*

Material specific requirements add to these constraints as a material advisor from RWS (MA2_GB) mentioned, *"Contractors are only allowed to use crushed stones with high polishing resistance in the top layers."* The material advisor further explained, *"For top layers, particularly porous asphalt, we have strict standards, for example, the stones used must be 100% crushed and have a polishing value of 58 or higher."- (MA2_GB).* These insights highlight how strict technical requirements, especially for surface layers, limit the adoption of RAP.

Constraints in the ownership of RAP

The next challenge concerns the ownership of reclaimed asphalt after the milling process. While the issue of RAP ownership is contractually regulated and fits within the regulatory challenge heading, it has market implications, as apart from defining legal responsibility, it also shapes contractor incentives. A material advisor from RWS (MA1_GB) explained the current model of ownership, *"Our contracts include a clause stating that, once the contractor mills off the asphalt and loads it onto their truck, they become the owner of that RAP."*

From the perspective of the road authorities, this transfer of ownership poses imitations, as explained by a Circular Economy advisor from RWS (CEA_GB) explained, *"Once it's reclaimed, it's the contractor's material, and we lose control over how it is distributed or reused."* He further explained *"If the road owner owns the material, they can specify demolition methods, required quality, and designate depots (A or B) where RAP is processed to the desired quality. Then material could be sold to the highest bidder accordingly.*

Contractors provided contrasting views. A sustainability manager from a contracting firm said that the existing system works efficiently for them and aligns with commercial incentives, *"When the ownership shifts to the contractor, using RAP makes the mixture more profitable. So, the contractor will naturally want to use it because it's cost-effective. There's no need to change anything in that system."- (SM_CON).* This contractor driven model allows the firms to stockpile RAP in their asphalt plants and reuse it in mixtures based on internal needs. Another contractor noted that, *"It should be the road authority's responsibility because it's their material." They are the owner of it, so they should also reuse it."* Therefore, while acknowledging the logic behind client ownership of the material, they still advocated greater responsibility and circular thinking from the road authority itself.

Therefore, there is no consensus on the optimal ownership model. This suggests there is a need for further institutional clarification and reform like conditional ownership models or shared responsibility mechanisms to ensure that RAP is treated as a strategic and valuable resource.

Material Traceability Challenges

The next challenge is the lack of a centralized oversight for RAP quality and availability tracking. Currently much of the quality control responsibility lies with the contractors as a material advisor from RWS mentioned, *"There's no centralized body to monitor municipal sections, quality tracking is left to contractors who want to prove their products meet the expected lifespan and quality."- (MA1_GB)*

It was mentioned that without centralized tracking or coordination of the incoming and outgoing RAP material, a big share of the material remains unaccounted for. To overcome this, some stakeholders suggested systematic changes in how RAP data is recorded and exchanged. A sustainability consultant at an engineering consultancy firm suggested, *"What we need in the Netherlands is a system that uses material passports. This would allow us to track which materials were used when and where, so we could know the quality of the material 10-15 years down the line."* While several stakeholders pointed out the need for such a system, no one mentioned an existing framework addressing this issue.

Constraints on tar content in RAP

Another issue pointed out by some stakeholders was the presence of tar in reclaimed asphalt. But RAP that contains tar is considered hazardous and cannot be used in new mixes. A material advisor at RWS explained that once the reclaimed material becomes the property of the contractor, *"Under environmental law, they're then responsible for ensuring that it is handled safely like testing for contaminants like tar (by archive research) before milling and managing any hazardous material appropriately."*

The question of who holds responsibility for identifying tar remains contested. According to a representative from the research and development department of an asphalt plant, it's the road owner's responsibility to make them aware of the tar content in their reclaimed asphalt, *"We don't allow tar in our process, so this has to be avoided. That means road owners are obliged to investigate whether there's tar in the asphalt, because it's their material."- (R&D1_APS).* At the same time, producers emphasized the financial burden, noting that disposal of tar-containing asphalt is significantly more costly: *"It costs a lot more money to clean up tar-containing asphalt than to reuse clean RAP. So, the traceability of the material that's something we want to know, and that data isn't available."- (R&D1_APS)* Others argued that the contractor ultimately bears the liability once ownership is transferred. A business unit manager from an engineering consultancy explained, *"The materials in the asphalt if there's tar in it, for instance, then the contractor has a problem, because it can't be reused and they have to pay for removing it."- (BUM_ECF)*

Market Barriers

Procurement prioritizes cost

Despite the cost effectiveness of RAP, interviewees stressed the prioritization of cost over circularity and innovations in procurement procedures. This is not the case always, as mentioned by a representative from an asphalt plant who, when asked do tenders still prioritize cost over circularity, said that, *"Sometimes, yes. Not always but in most cases, it's still mostly about cost."- (R&D2_APS)*. A sustainability advisor from RWS also agreed that

"Contract models also need to change: too much emphasis is on price rather than quality. As a government, we must demand quality, not just the lowest cost."- (SA_GB).

