Identifying Stakeholder Perceptions of Overhead Catenary Electric Road Systems

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EXECUTIVE SUMMARY

Heavy-duty trucks (HDTs) are a significant contributor to global anthropogenic carbon emissions. In contrary to passenger cars, HDTs have to cope with decarbonization complications due to range and weight characteristics. Overhead catenary electric road systems (ERS-OC) can aid in decarbonizing this sector. Here, trucks are equipped with a pantograph and connect to catenaries on the highway, using electricity from the grid for propulsion. This technology complements other drivetrains and eliminates some of their major flaws, allowing HDTs to travel large distances with modest batteries or fossil-fuel consumption. Countries like Germany and Sweden have dedicated efforts and resources to ERS-OC as a carbon mitigation solution, and have multiple demonstration projects in use. However, this technology is lacking attention in the Netherlands, while emission reduction targets are closing in, and emissions keep rising.

Initiating ERS-OC activities through a demonstration project is determined to be a logical starting point in various countries. Identifying their perceptions is considered an essential step when aiming to implement an ERS-OC demonstration project. The aim of this research is therefore to answer the following research question: *What are stakeholder-perceived factors that affect the feasibility of creating an overhead catenary electric road system demonstration project?* This research is performed by conducting a qualitative case study for ERS-OC in the Netherlands. Nine interviews were conducted with organizations that have shown interest in the technology as a business opportunity. These nine respondents represent six out of the seven stakeholder groups that compose the ERS-OC system-of-systems. It has to be noted that no energy supplier was able to respond. Their perception of ERS-OC is therefore not considered during this research. The respondents were able to talk freely to avoid biases resulting from suggestive questioning, but the conversation was guided to other topics when necessary. The factors explaining stakeholder perceptions were extracted from the transcripts and coded to enable statistical analysis.

First, the perceptions of the individual stakeholder groups were analyzed. From the results can be concluded that the truck manufacturers mainly foresee implementation issues in the first years due to complications gathering investments. They think that when profitability is proven and the system will have shown it can play a vital role in decarbonizing HDTs, that upscaling will be just a matter of time. Freight operators are willing to engage, but need others to finance and construct the infrastructure, since they cannot afford to build infrastructure on their own. They are looking for the most cost-efficient manner to decarbonize their fleet, and it does not matter what technology that would be. The governmental entities acknowledge the potential of ERS-OC as a carbon mitigation tool, the huge reduction potential of electrifying the core highway network, and other advantages like decreased resource dependency, but await international developments to have guidelines on how to configure the system-of-systems, which explains stakeholder roles, responsibilities, and the interfaces between stakeholders,. They highlight that political acceptance of the technology is essential for the successful implementation of an ERS-OC network. Road power component producers highlight the unique capability of complementing other zero-emission drivetrains, and emphasize that ERS-OC should be considered as support for other powertrains rather than competition. They also consider it a cost-efficient measure compared to zero-emission alternatives, and say that ERS-OC is the only zero-emission technology that is currently implementable on a large scale for HDTs. There are few technical hurdles to overcome, proof of concept is present, but political urgency is lacking. Their biggest perceived barrier is a lack of leadership and priority with policymakers, and they think ERS-OC copes with an image problem. Standardization of catenary systems is considered key for the rollout of an international network. The construction firm sees the opportunity of bringing stakeholder groups together to create awareness and support base, and identify the lack of leadership as the main obstructing factor. Awareness among potentially involved parties is absent and increasing which could induce fast progression of ERS-OC implementation. The researchers state that ERS-OC seems expensive, but can have short payback periods, especially when compared to alternatives. Shuttle routes should be used when creating a demonstration project. They express concerns about power transfer issues when system occupation is high, and about the overall circularity of the system. They state further research is required before efforts and resources should be dedicated to ERS-OC.

The second sub-question investigates the perceived enabling and disabling factors for ERS-OC. Setting up policies stimulating engagement in ERS-OC is mentioned as a key enabling factor. The respondents state that they perceive

configuring the system-of-systems as a significant challenge. Technological maturity is perceived as an opportunity that has to be exploited. Proof of concept is present and cost estimations are predictable, and there are few technical uncertainties. Catenary infrastructure can complement alternative powertrains, which is considered a vital enabling factor by the respondents. On the other hand, the possible technological breakthroughs of the other technologies is considered a disabling factor. On a political level, a decreased dependency on foreign resources is mentioned as an enabling factor, while the lack of political urgency to decarbonize HDTs in general is perceived as disabling. Economically, the potential cost reduction is an enabler, while the large upfront investment required is seen as an obstructing factor. The opportunity to lobby for a support base is frequently mentioned as an enabling factor. The emission reduction that can be achieved is mentioned often as an enabling factor of ERS-OC, a technology that complies with the ambitions of the organizations. However, the researchers mention that the circularity of the system as a whole should be furtherly assessed before conclusions on the overall environmental impact of ERS-OC can be made.

The last sub-question is dedicated to extracting the enabling and disabling factors that directly affect the feasibility of a demonstration project through the yes/no approach. Enabling incentives for organizations to engage in a demonstration project are that ERS-OC is a zero-emission technology that is considered sustainable. The opportunities that enable a demonstration project are technological maturity, setting up policies, lobbying for a support base, and using a shuttle route for the demonstration to ensure utilization. The perceived barriers to a demonstration project are a lack of leadership, vision, and perspective. This puts a risk on the significant investment that is required for the realization of the demonstration. The challenges that have to be overcome exist in configuring the system-of-systems, and gathering the investments required for the demonstration. Politically, the urgency to decarbonize HDTs has to increase, and ERS-OC has to be accepted by policymakers as a decarbonization measure before the demonstration project can take place.

Aggregating the findings of the three sub-question enables answering the main research question. The stakeholder-perceived factors that affect the feasibility of creating a demonstration project are divided into internal and external factors for the organizations. The incentives that positively affect the feasibility of creating a demonstration project, according to stakeholders, are organizational ambitions, political urgency, the need for electrification, the societal pressure on decision-makers, and the opportunity for stakeholders to generate more business by entering new markets. The opportunities, perceived by stakeholders, that positively affect the feasibility of creating a demonstration project are the technological maturity, lobbying for support base, creation of enabling policies, the proof of concept that shows the functionality of the technology, and creating a test site or game to familiarize stakeholders with the technology and their future role and responsibility. Starting with a shuttle route and gradually expanding the network is an opportunity that needs to be kept in mind when choosing a location. Stakeholders can take an early advantage when engaging in the demonstration project, and green investors that aim to gain profits from the sustainability trend can be attracted when struggling with financing the project. The stakeholder-perceived barriers that negatively affect the feasibility of creating a demonstration project are waiting for international developments to provide an example, a lack of leadership, a lack of vision and perspective, absence of incentives to engage in ERS-OC projects, the lack of consequences when emission agreements are not met, the magnitude of investment that individual organizations have to make, and the risk of losing that investment when the technology will not become successful as an HDT decarbonization measure. The challenges that might negatively affect the feasibility of creating a demonstration project are mainly political. Setting up the system-of-systems that explains stakeholder roles, responsibilities, and interactions is required before a demonstration project can be set up. An attractive business case that is profitable for all involved parties needs to be composed before the required suitable partners can be attracted. It is essential that ERS-OC is politically accepted as a decarbonization measure, and that the political urgency is present that allows for the required resources to be released.

When interpreting the results, the following statements can be made. All respondents acknowledge the potential added value of ERS-OC to HDT decarbonization. They are also all positive about engaging in a demonstration project. But, there are planning and financing concerns that have to be addressed first before stakeholder engagement can be ensured. The respondents expect governmental entities to take the lead, and account for (part of) the funding. But, they are waiting for international developments and feasibility reports before dedicating efforts to ERS-OC. Still, it is this stakeholder that is expected to take the lead and induce progression. It is up to the researchers to provide the substantiated information on ERS-OC implementation that justifies investments for the governmental entities. When clear statements and promises about the future of ERS-OC are subsequently made, freight operators and truck manufacturers will investigate the possibility to engage in ERS-OC. When these stakeholders decide to engage in ERS-OC-related projects as well, ERS-OC is likely to succeed. Trust in the future of the technology will increase among stakeholders. And then, the construction firms, road power component suppliers, and energy suppliers will engage too, adding an additional market to their portfolio without having to change their core business.