These perspectives show that while RAP reuse is economically viable, procurement systems skew towards short term savings, which discourages experimentation, limits innovation & standardization.

Inconsistent use of Environmental Incentives

The Environmental Cost Indicator (or Milieu Kosten Indicator (MKI)) was frequently cited during interviews as a driver within procurement processes. A circular economy advisor from RWS (CEA_GB) explained, *"In our tenders, we add an environmental cost indicator. The more reclaimed asphalt used in the design, the lower the environmental cost indicator. This method is very effective in promoting the use of reclaimed asphalt."* It was further supported by a provincial actor who mentioned, *"MKI as an award criterion stimulates sustainable choices."- (AM_GB)*

However, a member of the research and development department of an asphalt plant described how MKI is not often utilized by municipalities, however, they should consider some simpler reward mechanisms to reward sustainability as it will provide incentive for reusing RAP, *"Right now, sustainability is rewarded using the MKI value, which Rijkswaterstaat uses a lot. But for municipalities, it's harder to use because it's complex. Maybe they need a simpler system. In any case, find a way for them to objectively reward sustainability that would help."- (R&D1_APS)*

Monopolized value chain

Another observation that was made was that some general contractors frequently own and maintain their own asphalt plants which help them maintain material supply and reuse strategies. A circular economy advisor from RWS (CEA_GB) noted that, "*I think the general contractors who own the asphalt factories are also the ones who end up storing and using the reclaimed asphalt. This creates a very monopolized value chain."*

Even though this structure leads to efficiency gains and might lead to better collaboration as there are only few major players to collaborate with, it raises questions about distribution in responsibility in material reuse. It reinforces closed innovation systems where those who control production are better positioned to win tenders.

Appendix H: Case Projects

Project A: Middenweg Project Amsterdam

Project Description

The Middenweg project involves the City of Amsterdam as the client and Bam Infra as the contractor. It involved major maintenance of various pavements along Middenweg. This project involved major maintenance works on the Middenweg in Amsterdam executed by

BAM Infra, started in 2024. The sidewalks, parking spaces, bicycle lanes, and driving lanes were renewed. Asphalts on or immediately adjacent to the streetcar tracks were outside the project scope. The project implemented several sustainable asphalt solutions. For instance, Low energy asphalt concrete (LEAB) was utilized for all sub, intermediate, and surface layers. LEAB means the temperature for producing the asphalt mix was lower, around 110 degrees Celsius (BAM, 2020), compared to 165 degrees Celsius used in Hot mix asphalt. This resulted in reducing CO2 emissions by around 30% compared to conventional hot mix asphalt. The base and binder layers were made with 70% reclaimed asphalt and secondary aggregates, resulting in achieving nearly 93% secondary material in these layers (compared to the standard 50%). In the surface layers, around 60 % RAP was utilized, which is 30% more than what is allowed by RAW guidelines.

RAP Reuse

A proposal was made by BAM Infra for the project to apply several sustainable asphalt mixtures. These include:

- Warm asphalt mix (LEAB technology): It was applied in all layers saving approximately 30% CO2 e^- emissions compared to hot mix asphalt.
- Base and intermediate layers utilized 70% RAP combined with secondary aggregates like Pouw bricks (tar-free crushed stone). This resulted in mixes with at least 93% secondary material content.
- Surface layer (AC Surf) utilized 60% RAP which exceeds the standard RAW provisions (normally 30%)
- The sustainable mixture proposals were validated at TRL-9 level for LEAB techniques.
- Separate milling of Middenweg's surface layer was done to secure high quality RAP fractions for reuse in surface layers.

This project implemented a range of sustaibnable asphalt mixes, as described in the memo provided by BAM Infra. An overview of the mixes is shown in Figure 8. It describes a refernce prposal with standard allowable RAP content and a sustainable option (which was utilised in the project) with increased RAP content in all layers. Quantities are based on an area of 1000 m^2 .

		reference construction	amount of asphalt			secondary material	
35	mm	AC 11 surf DL-C	87,5	ton	30%	26,25	ton
55	mm	AC 16 bin TL-C	137,5	ton	50%	68,75	ton
70	mm	AC 22 base OL-C	175,0	ton	50%	87,50	ton
			400,0	tonne		182,5	tonne
					percentage of secondary material	46%	

		reference construction	amount of asphalt			secondary material	
35	mm	AC 11 surf DL-C	87,5	ton	60%	52,5	ton
55	mm	AC 16 bin TL-C	137,5	ton	93%	127,88	ton
70	mm	AC 22 base OL-C	175,0	ton	93%	162,75	ton
			400,0	tonne		343,1	tonne
					percentage of secondary material	86%	

Figure 8 Asphalt Mixes: Project A

Project B: Rijkswaterstaat Groot Variabel Onderhoud (GVO) West Nederland Noord (WNN) Project

Project Description

This project is large scale maintenance project commissioned by Rijkswaterstaat in the Amsterdam and North Holland region. Unlike new-built or road widening projects, this program focuses solely on the maintenance which involves replacement of the surface layer and, where required, one or two base and binder layers. Bam Infra was responsible for both engineering and execution. The project is associated with a significant amount of asphalt volumes, approximately 220,000 tons. This cover works already completed in 2025 (started in 2023) and planned for 2025-2026. About 45% of this total asphalt volume constitutes porous asphalt (ZOAB), which is a standard asphalt type for national highways in the Netherlands. It includes DZOAB 16, 2L-ZOAB 16 (the under-layer of a two layered porous asphalt), 2L-ZOAB 8 (the top layer) and 2L-ZOAB 5 (also a top-layer). From a circular perspective, the project utilizes 41% secondary materials. The contractor and the client had validated asphalt mixtures with much higher RAP content- nearly 60- 70% in ZOAB layers, which could have reduced primary material use by approximately 37,000 tons and lifting the overall share of secondary materials to 58%. However, this could not be achieved due to some challenges which are described in the sections below.

RAP reuse

Figure 9 provides an overview of the mixes used in this project. The table lists the total production of hot mix asphalt (HMA) and warm mix asphalt (WMA) for different mixture types along with the percentage of primary materials used. In the table, the notation PR refers to partial recycling, so it demonstrates the percentage of RAP in the mix. For instance, the amount of RAP in AC bin/base and LEAB bin/base mixes is 60% and that in surface layers AC Surf is 30% with ZOAB mixtures also containing 30% RAP.

Total percentage of primary materials used is 59% and secondary material used is 41%. The project had technical clearance to use more RAP in certain mixes:

- 40,000 tons DZOAB: 30% → 70% = 40% extra= 16,000 tons of primary materials could be spared on top of what was already done
- 40,000 tons 2L-ZOAB 16: 30% → 70% = 40% extra = 16,000 tons of primary materials could be spared on top of what was already done
- 13,000 tons 2L-ZOAB 8: 0% → 40% = 40% extra = 5,200 tons of primary materials could be spared on top of what was already done

Total missed opportunity: 37,000 tons of primary materials. This means primary/secondary ratio could have shifted from 59%/41% TO 42%/58%.

project_name	totaal HMA	totaal WMA	primair %
GVO WNN A-Wegen 2023-2025			
DZOAB 16 70/100 30%PR BSt 10+	42.118		70%
2L-ZOAB 16 70/100 30%PR BSt Fluisterfalt	39.685		70%
2L-ZOAB 8 70/100 BSt Panacea	12.999		100%
AC 22 Bin/Base 35/50 60% PR BSt Cat C	8.645		40%
SMA-NL 11B 70/100 BSt	5.393		100%
AC 16 surf 50/70 30%PR BSt	4.662		70%
2L-ZOAB 5 PMB BST	4.594		100%
Asfalt tijdelijk mengsel	3.000		100%
AC 16 OL -TL (alle klasse) 35/50 + PR (	1.683		70%
AC 22 OL -TL (alle klasse) 35/50 + PR (	1.605		100%
AC 22 bin/base 30/45 60%PR BSt/ZM	336		40%
AC 16 bin/base 30/45 60%PR BSt/ZM	238		40%
LEAB 16 bin/base 40/60 60% PR sbP		6.770	11%
LEAB 16 bin/base 40/60 60%PR BSt		78.219	40%
LEAB 22 bin/base 40/60 60% PR sbP		595	20%
LEAB 22 bin/base 40/60 60%PR BSt		5.914	40%
LEAB 22 bin/base 40/60 70%PR BSt		388	30%
Totaal	**124.958**	**91.886**	**59%**