The main themes that are identified when aiming to create a demonstration project are questions like: who will take the lead? What is expected from me? Where do we start? How do we finance this? How do we start? Based on the findings of this research, the following can be recommended. Start with assigning a project leader, and create a clear vision for the future of ERS, this will create trust among stakeholders about the investments they have to make. Then, the required investments for the infrastructure should be gathered from either public or private money. When this is secured, find a suitable corridor where multiple operators drive back and forth daily and which has a high truck occupation. Bind them by making a financially attractive offer, for instance by subsidizing catenary trucks or usage of catenary infrastructure. When legal matters are in order, construction can initiate.

Further research is required on the potential environmental and financial gains when electrifying the core highway network. Here, ERS-OC should be approached as a complementary technology, thus, also integrating other zero-emission technologies into the calculations.

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List of Acronyms

BET	Battery-electric truck
ERS	Electric road system
ERS-OC	Overhead catenary electric road system
EV	Electric vehicle
FCET	Fuel cell electric truck
GHG	Greenhouse gas
HDT	Heavy-duty truck
ICE	Internal combustion engine
ICET	Internal combustion engine truck
I&W	Infrastructure and Water Management
MLP	Multi-level perspective
SNM	Strategic niche management
SoS	System-of-systems
TCO	Total cost of ownership
TIS	Technology innovation system
ZET	Zero-emission truck

1 INTRODUCTION

1.1 THE NEED FOR ROAD TRANSPORT DECARBONIZATION

Global anthropogenic greenhouse gas (GHG) emissions reached an all-time high in the year 2021 (Figure 1). After a minor fall in 2020 due to the COVID-19 pandemic, the world's economy has recovered and trade routes are revived, resulting in a record-breaking 36.3 gigatons of carbon dioxide emitted by energy combustion and industrial process (IEA, 2022). To mitigate the effects caused by anthropogenic climate change, the European Union has set up the European Green Deal that includes the ambitious goal of emitting zero net harmful GHGs by 2050, with an intermediate step of at least 40 percent reduction by 2030, relative to 1990 (European Commission, 2019). It is, however, questionable whether these goals will be met, since annual emissions continue to rise.

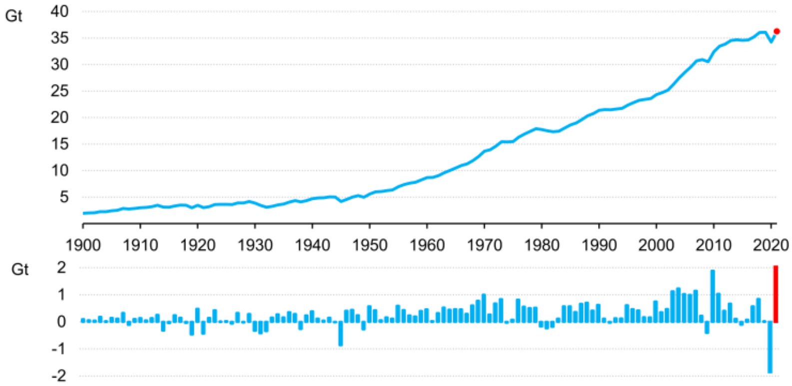

FIGURE 1 – TOTAL CARBON DIOXIDE EMISSIONS FROM ENERGY COMBUSTION AND INDUSTRIAL PROCESSES AND THEIR ANNUAL CHANGE (1900-2020) (SOURCE: IEA (2022))

The road transport sector is a large contributor to total emissions, being accountable for almost a quarter of the world's GHG emissions (European Parliament & Council of the European Union, 2019; Plötz et al., 2019; Tongur & Sundelin, 2017). The transition from fossil fuels to electric vehicles (EVs) is in full swing for passenger cars, buses, and delivery vans, but heavy-duty trucks (HDTs) are falling behind this trend. At the start of 2020, 98 percent of HDTs were powered by a conventional internal combustion engine (ICE), consuming fossil fuels (Otten et al., 2020). While HDTs make up for less than 10 percent of all vehicles on the road, they emit roughly 40 percent of their total carbon emissions (Kluschke et al., 2019; Lutsey & Moultak, 2017). Without further measures, their share of GHG emissions will grow from 6 to 9 percent up to 2030 (European Parliament & Council of the European Union, 2019). Moreover, it is the only sector in which the total emissions are expected to grow. Research suggests that emissions from the HDT sector will almost double by 2050 (Figure 2), due to growing global trade (IEA, 2017; ITF, 2016). The need for decarbonization in this sector is therefore high.

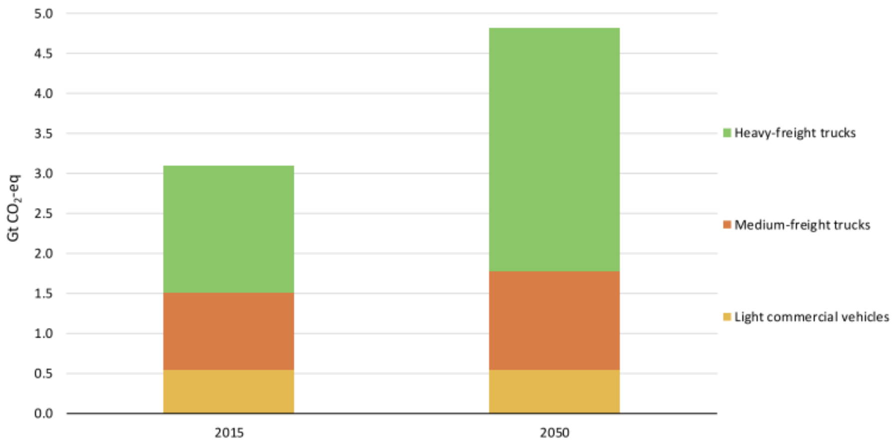

FIGURE 2 - EXPECTED GHG EMISSIONS OF DIFFERENT TRUCK CATEGORIES FOR THE REFERENCE CASE (2015) AND THE REFERENCE SCENARIO (2050) (SOURCE IEA (2017))

1.2 ALTERNATIVES FOR DECARBONIZING HDTS

The decarbonization process of HDTs imposes challenges resulting from their high range and weight demands compared to other vehicles. Renewable alternatives do not yet meet these demands, causing the uptake of zero-emission trucks (ZETs) to lag. The most familiar ZET is the battery-electric truck (BET). While current batteries can provide sufficient power for delivery vans, buses, and passenger cars, they cannot meet the demands of HDTs. These trucks require a powertrain that can propel heavy goods for long distances. Current batteries struggle to achieve this without having to compromise on payload capacity due to the size and weight of the required battery (Earl et al., 2018; Lajevardi et al., 2019). The second alternative for HDT decarbonization is hydrogen-fueled fuel cell electric trucks (FCETs). These have comparable range, density, and refueling characteristics as ICETs, eliminating the weight and range constraints that occur with BETs (Hydrogen Europe, 2021). However, FCETs require green hydrogen – produced from 100 percent renewable energy sources – to be sustainable, which is scarcely available and expensive (Dawood et al., 2020; European Commission, 2020). FCETs also cope with low efficiencies, lack of infrastructure, and high vehicle investments (Calvo Ambel, 2017). Other alternatives for decarbonization are present in the form of, for instance, liquefied natural gas, biofuels, and syngas. These fuels are in the end not capable of reaching zero emissions due to their chemical properties, and are considered more as an intermediate step toward zero-emission trucking (Rijksoverheid, 2019), and are therefore not considered a viable option for the long-term decarbonization process of HDTs.

Scientists and policymakers agree that the decarbonization of HDTs through one technology is not likely. A mixture of technologies is projected as the solution for HDT decarbonization (Taljegard et al., 2020). A solution to solve the challenges that occur with BETs and FCETs can be electric road systems (ERS) that can reduce the need for large and heavy batteries (Taljegard et al., 2016). These systems allow vehicles to tap electricity directly off the grid for propulsion, while dynamically charging the vehicle's battery. ERS is a collective name for a range of solutions, including inductive and conductive power transfer systems. Inductive solutions transfer electricity wirelessly through coils that are embedded in the vehicle and in the road. Wireless ERS is currently not a feasible solution due to low power transfer capabilities that cannot support HDTs, so research is more focused on applications for buses and passenger cars (Bateman et al., 2018). Conductive ERS can be either catenary or rail solutions. Rail solutions are not extensively researched and have few practical examples. ERS that uses overhead catenaries (ERS-OC) is considered a promising technology for HDT decarbonization. With ERS-OC, overhead catenaries are installed on the right lane of a highway. HDTs can directly tap electricity from the catenaries at highway speeds by the pantograph that is installed on the vehicle, 'with a higher efficiency than static charging or battery swapping' (Speth & Funke, 2021; Taljegard et al., 2017). This intelligent device extends from the roof of the vehicle automatically through sensors noticing the ERS-OC. When equipped on a BET or FCET, this is directly transferred to the battery for charging, while simultaneously propelling the vehicle. Pilot projects with ERS-OC have been performed in various countries across the globe, and are commercially in use on multiple highway corridors in Germany (Bateman et al., 2018; Boltze et al., 2021). The German government is investing in ERS-OC as one of the three means for decarbonizing HDTs, next to battery and hydrogen technologies (BMVI, 2020). Hypothetically, unlimited range can be achieved without charging stops, when equipping all roads with ERS-OC. Despite this being unlikely, much greater distances can be realized for HDTs when highways are electrified using ERS-OC. The ERS can complement ZETs and hybrid ICETs so that the primary fuel source of the truck is only used for the first and last mile of its journey, allowing for battery size optimization suited for specific ranges (Hartwig et al., 2020). In Germany, this is no more than 50 kilometers off the highway in about 90 percent of the cases. 80 to 90 percent of HDT journeys take place on highways. Moreover, over two-thirds of HDT emissions in Germany are emitted on just 4000 kilometers of highway (Siemens, 2021). ERS-OC forms therefore an interesting tool to accelerate the uptake of ZETs.