Figure 9 Asphalt mixes: Project B

Project C: A1 Apeldoorn-Azelo Project Rijkswaterstaat

Project Decsription

The A1 Apeldoorn-Azelo Project is part of the broader expansion and reconstruction of the A1 highway in the Netherlands. This project is a large-scale highway expansion and maintenance project commissioned by Rijkswaterstaat with Heijmans as the contracting firm. The project forms part of the E30 European highway corridor and involves the upgradation of nearly 55 km of roadway between Apeldoorn and Azelo. The reconstruction took place in phases, including the Twello-Rijssen and Rijssen-Azelo sections, with further works (Apeldoorn-Twello) starting in 2022. The main goals were to improve accessibility and road safety while integrating sustainability measures in design, construction, and maintenance. Major reconstruction activities include adding extra lanes, building parallel roads, and constructing new bridges. From a circularity perspective, The Best Price Quality Ratio (BPKV) was used by RWS, which is a very commonly used procurement procedure used across projects. This means that instead of selecting the contractor solely based on the lowest bid, BPKV allows the client to weigh both price and qualitative criteria like innovation, sustainability, safety etc. This gives a fictional discount, which is if a contractor scores highly on sustainability (like lower MKI value) their bid receives a fictional monetary deduction in the tender scoring. For this project, Heijmans received a 50% reduction on MKI. With regards to asphalt, the project utilized nearly 40-60% RAP in asphalt mixes in different layers (for instance 40% in ZOAB as described in Appendix F). Apart from this, some pilot sections were tested with three new mixes in the surface layers. Out of the three, two were TRL level 9 and one was TRL level 8 which required further testing before full scale implementation.

RAP Reuse

The project utilized a wide range of asphalt mixes across different pavement layers. The Figure 10 summarizes the mixtures used in the surface (deklaag) layer, binder/base (tussenlaag/onderlaad) layer.

- In surface layers, mixtures included 30%-50% RAP (example, AC 16 Surf and 2L-ZOAB 8)
- In base and binder layers, higher RAP contents of 60% were common (AC 22 Bin/Base 35/50 60% PR, LT 16 Bin/Base 40/60 60% PR)

In addition to standard certified mixtures, the project also tested TRL 9 mixes like

- 2L-ZOAB 8 PmB 40%PR BSt/KaZa Advansa
- LEAB 2L-ZOAB 16 60%PR
- LEAB DZOAB 16 50/70 60%PR BSt/KaZa

The DZOAB16 and 2L-ZOAB 16 were certified on a TRL9 level, the 2L-ZOAB 8 needed a bit more testing before certification on TRL 9. Beyond RAP reuse, the project integrated broader sustainability practices: Application of warm mix asphalt (110–130 °C) instead of conventional hot mix. Then, reuse of concrete granulates (30%), experiments with circular concrete (e.g., Smart Crushing, geopolymer applications) and use of zero-emission equipment on-site (pilot stage).

Deklaag	
	25501 AC 16 surf 40/60 50%PR BSt
	25317 AC 16 surf 40/60 30%PR BSt
	83447 2L-ZOAB 8 PMB 40% PR Twinlay
	82541 2L-ZOAB 16 50/70 40% PR Twinlay
	84940 D-ZOAB 16 70/100 BeStone 40% PR
Tussenlaag	
	20060 AC 22 Base Bin 35/50 60% PR BeStone
	20069 AC 22 Base Bin 40/60 60% PR Greenway LE (healing 2,65)
	20460 AC 16 Base Bin 35/50 60% PR BeStone
	20469 AC 16 Base Bin 40/60 60% PR GreenwayLE
	20756 AC 16 Base Bin PMB EVA 50% PR BeStone
	15699 LT 16 Bin/Base 40/60 60%PR sbP/ZM
	16699 LT 22 Bin/Base 40/60 60%PR sbP/ZM (healing 3,76)
Onderlaag 3	
	20060 AC 22 Base Bin 35/50 60% PR BeStone
	20069 AC 22 Base Bin 40/60 60% PR GreenwayLE
	15699 LT 16 Bin/Base 40/60 60%PR sbP/ZM
	16699 LT 22 Bin/Base 40/60 60%PR sbP/ZM (healing 3,76)
	5. AC bin/base 50% PR
Onderlaag 2	
	20060 AC 22 Base Bin 35/50 60% PR BeStone
	20069 AC 22 Base Bin 40/60 60% PR GreenwayLE
	20070 AC 22 Base Bin 30/45 70% PR BeStone
	20260 AC 22 Base Bin 40/60 60% PR BeStone
	20269 AC 22 Base Bin 40/60 60% PR Greenway LE Gold (healing 3,7
	20460 AC 16 Base Bin 35/50 60% PR BeStone
	20469 AC 16 Base Bin 40/60 60% PR GreenwayLE
	15699 LT 16 Bin/Base 40/60 60%PR sbP/ZM
	16699 LT 22 Bin/Base 40/60 60%PR sbP/ZM (healing 3,76)
	5. AC bin/base 50% PR
Onderlaag 1	
	20060 AC 22 Base Bin 35/50 60% PR BeStone
	20069 AC 22 Base Bin 40/60 60% PR GreenwayLE
	20070 AC 22 Base Bin 30/45 70% PR BeStone
	20260 AC 22 Base Bin 40/60 60% PR BeStone
	20261 AC 22 bin/base 35/50 60%PR BSt Cat C (healing 3,91)
	20269 AC 22 Base Bin 40/60 60% PR Greenway LE Gold (healing 3,7
	16698 AC 22 Bin/Base 30/45 60%PR Bst/ZM
	15699 LT 16 Bin/Base 40/60 60%PR sbP/ZM
	16699 LT 22 Bin/Base 40/60 60%PR sbP/ZM (healing 3,76)
	5. AC bin/base 50% PR