1.3 Challenges when implementing ERS-OC

The potential added value of catenary trucks has been investigated in several European countries. The reports of Ainalis et al. (2020), Aronietis & Vanelslander (2021), BMVI (2020), Movares (2020), and Pettersson et al. (2017) assess ERS-OC as an opportunity for road freight decarbonization in the United Kingdom, Belgium, Germany, the Netherlands, and Sweden. They all conclude that the technology has the capabilities to contribute to the decarbonization of road freight and achieving climate goals. While proof of concept is available, ERS-OC is not penetrating the market, despite its high technological maturity and predictable investments. This is because the introduction of ERS-OC to the existing road network comprises more than the installation of the physical infrastructure and the manufacturing of ERS-compatible vehicles. The electrification of roads requires reconfiguration of the entire existing road system. Involved actors will get new roles and responsibilities, and have to cooperate intensively and continuously. Since ERS-OC is part of a niche, there are little to no examples of how these stakeholder interactions should function and how such a system should be integrated into the existing road system to the fullest extent. Also, the installation of ERS-OC requires extension of the electricity grid, since the HDT fueling method will shift from static to dynamic. The uptake of ERS-OC depends on how the above-mentioned points of attention are addressed.

The implementation of ERS-OC is part of the larger technological transition in road transportation towards renewable fuel sources. To understand what is required to induce such a transition, the process of major technological transitions needs to be understood. The core concepts explaining technological transitions will now be discussed.

1.4 Transitioning the existing road system

This section is dedicated to explaining the core theoretical concepts around the implementation of an ERS-OC. Comprehension of these concepts is required to understand what the implementation of ERS-OC demands from stakeholders, society, and the existing road system that require significant adjustments when introducing ERS-OC. The multi-level perspective (MLP) aids to dive into the system functions that require attention by explaining how technologies in niches, like ERS-OC, can penetrate the existing market and eventually replace the embedded current technology with the help of strategic niche management (SNM). The technology innovation system (TIS) explains how the implementation of niche technologies can progress. System-of-System (SoS) engineering explains how the many actors that need to cooperate can be merged into a single system.

1.4.1 Introducing niches to existing markets

Major technological transformations, like the energy transition in general and the shift towards ZETs, require not only technological changes, but often also system changes and adjustments in other fields like regulations, infrastructure, and social behavior, to name a few (Geels, 2004). These transitions are long-term changes that are induced by a sociotechnical shift of the various actors that are affected by such a change. Geels (2002) defines three levels that make up the dynamics of sociotechnical change; the macro-, meso-, and micro-level in the multi-level perspective.

The macro-level consist of the socio-technical landscape containing slowly, but surely changing structural trends. The trends in the transportation landscape include climate change, oil prices, and battery development. This landscape functions as the context for actors to interact. The meso-level is where technological regimes act.

Regimes consist of the organizations and people that follow the routines and habits of a certain technology. The regime manages and improves the technological trajectory through incremental innovations. The regime in the field of transportation is the automotive industry that relies on gas stations, ICEs, and gasoline and diesel as conventional fuels. These regimes are not easily replaced, but can be disrupted by radical innovations that are generated in niches over time. These niches act at the micro-level. They are not able to disrupt regimes on their own, and are often divergent and more expensive than conventional technologies. They are embedded as novelties in regimes and function as the 'seeds' for technological transitions. The niche technologies in the field of electric transportation are BETs, FCETs, and ERS-OC, among other sustainable powertrains, as is displayed in Figure 3.

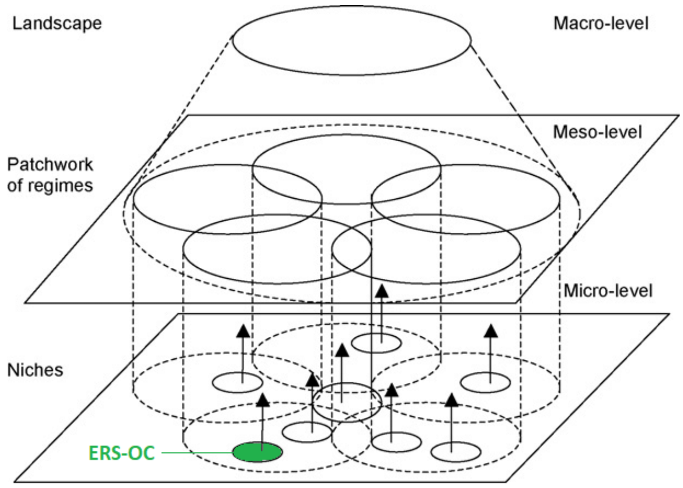

FIGURE 3 - ERS-OC AS A NICHE TECHNOLOGY IN THE MULTI-LEVEL PERSPECTIVE (ADJUSTED FIGURE FROM GEELS (2002))

ERS-OC is thus part of the energy transition towards zero-emission transportation. It requires reconfiguration of the regime. The landscape developments that induce this transition are clear; global temperature is rising, emission agreements are signed, and recent oil price increases make gasoline- and diesel-powered vehicles less preferable. However, the infrastructure of gas stations and the current skillsets of automotive manufacturers are regime habits that are not easily disrupted. ERS-OC requires new infrastructure, stakeholders acquiring new skillsets, and new and continuing collaborations and interactions of the involved parties.

1.4.2 THE IMPORTANCE OF A DEMONSTRATION PROJECT

The strategic niche management (SNM) approach of Schot & Geels (2008) provides solutions for niches that want to penetrate the market of embedded regimes. The approach states that expectations and clear vision, the building of support base and social networks, and learning processes in various dimensions are essential for the penetration of niches into embedded markets. They emphasize that creating a test site, a so-called demonstration project, aids in the development of niches. Such sites allow for the testing of new technologies, and act as building blocks for creating regulatory structures and enhancing user understanding of and experience with the technology. This will increases the chance of successful deployment of niche technologies like ERS-OC into real-world applications. This is explicated by the Technological Innovation System (TIS) approach of Hekkert et al. (2007). This is used for the identification of possible bottlenecks that may hinder the anchoring of initiatives for system innovation. This approach is applied by analyzing seven system functions. The analysis reveals weak or absent system functions that hinder the implementation of the technological innovation. The seven system function are entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation, resource mobilization, and creation of legitimacy. These system functions influence each other, and self-enhancing virtuous cycles can be created when the right activities are triggered.

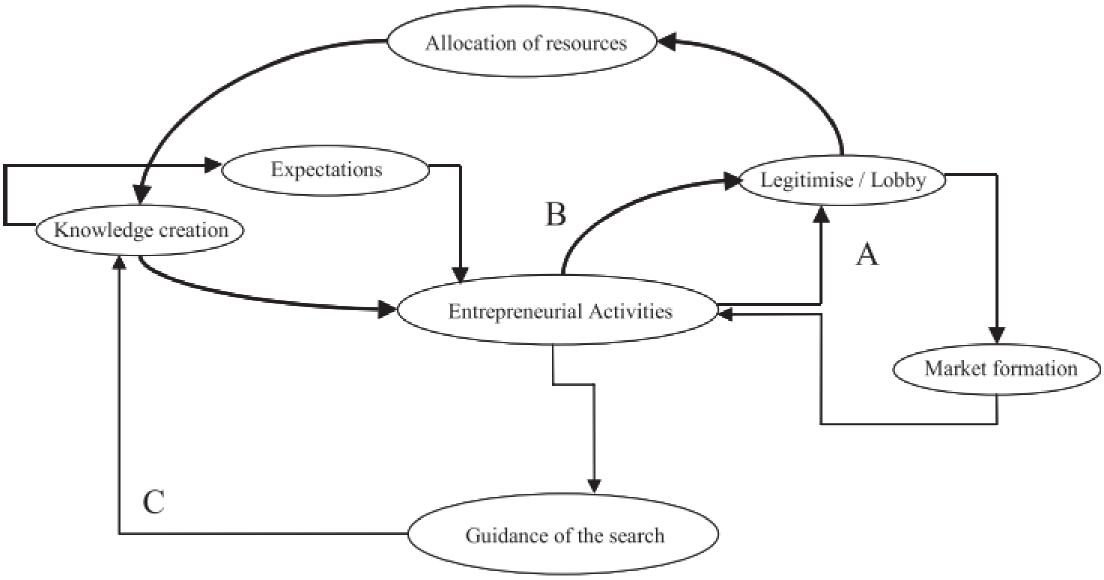

FIGURE 4 – THE DRIVERS OF CHANGE, ACCORDING TO HEKKERT ET AL. (2007)

While Hekkert et al. (2007) identify seven system functions, three common triggers are discussed that induce technological progression (A, B, and C in Figure 4). Societal problems, like environmental pollution, raise the need for knowledge creation on the subject. This will result in entrepreneurial activities that aim to solve these problems. The outcomes of these activities provide the foundation for more specific guidance of the search in the form of creating a vision (C). This specified vision allows for more specific knowledge creation, and so on, improving the system functions. As a result, the increase in entrepreneurial activities will not only facilitate specification of guidance, but can also induce the allocation of more resources (B) and market creation (A), starting another self-reinforcing virtuous cycle that allows for more experimentation and upscaling by entrepreneurs. The demonstration project that was emphasized in the SNM approach is part of the entrepreneurial activities. Creating such a demonstration will create a better understanding of the technology in real-world conditions, enhance the legitimacy of ERS-OC, and facilitate lobbying for the formation of a market that is currently non-existent.

Creating a demonstration project should therefore be considered a vital starting point for introducing ERS-OC to the conventional road system. Setting up such a demonstration is, however, dependent on the engagement of many stakeholders. Some of which have little to no experience with such technologies. These stakeholders have to continuously cooperate to make the ERS-OC function properly. To comprehend how this cooperation can be achieved in the specific case of ERS-OC, one should understand how an ERS-OC is built up out of different systems that together form a System-of-Systems (SoS). The importance of configuring the ERS-OC SoS will now be discussed.

1.4.3 THE IMPORTANCE OF STAKEHOLDER INVOLVEMENT

An electric road system is not just a technical installation, but comprises various stakeholders and industries that together function as an SoS (Tongur & Sundelin, 2017). An SoS consists of multiple complex systems that are autonomous, but integrated into a larger interoperative network of subsystems with fluid boundaries between them (Nielsen et al., 2015). An SoS arises when the product, service, or technology of single subsystems are fully developed, and the systems combined create a new product or service, which in this case is ERS-OC (Bonnema et al., 2015). An SoS aims to achieve multiple goals, because of the plurality of stakeholders present. All subsystems have individual goals that together contribute to the success of the SoS as a whole, contrary to single systems where there is one main goal to address (Keating et al., 2003). ERS-OC is such an integrated complex system and needs to be assessed and configured following SoS engineering methods before it can be properly introduced to the existing road system. The traditional road system is already an SoS. This system will be complemented when electric roads are introduced. Road power component producers, energy suppliers, and perhaps an ERS operator will be introduced to the existing SoS (Bateman et al., 2018; Tongur & Sundelin, 2019). Designing an ERS-OC SoS is facilitated by explicating the incentives of the stakeholders acting within the subsystems.

1.5 SUBSYSTEMS AND STAKEHOLDERS

To comprehend how an ERS-OC demonstration project can be launched, it is important to understand how the ERS-OC SoS is composed. The ERS-OC subsystems together form an interdependent system-of-systems. Stakeholders are acting within these subsystems, having their specific role, responsibilities, and revenue streams in the greater SoS. Sundelin et al. (2016), Tongur & Sundelin (2017), and Wang et al. (2019, 2020) have investigated the ERS-OC subsystems, stakeholders, their future role, responsibilities, and revenue streams. These will now be discussed.

1.5.1 SUBSYSTEMS

The conventional road system is already an SoS composed of the road, operation, vehicle, and transportation system. The electrification of roads introduces the energy and power transfer subsystems to the SoS (Sundelin et al., 2016; Wang et al., 2020). Figure 5 shows a schematic overview of the subsystems that form an ERS-OC and will now briefly be discussed.

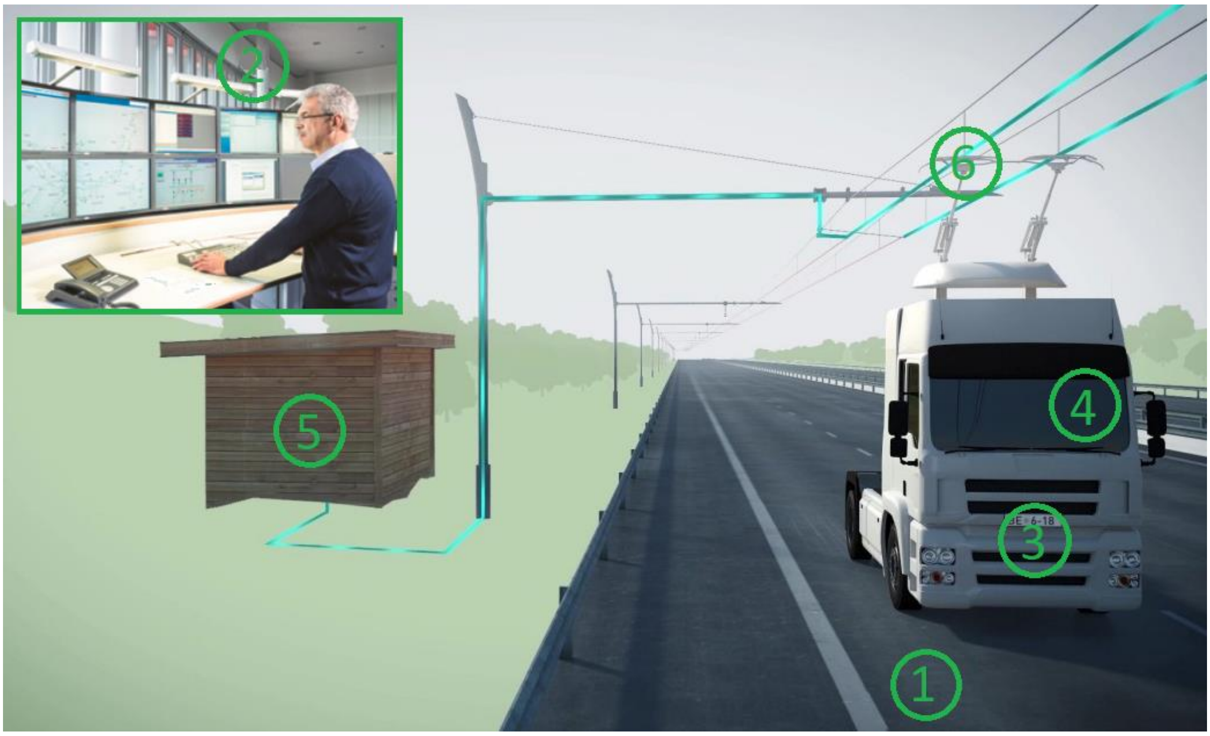

FIGURE 5 - SCHEMATIC DISPLAY OF ERS-OC SUBSYSTEMS (ADJUSTED FIGURE DERIVED FROM BOLTZE ET AL. (2021) AND SIEMENS (2022))

The **road system (1)** consists of the pavement, auxiliaries, and surrounding physical structures like the catenaries structure. The **road operation system (2)** is the control center and manages the energy of the overall system. The vehicles connected to the ERS are being monitored in real-time from a centralized point, comparable with rail traffic control centers. This system also checks vehicle credentials before being allowed access to the system, preventing illegal activities. The road operation system is also responsible for the payment and billing system. The **vehicle system (3)** contains the vehicles on the road that are equipped with a pantograph, battery, electric converters, and an electric motor (Mareev & Sauer, 2018). The **transportation system (4)** consists of the freight operators that will buy the catenary trucks and make use of the catenary infrastructure (Tongur & Sundelin, 2017). The **energy system (5)** is responsible for the production and distribution of the electricity from the source to the catenaries. The **power transfer system (6)** contains the on-road and in-vehicle components that enable the transfer of electricity from the grid to the vehicles, and the conversion of the electricity into propulsion energy (Sundelin et al., 2016).