Figure 10 Asphalt mixes: Project C

Appendix I: Interview Quotes: Project level analysis of governance characteristics

In this section, detailed quotes from the various interviews conducted on the second wave are provided. The quotes are placed and explained under the four main governance characteristics of MLG and within each of them, the general projects practices and the three case studies are provided as subheadings. The quotes are provided under each subheading. First, an overview of the interviewees is given in Table 10.

Table 10 Overview of the stakeholders interviewed: Wave 2 (author)

Number	Role	Organization	Perspective	Abbreviation
1	Manager of road engineering and consultancy department	BAM Infra	Contractor (Project A & B)	CON1
2	Head of advisory and development	Van Gelder BV	Contractor (general sector perspective)	CON2
3	Specialist Operational Excellence	BAM Infra	Contractor (general sector perspective)	CON3
4	Asset Manager, Highway Network	Rijkswaterstaat	Client (general sector perspective)	CLT1
5	Technical Manger (Project department)	Rijkswaterstaat	Client (Project C)	CLT2
6	Technical advisor (maintenance and heavy maintenance, focus on asphalt)	Rijkswaterstaat	Client (Project B)	CLT3
7	Technical advisor (maintenance and heavy maintenance, focus on asphalt)	Rijkswaterstaat	Client (Project B)	CLT4

Authority in Decision Making

General Project Practices

Decision making authority lies with the client**,** as explained by a contractor, *"They determine how much we can use in our asphalt mixtures. And if they don't ask for it, we're not allowed to use it."- (CON2).* Another contractor supported this claim and further explained the reason why clients are reluctant to increase the content of RAP in a mix, *"In general, it hasn't happened often that a road authority sets a minimum RAP content, a maximum RAP content is much more common. Very often, a road authority states they do not want recycling in surface layers...I wouldn't exaggerate if I said that over 30% of all road authorities do not want recycling in surface layers. They don't trust the quality of the final mix."- (CON1)*

Clients agreed with this, as explained by someone from RWS (CLT1), *"As long as they (contractors) comply with our demands, it's up to the contractor. The asphalt producer must ensure their mix is validated by RWS. Once it's validated, they can use it in our projects."*

Clients are reluctant to allow high RAP content due to long-term performance risk as a contractor explained, *"The client is reluctant because it's new, and I think they believe the quality is not the same...... They're afraid that a road with new material may last 25 years, but with high reuse it might need replacement after 20 years."- (CON3)*

Project A: Middenweg Project Amsterdam

In this project, the decision-making process involved both the client and the contractor, and subsequently the asphalt plant, during the discussion on the content of RAP in the mix to be used in this project. As explained by the contractor, *"For the surface layers, the national regulation sets a 30% RAP limit. However, in consultation with the Municipality of Amsterdam, we developed a framework to deliver a high-quality asphalt mixture with 60% RAP in the Middenweg project. We closely inspected the milled materials coming from the project and designed a mix using only those materials."- (CON1).* The contractor further explained that, unlike most projects, where the regulations and the client set the requirements and limits for RAP reuse, this case focused on technical possibilities, *"In the Amsterdam project, we didn't talk about regulations, we just talked about what's possible and what's the best we can do. We focused on quality and on achieving the biggest improvement we could. -(CON1)*