1.5.2 Stakeholders

The subsystems contain stakeholders that are responsible for the proper functioning of the SoS. The stakeholder groups that are identified derive from literature are complemented with reports on prior ERS-OC projects, and are shown in Table 1. Their future role, responsibilities, motivations, and revenue streams will now be discussed.

Truck manufacturers have the responsibility to produce and deliver catenary trucks that are compatible with the ERS-OC infrastructure (Tongur & Sundelin, 2017). These organizations will also be responsible for the development and maintenance of the vehicles (Wang et al., 2019). Catenary trucks can become part of their core business when ERS-OC is implemented on a large scale and they recognize the opportunity for profitability. Demand for catenary trucks will rise when governments dedicate their resources to the implementation of ERS-OC infrastructure. Truck manufacturers want to respond to that demand to increase their revenue. Engaging in demonstration projects can provide an early competitive advantage, yet required production volumes are highly dependent on the construction of ERS corridors (Andersson et al., 2019).

Freight operators are the users of the system, and have the obligation to gradually decarbonize their fleet. Environmental policies will force them into realizing significant carbon reductions within a limited time frame, so they have to switch to more sustainable forms of trucking soon to avoid financial penalties. When the shift to catenary trucks is economically justifiable, the freight operators will buy catenary trucks from the truck manufacturers. Usage of ERS-OC infrastructure will change their conventional refueling and corresponding invoicing methods; Refueling will change from static refueling at gas stations to dynamic on-road charging, and invoicing will change from direct payment to post payment or perhaps a subscription. Besides that catenary trucks can contribute to achieving their emission obligations, ERS-OC also has a higher energy efficiency than diesel, potentially saving fuel costs (Tongur & Sundelin, 2017). ERS is also said to have a lower TCO than any other zero-emission alternative – or even conventional diesel trucks - in 2030 when available large scale (Plötz et al., 2018; Wietschel et al., 2019), and alternative ZETs are scarce.

Governmental entities are the road owners and will act as facilitators and presumably also investors (BMVI, 2020). They are the problem owners, since they are bound to the emission reduction agreements they have agreed to. Their focus lies mainly on the environmental and socio-economic aspects; they aim to achieve climate goals by decarbonizing road freight. Contrary to the other stakeholders, who prioritize profit maximization and operational efficiencies (Bernecker et al., 2020). They have to grant permission for demonstration projects and aid financially to facilitate realization (Bateman et al., 2018; Wang et al., 2019). Introducing ERS will require new regulatory systems and regulations. New institutions have to be set up to streamline the rules and responsibilities of new entrants. Standards for vehicles, pantographs, and ERS constructions are needed to prevent fragmentation into multiple comparable, but slightly different, systems that are non-compatible. It is the task of governmental entities to arrange and implement this. ERS-OC can aid governments in achieving climate goals by reducing fossil fuel usage and increasing energy efficiency, causing significant carbon reductions, and avoiding future fines (Tongur & Sundelin, 2017). Furthermore, ERS-OC can decrease the dependency of other countries on fuel supply. By using electricity from the national grid, the country will be less vulnerable to foreign fuel price fluctuations.

Road power component producers have the role to provide the components and expertise that enable the power transfer from the grid to the vehicle, and the transformation from an electric current into propulsion energy within the vehicle. These include the on-vehicle pantograph, the catenaries, and the in-vehicle components. Since similar technology is currently used in the railway industry, component suppliers can broaden their scope from rail to road, while using similar technologies (Tongur & Sundelin, 2017), providing new business opportunities.

Energy suppliers are electricity companies that will be responsible for producing, distributing, and delivering electricity to the system. ERS-OC opens a new market for the energy suppliers, since the primary fuel of the catenary trucks will become a direct electric current. The construction of rectifier stations that deliver the electricity to the system will also provide new business opportunities. The energy suppliers are responsible for ensuring adequate power delivery to the catenary system. These organizations will sell electricity to the freight operators either directly after usage or on a contractual basis, or indirectly through the operator of the ERS-OC.

Construction firms will construct and deliver parts of the physical catenary construction. Their experience has to ensure sustainable and safe electric roads (Wang et al., 2019). They are responsible for building the physical structure as well as connecting the ERS to the electricity grid (Tongur & Sundelin, 2017). Large-scale implementation of ERS-OC will provide new projects for the construction firms.

Researchers have the task to provide scientific proof of concept through feasibility reports, and advising decision-makers. They will continue to research ERS-OC-related subjects to optimize processes and execution of ERS-OC activities. They can influence other stakeholders by delivering convincing evidence on a potential rollout plan.

The **ERS Operator** (ERSO) is introduced by Tongur & Sundelin (2019) as a new stakeholder that handles the relationship between the supply and user sides on an ERS-OC. The ERSO will manage the system when operative. Tasks include checking vehicle credentials to prevent illegal activity, and setting up invoicing contracts with or between energy suppliers and freight operators. The exact role of the ERSO is dependent on how open or closed the system will become in the future. A small-scale ERSO – like with a demonstration project - could be one of the ERS-OC stakeholders performing a double role, for instance, the governmental entities. They will not have a complex role since the system is rather small and would not require more than one or two energy suppliers. In large-scale projects, when ERS-OC is rolled out towards an extensive network, there could be multiple ERSOs with their own designated areas. They must handle standardized contracts with the various suppliers and owners that utilize the system. Large quantities of freight operators have to be controlled by the ERSO, increasing the responsibility of the actor.

Stakeholder	Responsibility
Truck manufacturers	Produce and deliver ERS-compatible vehicles, perform maintenance activities
Freight operators	Use ERS-OC and provide feedback
Governmental entities	Create support base, configure SoS, invest in and execute project
Road power component producer	Develop and deliver on- and in-vehicle components of catenary trucks
Energy suppliers	Produce, distribute, and deliver electricity to ERS-OC
Construction firms	Install and maintain physical infrastructure
Researchers	Provide scientific proof of concept
ERSO	Operate ERS-OC when in use

TABLE 1 - ERS-OC STAKEHOLDERS AND THEIR RESPONSIBILITY

Now that the stakeholders are identified, it is important to analyze what other authors have found when looking into ERS-related stakeholder research.

1.6 GAPS IN LITERATURE

From the SNM and TIS approach can be concluded that a demonstration project will help ERS-OC to penetrate the embedded market, as is the case in Germany. These demonstration projects cover shuttle routes that freight operators use daily to optimize utilization (Boltze et al., 2021; Otten et al., 2020). Geels (2004) emphasizes the need for innovation systems to transform into socio-technical systems. This means that user-side analysis also has to be incorporated for the technology to become successful, since they determine the uptake rate of the technology. After all, the outcome of a project is largely determined by how well it meets the expectations of stakeholders (Börjesson & Gustavsson, 2018; Bourne, 2006). These expectations can be investigated by identifying their perceptions of the technology. As described before, the user side consists of multiple subsystems making up the SoS. Fulfilling their single requirements is not an easy task. It is therefore of great importance to investigate and understand the stakeholder perceptions of the individual subsystems before engaging in a project. Proper alignment of these perceptions can facilitate the creation of a common vision, which is considered to be key (Scherrer et al., 2020).

Past research on ERS projects is mainly focused on technological, environmental, and financial aspects regarding implementation. Various authors emphasize the importance of elaborating on stakeholder perceptions. However, few sources investigate stakeholder perceptions to increase the chance of successfully launching a demonstration project. Tongur & Sundelin (2017) investigate stakeholder perceptions on ERS-OC from a holistic view identifying possible implications when introducing electric roads for a Swedish case study. Wang et al. (2019) assess stakeholder influence and interest for the Swedish case study of eRoadArlanda, using respondents that are closely involved in a real-world project. While these studies relate to stakeholder perceptions of ERS in general, they do not assess the possibilities of creating a demonstration project. Moreover, a Swedish case study does not represent a Dutch one. Dutch stakeholders will have divergent motivations and arguments, and the Swedish road system is not identical to the Dutch road system, having different routines and regulations in place. Currently, no scientific papers discuss this matter. Gadgil et al. (2022) investigate the success factors of wireless ERS by engaging stakeholders from the United Kingdom. This research has not been performed in the Netherlands for ERS-OC.

While ERS-OC feasibility reports are written for various western European countries, including the Netherlands, these fail to investigate stakeholder perceptions. The feasibility reports are often commissioned by governments and fail to approach the feasibility from a holistic perspective, implying that it might be a biased and one-sided conclusion. As stated by Bourne (2006) and Scherrer et al. (2020), the perceptions of stakeholders have to be identified and assessed to increase the chance that the demonstration will succeed. Such an assessment of stakeholder perceptions on an ERS-OC demonstration project from a holistic perspective is currently lacking. This is the knowledge gap that will be addressed in this study.

1.7 Research objective

This research will investigate stakeholder perceptions of ERS-OC in the Netherlands. The aim is to explicate their perceptions to increase the chance of stakeholder engagement when a demonstration project is set up, and enhance the chance of stakeholder engagement in future ERS-OC projects by showing the functionality of the system and the feasibility of meeting their expectations. The objective of this research is therefore *to set out the factors that stakeholders mention when asked about their perception of ERS-OC, to identify the consensus on the technology and points of attention perceived by those stakeholders. The created holistic stakeholder perception should provide guidance for setting up an ERS-OC demonstration project that satisfies the expectations of all stakeholders, and therewith increase the probability of stakeholder participation and the likelihood of successful implementation of an ERS-OC demonstration project. Ultimately, this should accelerate the decarbonization process of heavy-duty trucks in the Netherlands.* This research objective leads to the following research question:

What are stakeholder-perceived factors that affect the feasibility of creating an overhead catenary electric road system demonstration project?

This research question will be investigated through a Dutch case study of creating an ERS-OC demonstration project. To provide a well-substantiated answer to this question, the research question is dissected into the following sub-questions:

SQ1. What are the stakeholder-specific perceptions of ERS-OC?

SQ2. What enabling and disabling factors are mentioned by stakeholders?

SQ3. What stakeholder-perceived factors affect the feasibility of a demonstration project?

1.8 Research approach

Section 1 has stated the problem of HDT decarbonization and the potential contribution of ERS-OC in solving this problem. The subsystems and stakeholders that compose the ERS-OC SoS are described. The knowledge gap that was found in existing literature, and how this research aims to address this gap is explained. Section 2 discusses past ERS-OC stakeholder research, and other relevant stakeholder research. Section 3 elaborates on the method that was followed during this research. In section 4, the results are set out and analyzed. First, the mentioned factors are analyzed per stakeholder group. Then, the factors are discussed through the PESTEL approach. Then, the factors that directly affect the feasibility of a demonstration project – according to stakeholders – are set out. In the end, one paragraph is dedicated to the interpretation and added value of the findings. Section 5 will explain the conclusions of the research and answer the research questions. In section 6, the research findings, their societal and scientific relevance, and reliability are debated and compared to other research. It also provides recommendations for further research. The appendices can be found at the end of this paper.

2 LITERATURE REVIEW

This research aims to set out perceptions of stakeholders on ERS-OC. The previous section explained the importance of stakeholder involvement when aiming to create an ERS-OC demonstration project. This section reviews existing literature that addresses stakeholder research on ERS. Existing literature addressing stakeholder views on various forms of ERS is examined to gain a better understanding of the existing problem that arises when creating a demonstration project. Also, stakeholder research on similar problems is discussed to see how similar problems are investigated. This literature review is also used to select an appropriate research method. The literature on stakeholder views on ERS will now be discussed.

Börjesson & Gustavsson (2018) have investigated the perspectives of freight operators on electric roads through workshops and interviews. They found a generally positive opinion on ERS, but noted that transport buyers and industries need to show intentions that they will order goods that are transported by ERS. The respondents stated that they are willing to pay for the catenary trucks and usage of the infrastructure, under the condition that using the system can still be profitable for them. The freight operators expect other parties to finance the physical infrastructure. They find that using ERS could improve the brand image of the freight operators because of their investments in sustainable initiatives. The authors recognize the potential of freight operators to become advocates for ERS through word-of-mouth advertisement.

Scherrer et al. (2020) integrate the theories of MLP and TIS with ERS case studies to identify barriers that are perceived by actors in the ERS landscape. The authors use three types of data input for their research. First, actor connections were detected by social network analysis and a web search. Then, they identified actor opinions and actor characteristics through the same documents and complemented by public sources, surveys, and interviews. Their research resulted in the following conclusions on the six barriers that they identified: a lack of legitimacy is not perceived as a barrier to ERS implementation. The lack of social networks with powerful actors, and the lack of overlap between the regime and niche actors were also not perceived as barriers. On the other hand, the lack of support from actors and lobby for improvement is seen as a small to moderate barrier. The resistance of the current regime and the lack of clear and broadly accepted expectations were seen as moderate barriers. They conclude that removing the latter three barriers will stimulate the uptake of ERS.

Tongur & Sundelin (2017) assess ERS as an SoS. They aim to address the research gap in approaching the system transition required when implementing ERS, from a holistic perspective. They examine how the introduction of ERS increases business, system, and technology complexity. They investigate how ERS will evolve when scaled up, and what stakeholder implications could occur when the conventional road system is converted to an electric road system, based on interviews with stakeholders and project managers, complemented by intensive research on the subject. The conclusion of the first question is that additional subsystems will be added to the road system, dependent on it being an open or closed system. Identified stakeholder implications include a lack of leadership, who will make the transition happen? Also, the success of ERS depends on implementation costs and utilization; the chicken-and-egg problem. Other implications that can occur are: Who will and can finance the operation? Who will own the system when in use? And how to encourage early adopters?

Wang et al. (2019) analyze the Swedish eRoadArlanda, an ERS-OC demonstration project, to identify the influences and interests of stakeholder groups. It is a longitudinal study performed in two rounds of data gathering in 2016 and 2017, with stakeholder interviews as their primary data source. They used two separately executed methods. The first method captured stakeholder perceptions using an action, factor, goal (AFG) list, containing ERS-related aspects that stakeholders would consider. The interviewees had to fill in this list, providing the authors with the objectives that stakeholders within the project had. The second method, a year later, the data collection process was interviewing primary stakeholders again. They conclude that the financial and planning aspects of ERS projects are the biggest concerns. Also, the social aspect – including public image and safety – is something all stakeholders concerned. The authors acknowledge that a demonstration project can provide clarity about safety concerns, and create a better public image.

Wang et al. (2020) investigate the complexity of integrating the individual subsystems that compose an ERS SoS. They aim to clarify how the hurdle of stakeholders having different objectives can be overcome, since the stakeholders have to cooperate to make the system function properly. The goal of their research is to align stakeholder perceptions of ERS with system characteristics. The system characteristics were derived from a web search and the stakeholder perceptions through an AFG list. They conclude that stakeholder concerns are present regarding financials, safety, service, environment, and social influence, for the long-term development of ERS.

Gadgil et al. (2022) use stakeholder engagement as a tool to determine political, economic, social, and technological (PEST) factors that will determine the success of inductive ERS. They identify a knowledge gap in explicating the application requirements of this technology. They organized a workshop where the PEST factors were identified. They conclude that organizational relationships are currently not considered. The most discussed concerns were if the vehicle will function well and with what power, the journey towards implementation of the technology, the availability of infrastructure, what type of charging technology will prevail, how much energy high-occupancy traffic flows demand, and the cost factors.

Späth et al. (2016) investigate how stakeholders look at the shift to sustainable mobility in the German region of Stuttgart and the role of public policy. They aim to disaggregate actor strategies to assess the potential of the regime – as described in the MLP – to transform the market towards sustainable mobility. Their data collection methods consist of desk research and interviews. They note that significant efforts have been made to induce this transformation, but that these are driven by short- and medium-term profit projections. This creates a lock-in effect with the regime, hindering technological progression. They conclude the MLP focuses on how regimes 'adapt' to challenges from niches and landscapes, but that it should rather focus on reverse impacts; how the regime impacts niches and landscapes. Now, regimes are not keen on transforming landscapes when it affects their interests. This would require more political pressure on governments and large businesses.

After examination of the literature, the method of Gadgil et al. (2022) seems to provide an excellent framework for this research. They explored the macro-environment of inductive ERS through the PEST factors that can 'assess a market from the viewpoint of a particular technological proposition or business'. This research will use the PESTEL factors to identify the perceptions that stakeholders have toward an ERS-OC demonstration project. The 'EL' factors – the environmental and legal factors – are also being considered in this study to provide a broader and more complete view of the macro-environment of ERS-OC (Dockalikova & Klozikova, 2014). This research focuses on the Dutch case study regarding the implementation of an ERS-OC demonstration project. The next section explains the method that was followed during this study.

3 METHODOLOGY

This section explains and discusses the research method and methodology that was applied to perform the research.