Project B: Rijkswaterstaat GVO WNN Project

In this project the decisions related to the reuse of RAP were based on the client's requirements and the contract. The contractor then was allowed to make decision on their own about the content of RAP in the mix, but remaining within the regulatory limits set by the client, *"In the Rijkswaterstaat project, we only talked about regulations , what's possible and what's not.....Rijkswaterstaat is a very large organization, and it relies heavily on guidelines and contracts, which are basically the same for every project."- (CON1)*. He further explained that *"Rijkswaterstaat wasn't involved in decision-making, they were simply informed about our plans. As long as we met all requirements, they couldn't say no."- (CON1)*

From the client's perspective, the main control mechanism was the MKI value and already validated mixtures, as explained by the client in this project, "*The contractor has to meet a certain MKI value, that's the environmental performance value they committed to when they won the contract. Depending on which asphalt recipes have been approved by us, they can use a certain amount of recycled asphalt within that limit."- (CLT4)*

Project C: A1 Apeldoorn-Azelo Rijkswaterstaat

In this project, the decision making authority was with the client and they set requirements for the reuse of RAP in this project, as explained by the client in this project, *"Well, it's more that we have some specific demands in the contract, to make sure that the mixture is safe enough....If a contractor can show that their specific mixture meets those demands, then it's OK for us."- (CLT2).* The client confirmed that the choice of mixture and the proportion of RAP was up to the contractor, provided that it met the requirements and was validated. *"The contractor has to make sure that in the end, the asphalt that is on the highway meets the requirements, and he has to prove that it meets the requirements." -(CLT2)*

Jurisdictional Boundaries

General Project Practices

In the Dutch road infrastructure sector, the jurisdictional boundaries for RAP reuse are clearly defined. Someone from the client's side explained this and also explained that budget is one of the main reasons for this separation, *"We mostly work within our own management area. The boundaries between our area and someone else's are quite strict, largely because of how budgets are allocated. We receive a budget for maintaining our area, not for municipalities or provinces. They handle their own networks, we handle ours."- (CLT1)*

Another reason for this separation is the different types of asphalt used by road authorities. Someone from RWS explained this by mentioning, "*On highways, we use the ZOAB mixture more, while on provincial and municipal roads, it's the dense asphalt mixture which is used. This plays a role in the differences in knowledge and application."- (CLT2)*

A contractor explained that this means there is hardly any sharing of resources, specifically RAP material, between different levels of governance, *"In the context of using each other's materials in projects? No, there's no communication whatsoever between the different levels of government."- (CON 1).* Another representative from the client organization further imposed this point by explaining that even when there is some cross-level collaboration, it is mostly regarding knowledge sharing and not in joint projects, *"I think there is some cross-level collaboration, but it's more in the area of knowledge sharing than in actual joint projects. In the Netherlands, it's quite strict, highways are under Rijkswaterstaat, and provincial roads are managed by provinces. It's a clear, hard separation. That separation is made to ensure everyone knows their responsibilities."- (CLT2)*

Coordination & Communication Mechanisms

General Project Practices

Contractors explained communication with the client as minimal, once the requirements are set, with most of the communication taking place with the asphalt plant, as explained by a contractor*, "Regarding RAP specifically, there's hardly any communication with the client or other external parties. It's mostly internal, between the contractor and the production plant, about whether we have enough material and if the quality is good."- (CON1).* This was explained by someone from the client side as well, who mentioned, *"Once a project starts, there is hardly any communication with the contractor. Also, contractors can't introduce a new mix, for example, with a higher RAP percentage, during a project. That must be addressed and validated before the project starts."- (CLT1)*

Interviewees also highlighted how the current ownership model reduces the incentive for coordination between the client and contractor. They mentioned how a new model might increase coordination, "Imagine a scenario where the road authority remains the owner of the material, and simply lends it to the contractor to make new asphalt, then takes it back. In that case, which would require many agreements and much closer coordination. But under the current arrangement, where the contractor owns the material after milling, that kind of communication isn't necessary, and therefore doesn't happen."- (CON1)

Finally, while platforms like CROW provide opportunities for exchange, participation remains narrow as only limited number of actors take part in these sessions, as explained by a contractor, *"It's a small community, the asphalt sector in the Netherlands. So, you always end up with the same people. You end up with a limited set of opinions from the same people over and over."- (CON2).*

Project A: Middenweg Project Amsterdam

The contractor, from this project, explained that the project involved joint discussions with the client about setting new standards and reusing more RAP that is generally allowed., *"With Amsterdam, we discussed what could be done to set a new standard, and we worked together on it. Both sides were responsible for doing the right thing, figuring out what each could contribute, and helping each other."- (CON1)*

Project B: Rijkswaterstaat GVO WNN Project

In this project, communication between the client and the contractor follows the typical structure that is followed in projects generally. As long as the contractor used the approved mix, there was no need for further communication. The contractor described this, *"The general case is like the Rijkswaterstaat example: you work within regulations, and as long as you stay within the limits, you can decide for yourself. If you want to go beyond the limits, then you need to start a discussion with the client. In about 90% of cases, it's the standard approach."*

Project C: A1 Apeldoorn-Azelo Rijkswaterstaat

In this project, a specialist from the client's side was involved through with the contractor to ensure efficient RAP reuse as this project involved TRL 7-8 mixture. This was explained by the client of the project, *"It's the contractor's responsibility to make sure and prove that in the end, the asphalt that is on the highway meets the requirements. And in our case a specialist was involved to make sure that everything is also correct."- (CLT2)*

He further explained that this was project specific and doesn't usually happen, *"Normally, like now, the mixture that we used on the A1 is at TRL 9 level. So nowadays, I wouldn't have someone involved, because yeah, it's TRL 9, and it's proven that it's a safe mixture with the required quality"- (CLT2)*

Adaptability of Governance Mechanisms

Project A: Middenweg Project Amsterdam

This project faced some logistical issues, in the sense that due to large amount of storage required for material for this project, there was no more storage for other projects. As explained by the contractor, *"We used a milling process to separate the surface layer from the underlying layers, then stored the materials at a specific location in Amsterdam for four months. During that time, this storage area at the asphalt plant was unavailable for other uses. This was a big logistical challenge for the plant owner."- (CON1)*

The plant owner explained to the contractor that, storing large quantities of material for one municipality meant less flexibility for other projects, as explained by the contractor, *"They told us that while the project was a success, they would not want to repeat the arrangement because storing material for Amsterdam, and then potentially for other municipalities like Zaandam, Haarlem, or Delft, would disrupt daily operations. It would mean having multiple piles of material in storage, which they simply don't have the space for. They also claimed that because the storage area was blocked, they had to improvise on other projects, resulting in suboptimal processes that affected environmental performance elsewhere."- (CLT1)*

Project B: Rijkswaterstaat GVO WNN Project

In this project, more could be done with regards to RAP reuse, but planning and logistical issues didn't allow, as explained by the contractor, *"For the Rijkswaterstaat project, we could technically have done more. The porous asphalt we're allowed to use there can contain over 70% RAP. This is achieved by combining standard RAP for porous asphalt mixtures with PA Stone. The issue is availability. When paving a national highway, you have to work in a short time window with huge asphalt quantities. That means you need a large stockpile of these materials ready at the plant. But such materials are scarce."- (CON1)*

He further explained how operational issues arise due to a mismatch in the pace of different activities like milling, processing, and paving, *"Milling process is done quickly, about 1,000 tonnes per hour and paving goes at a similar rate. But the process of converting milled asphalt into high-quality secondary materials goes at about 50 tonnes per hour, far slower than milling or paving. To prepare enough material, you'd need three to four weeks of processing before paving starts. We simply don't have that kind of time."- (CON1)*

Project C: A1 Apeldoorn-Azelo Rijkswaterstaat

Although this project directly didn't demonstrate procurement challenges, the client of this project reflected on broader procurement practices. He explained how sometimes procurement procedures still prioritize cost, as many municipalities still don't utilize Best Price Quality Ratio, *"But as you see, within provinces and some smaller municipalities, it's just like, in a contract there are requirements, and you have to meet those requirements, and you get the contract if you can offer the lowest price possible. So, in that way, I think the use of the Best Price Quality Ratio in tenders is beneficial, it is supportive of more sustainable asphalt mixes."- (CLT2)*. This creates a fragmented market culture, where circular options are supported in some contexts but overlooked in others.

Appendix J: Cross-case overview of barriers

In this section a detailed explanation of what barriers were observed at the project level and which governance characteristics reinforced them is provided. This is presented under the four main barrier categories.

Technical barriers

The analysis of technical barriers across the general project practices and the three projects highlight that they cannot be understood in insolation with the governance characteristics. To begin with, the lack of long-term performance monitoring of mixes with RAP was explicitly highlighted in the general sector project practices, as mentioned in section 4.3.1.1. The absence of systematic monitoring of roads with high RAP mixes and feedback loops mean that reliable performance data is missing. This makes the client reluctant to approve higher RAP mixes in the projects as their authority in decision making Is bound to proven and validated mixes. This barrier is thus linked to authority in decision making and weak coordination structures for sharing long-term performance information across the sector.