3.1 RESEARCH METHOD

The most common data collection methods in research are quantitative and qualitative methods (Ghauri & Grønhaug, 1995). Quantitative methods aim to quantify empirical studies systematically through statistics and mathematics, relying on numerical interpretation. On the contrary, qualitative research is defined as non-numerical and unstructured and aims to understand real-world situations based on the observations and interpretations of people and things (Bryman, 2001). The research questions require documentation and analysis of the perceptions of different stakeholder groups of ERS-OC. The incentives and barriers for engaging in an ERS-OC project, and the opportunities and challenges regarding the technology that are perceived by stakeholders are set out. This aims to create a deeper understanding of what enables and disables the implementation of ERS-OC in the Netherlands. These incentives, barriers, opportunities, and challenges have to be examined by conversating with potentially involved parties that are familiar with the ERS-OC concept. It is for that reason that a qualitative approach has been selected for conducting this research. A quantitative approach is used for the analysis of the aggregated data.

The research approach that will be applied in this research is a case study approach. This approach can and will 'create an in-depth view on a complex, multi-actor opportunity in a real-world situation' (Crowe et al., 2011). Here, the event that is analyzed is the creation of an ERS demonstration project in the Netherlands. The Cambridge dictionary of English language defines a demonstration as *the act of showing someone how to do something, or how something works* (Cambridge University Press, 2022). The term *demonstration* is chosen, because the goal is to show the Dutch stakeholders – including the government – how an ERS-OC functions when in use. A demonstration project will test 'various legal, political, economic, and efficiency aspects of ERS', as Gustavsson et al. (2020) describe it. This is needed to create awareness and trust in the technology, and comfort investors and decision-makers in investing in the rollout of a large-scale ERS-OC network. The Q-method, where respondents have to state whether they agree or disagree with statements, was also considered (Jedeloo & Van Staa, 2009). However, because the factors influencing the feasibility of creating an ERS-OC demonstration project were not known beforehand, a preliminary set of statements could not be deducted from existing sources.

3.2 DATA COLLECTION

Data can be collected in either a primary or secondary manner (Ghauri & Grønhaug, 1995). Primary data consists of the data that is collected by the researcher on his own through interviews and surveys, for example. Secondary data is the data that is gathered by other instances or people than the author of the research, like literature or articles (Bryman, 2001). Both primary and secondary data sources are used to gather the data for this analysis. The primary data, collected through semi-structured interviews with relevant stakeholders with open-ended questions, forms the main data source for this research. Secondary data sources are used to complement the primary data and better substantiate the conclusions that can be drawn from the interviews. Furthermore, secondary data is used for a better understanding of the overarching problem that is present when aiming to implement ERS-OC on the roads.

The stakeholder groups were identified by examining prior projects and literature on the subject, and are discussed in Section 1.5.2. Then, relevant people of specific organizations of each stakeholder group were approached by email. These people were identified through the network of Siemens Mobility – the internship company – that had access to many contacts, and provided contact details of people and organizations with an affiliation with ERS-OC. The respondents were also asked for other contacts within their network that could be helpful for my data collection process at the end of each interview. For the stakeholder groups where no Dutch organizations were found that had an affiliation with ERS-OC, international counterparts were approached. The secondary data was found through a literature selection process on the online databases Web of Knowledge, Scopus, and Google Scholar, and a web search for recent reports on ERS-OC.

3.3 EXTRACTION AND ANALYSIS OF FACTORS

All interviews were conducted through Microsoft Teams and transcribed automatically. After all the interviews were conducted, the mentioned factors were extracted from the transcripts through open coding. Here, the analyst creates codes based on the data itself, contrary to deductive coding, where predefined codes are determined beforehand (Bryman, 2001). The factors are subsequently divided into enabling or disabling, and internal or external factors through axial coding, where the extracted factors are categorized. Extracting enabling and disabling factors from qualitative data allows for knowledge creation that can facilitate change (Yin, 2003). The distinction between internal and external factors helps to identify what is desired by the organizations, and what is required of the surrounding macro-environment. This explains what the respondents perceive as factors that either facilitate or hinder the creation of an ERS-OC demonstration project, within their organization or in the greater technological landscape. These concepts will now be explained briefly:

- **Incentives** are enabling, internal motivations. They are defined as 'something that encourages a person to do something' (Cambridge University Press, 2022). These are the factors that drive an organization to engage in an ERS-OC demonstration project.
- **Barriers** are disabling, internal factors. These are the factors that obstruct an organization from doing something. Thus, the reasons that make organizations withhold their engagement in an ERS-OC demonstration project.
- **Opportunities** are enabling, external motivations. These include the characteristics of ERS-OC technology that make it viable for an ERS-OC demonstration project to be created.
- **Challenges** are disabling, external factors. These are the factors that 'need great mental or physical effort to be done successfully' (Cambridge University Press, 2022). Here, this relates to the ERS-OC characteristics that require significant attention to realize an ERS-OC demonstration project.

The first sub-question will be answered by discussing the incentives, barriers, opportunities, and challenges mentioned by each stakeholder group. Subsequently, the factors were divided into categories following the PESTEL analysis approach, which has been proven to be functional for exploration of the macro-environment in a similar situation by Gadgil et al. (2022). This framework is used to analyze the political, economic, social, technological, environmental, and legal factors that affect the technology's macro-environment and provides a profound understanding of the ERS-OC environment (Dockalikova & Klozikova, 2014). These concepts will now be explained briefly:

- **Political factors** include the factors that relate to governments or governmental policies.
- **Economic factors** are the factors that have an economic impact on the organization.
- **Social factors** refer to the factors that relate to the social environment and emerging trends.
- **Technological factors** include all factors that relate to the technological aspects of ERS-OC.
- **Environmental factors** refer to factors related to environmental aspects.
- **Legal factors** are the factors that are backed by imposed rules and regulations organizations have to comply with.

This method assesses the market from the viewpoint of a technological proposition, which in this case is the creation of an ERS-OC demonstration project (Gadgil et al., 2022). Integrating the findings of the interviews into the PESTEL framework aims to create a deeper understanding of personal and general perceptions of ERS-OC demonstration projects that are currently unavailable in the literature. Mapping the factors in the macro-environment of ERS-OC that are perceived to enable or disable the uptake of ERS-OC, in general, are set out and discussed. Finally, the factors that directly influence the creation of an ERS-OC demonstration project are extracted from the enabling and disabling factors through the yes/no method. This method simply submits the factors, as defined in Appendix A1, to the question: does this factor have a direct influence on the feasibility of creating an ERS-OC demonstration project? These are finally presented as the factors that need to be addressed to increase the chance of stakeholder engagement when aiming to create a demonstration project.

3.4 INTERVIEWS

The goal of the interviews is to gain insights into the perceptions of people that are directly involved with ERS-OC-comparable projects within their organization. This will provide the most trustworthy data on real-world stakeholder opinions on ERS-OC matters and enables a deeper understanding of what stakeholders perceive as the factors that enable and hinder the implementation of ERS-OC in the Netherlands. Semi-structured interviews were conducted to collect the data, where the interviewer has a list of certain topics that need to be discussed, while letting the interviewees speak freely and abundantly. In this way, the perceptions of the interviewees can be revealed, without a bias created by the question of the interviewer. The conversations were only guided when the interviewees were finished talking and other topics still needed to be discussed. The following topics were discussed during the interviews, among others:

- Role and responsibility in their organizations
- General view on decarbonizing road freight
- Affinity and experiences with ERS-OC
- Willingness to engage in an ERS-OC project
- Goals when engaging in a future ERS-OC project
- Perceived opportunities for ERS-OC
- Perceived barriers for ERS-OC
- Perceived future for ERS-OC
- Organization-specific questions
- Contacts in their network with affinity to ERS-OC

3.5 The respondents

As described in the previous section, many stakeholder groups compose an ERS-OC. The aim was to interview at least one organization of each stakeholder group to create a representative sample. In practice, this was not successful, due to the minimal amount of Dutch organizations having experience with ERS-OC. In the end, no respondent representing the energy supplier side was found. The respondents were approached through the method explained in Section 3.2 through non-probability sampling. This form of sampling is characterized by samples not being randomly selected, but rather specific, relevant samples that act within the field of research and are approached directly (Bryman, 2001). Non-probability sampling was used, because the population of the ERS-OC environment is finite and relatively small. The respondents for this research derived from contacts of the supervisor and other colleagues at Siemens Mobility. Two colleagues of the internship company provided email addresses of samples from various stakeholder groups. This process is called convenience sampling; the researcher uses the accessible sources for samples. These primary respondents subsequently provided more respondents through a process called snowball sampling (Bryman, 2001). This turned out to be an efficient manner to reach out to the respondents, because the interviewees provided names and email addresses of people responsible for ERS-OC-related projects. Engineering firm Movares was the only organization that was approached via their general office. In the end, nine respondents were found. Obtaining contacts through Siemens Mobility was decided to be the most suited way to find the right respondents. Public sources and white and gray literature did not provide the required information of specific stakeholder identification, just a few respondents could be found from public sources. The respondents and their organizations will now shortly be described.