The next challenge is lack of standardized technical guidelines. This is not explicitly mentioned across the project level interviews; however, it is implied. Without long-term performance data about RAP mixes, sector-wide standardization has not been achieved, as explained under technical barriers in section 4.2.1.1. This fragmentation can be seen across the three projects: Project A developed its own norms by joint discussions between the client and the contractor. In Projects B & C, RWS was the client, and they adhered to their validation procedure. In Project C specifically, a material specialist was involved because TRL 7-8 level mixture was being used which had not been validated yet. This reveals that in the absence of standardized guidelines, each road authority follows its own procedures, which is not an issue, however it leads to less utilization of RAP in certain projects (especially with smaller municipalities). This barrier is reinforced by jurisdictional boundaries (clear and non-overlapping, so no coordination in projects across governance levels) and by client's authority in decision making to set project-by-project requirements for reuse of RAP.

Lastly, logistical issues were mentioned across all three projects. In Project A, selective milling of the surface layer (to maintain the high quality of surface material) required storing it separately at the plant which caused storage issues for the material for other projects. In Project B these issues include challenges due to availability of material, storage issues at the plant and planning uncertainties because of the tight schedules at the plant, as described in section 4.3.1.4. This is reinforced by the reduced adaptability of governance structures in projects.

Cultural Barriers

Cultural barriers included challenges that arise due to institutional, behavioral, and organizational cultures. Within this dimension, there is one barrier that was reinforced through project level analysis. This is lack of stakeholder collaboration, especially across governance levels. This is linked to strict jurisdictional boundaries, described in section 4.3.1.2, and to coordination mechanisms, described in section 4.3.1.3. It reveals that joint projects where national, provincial, and municipal road authorities are all present are rare. Even through knowledge sharing platforms (like CROW and NPDW), the collaboration is limited because not all municipalities and provinces are represented. Therefore, the opportunities for alignment of technical guidelines and material management are limited.

Regulatory Barriers

Regulatory barriers are associated with policies and legal frameworks surrounding the reuse practices of RAP. To begin with, fragmented regulations and lack of standardization overlaps with the technical barrier- lack of standardized technical guidelines. The technical challenge is about the lack of uniform procedures for mix design, performance testing and so on which leaves implementation highly dependent of road authority and contractors. On the other hand, the regulatory challenge is the lack of a national plan or rules that would bind or oblige the entire sector to adopt a uniform approach. The sector wide lack of standardized technical guidelines reinforces that there is an absence of a national roadmap. At the project level, it is already established that different road authorities followed different procedures for incorporating RAP in their projects.

Another barrier is restrictive and inconsistent regulatory standards. This is visible as there are less restrictions on RAP reuse in base and binder layers compared to surface layers. As a result, many road authorities are reluctant to increase the RAP percentages beyond a certain limit, and this varies from client to client across projects. As visible in the three case projects, where the RAP content was dependent on the client who has the authority in decision making. These restrictions are reinforced by technical challenges, especially the lack of long-term performance data and validation procedures for high RAP mixes.

Another regulatory barrier was the constraints in the ownership of RAP. At the project level, contractor from Project B noted that because the ownership of RAP shifts to the contractor post milling, there remain limited opportunities for collaboration with the client around joint planning of the management of the material. The coordination then is between the contractor and the asphalt plant, as explained in section 4.3.1.3.

Market Barriers

Market barriers are the economic and structural challenges within the asphalt market which affect the adoption of RAP reuse practices. A market barrier confirmed from the project level is that procurement procedures prioritize cost over innovation. This was not visible in any of the projects that were analyzed, but rather an insight presented during one of the interviews. This means that the barrier is sector wide but not true or common for all projects. As explained in section 4.3.1.4 under Project C, RWS utilizes BPKV (Best Price Quality Ratio) in tenders to which balances cost with qualitative criteria such as circularity. However, this is not followed by all road authorities across the sector, for instance many small municipalities and provinces don’t make use of this procedure and still rely on lowest bid wins model. Closely linked to this is the inconsistent use of environmental incentives. For instance, MKI values are used as an award criterion in many of the tenders of RWS but same is not the case for all municipalities and provinces. This creates an inconsistent situation for market parties as they can’t apply their circular innovations in all projects.