<u>Truck Manufacturers</u>

Scania is a Swedish truck manufacturer that is operative in over 100 countries. They are one of the pioneers in developing BETs and other ZETs. They are experimenting with all possible ZETs that have market potential. Scania has delivered the ERS-compatible trucks for the German pilot projects, of which 15 are in use by now on the three segments (Scania, 2021), making them currently the only European truck manufacturer with that experience. The respondent is the project leader for vehicle electrification at Scania, and is closely involved in the organization’s collaboration with Siemens Mobility in Germany. He is responsible for the trucks that are operative on the three ERS-OC corridors. He is the spokesperson of Scania regarding ERS-OC projects. While working in Sweden, he is considered the most relevant person regarding catenary truck development.

<u>Freight operators</u>

Heineken NV is a world-famous beer brewery of Dutch origins. Sustainability is one of the organization's key pillars. Heineken has investigated the opportunities to electrify the route from their brewery to their inland waterway terminal in the past. This route covers approximately 14 kilometers. While decarbonization is high on the agenda of Heineken, investment costs were too high to finance that on their own. Still, Heineken remains interested in the concept of ERS-OC. The respondent is Manager Projects Customer Service & Logistics at Heineken in the Netherlands. He has been working at Heineken for over 20 years and is responsible for logistic improvement over the entire spectrum, including sustainability matters. When Heineken would engage in an ERS-OC project, the respondents would be the person to manage the project.

Transport & Logistiek Nederland (TLN) is an entrepreneurs' organization for Dutch freight operators. It represents the interest of its members on a local, regional, national, and European level. TLN connects Dutch freight operators and is the largest employers' organization in the Dutch transport sector. It functions as the point of contact for and about the sector. The organization conversates with the Ministry of Infrastructure and Water Management (I&W) about decarbonization of the sector. The respondent is responsible for arranging sustainability and decarbonization policies in the logistics sector. He negotiated with governmental entities about the agreements in the Klimaatakkoord, the Dutch climate agreement. This provided a long-term vision and will guide the sector towards achieving the goals set in this agreement.

Governmental entities

The **Ministry of Infrastructure and Water Management** (I&W) is responsible for road connectivity and circular economy in the Netherlands. Furthermore, they are in charge of mobility issues, including decarbonization matters. Within the department Mobility, the unit Innovation was created. This unit aims to accelerate the ambitions that the Ministry has; making the Netherlands safer, smarter, and more sustainable. The unit Innovation is responsible for executing projects that help to achieve these goals. An ERS-OC project will be under the responsibility of I&W. The respondent is Innovation Manager within the unit Innovation at I&W for over three years. He is the spokesperson of the Ministry regarding ERS-OC. He is a member of a team named 'Verkenning Electric Road Systems' ('Exploring Electric Road Systems'). He has contact with his German counterpart, discussing the progression of ERS-OC on a monthly basis.

Road power component producers

Siemens Mobility is a tech firm that developed the intelligent pantograph system that is used for their so-called 'eHighway' in Germany. The organization is specialized in electrification, mainly on rail, but aims to expand to road solutions through ERS-OC. They offer solutions for rail and traffic issues with intelligent and innovative products. Siemens Mobility is the internship company during this research and contributed in the form of technological competence and an extensive network of people. Two colleagues were spoken during the interview. The first is the head of eHighway Business Development at Siemens Mobility in Germany. He is highly involved in ERS-OC projects in Germany and has tight connections with other countries that are investigating ERS-OC as an alternative for decarbonizing road transport. He provides governments with the necessary information so they can make sensible tenders and accelerate the process. He advises them on corridor selection and other issues they might run into. The second interviewee is Business Developer at Siemens Mobility in the Netherlands. He is bid manager and also responsible for the development of the eHighway in the Netherlands. He provided many links to organizations and people, as well as Siemens Mobility in Germany, which enabled the non-probability sampling approach to gain respondents.

Railtech is a catenary specialist that supplies components up to complete catenary systems for trains, trams, and metros. The organization is innovative in nature and an experienced player in the catenary field. While currently focused on rail solutions, the organization is interested in expansion towards road solutions. The respondent is business developer at the organization. He keeps an eye on market developments and new business options for the organization. While not experienced with electric roads, he thinks of ERS-OC as an interesting development for future business of the organization.

Construction firms

BAM Infra Rail is a construction company that has great experience with the construction of Dutch rail infrastructure, including catenary systems. They value sustainability to a great extent and could become the construction company that constructs and maintains the ERS-OC infrastructure in the future. BAM Infra Rail is specifically responsible for rail projects, including the installation of rail infrastructure and power supply installation. Catenaries on the road are considered an opportunity for the organization. Two people were spoken during the conversation. One interviewee is Acquisition Manager at the organization and is thus responsible for the acquisition of projects. He has intensive contact in the past and present with Siemens regarding collaborations where Siemens is component supplier and BAM Infra Rail is executor. He acknowledges that developments in the field of ERS-OC are interesting for the organization. The second interviewee is Tender Manager at the organization and has great experience with the technique behind the catenaries. He was invited to join the conversation and assess the technical aspects of the catenary technology.

Researchers

Movares is an engineering firm that is committed to making the Netherlands more livable, reachable, and sustainable through innovation. Sustainability is one of their key pillars, being the least polluting engineering firm in the country. Movares has written the first – and currently only – exploratory report on ERS-OC in the Netherlands as a means to mitigate GHG emissions, commissioned by the ministry of I&W. They investigated potential corridors, the costs, barriers, and GHG mitigation potential, among other factors. They concluded that there was too much uncertainty to pick a technology for decarbonizing road freight at this point and further research is required. Two separate interviews were conducted with the company. The first interview was conducted with the Innovation Manager and Mobility Advisor at the organization. He dedicates his energy to mobility issues regarding policy, digitalization, and data. He has contributed to the report by investigating the effects of ERS-OC on road traffic, like what the best corridor would be to commence, and when implementing ERS-OC would be attractive for involved parties. The second interview was conducted with the Energy Transition Advisor at Movares, who works on sustainability issues. She is investigating alternatives for decarbonizing HDTs, including ERS. She was involved in writing the report to a great extent. She has contributed to the report from an energy perspective, performed a technology assessment, and designed the business case. Furthermore, she investigated the circularity of ERS-OC by assessing material use and wear, and scarcity.

An overview of the interviews and corresponding information can be found in Appendix A2. The next section will discuss the findings of this research. First, the mentioned factors are discussed according to the PESTEL categories. Then, the factors per stakeholder group will be discussed. Lastly, the factors that directly affect the feasibility of creating a demonstration project are discussed to analyze what is perceived as being enabling and disabling factors regarding an ERS-OC demonstration project in the Netherlands.

3.6 Validity and reliability

As described by Bryman (2001), validity and reliability are essential concepts to consider when performing qualitative research. Valid and reliable research prevents biases and keeps the outcomes objective. Validity refers to the accuracy of a study, while reliability refers to the consistency of a study. These concepts will now be discussed for this research.

The aim of this research was to identify stakeholder perceptions of ERS-OC. The method of conducting semi-structured interviews ensures valid results of the individual interviews, by letting the respondents talk freely about the topic, without the interviewer being suggestive. The perceptions of the stakeholders are therefore considered valid. However, the interpretation of these perceptions is vulnerable to internal validity flaws, since the research is performed by one researcher determining the meaning of the findings. Internal validity concerns the interpretation capabilities of the authors and is dependent on the number of researchers performing the study. While multiple researchers can share their thoughts and ideas, get feedback and get to a consensus, a lone researcher analyzes the research findings from a single perspective (Bryman, 2001). More insights will result in more valid conclusions about the relationship between observations and theories. External validity refers to the extent to which the result can be generalized over larger sample groups and other settings. This increases when sample sizes are large, and is generally seen as a problem for qualitative research (Bryman, 2001). This research has interviewed nine respondents representing six stakeholder groups, mainly based in the Netherlands. It is therefore questionable whether the results can be generalized over a larger population, especially for researchers from other countries.

Reliability can also be tested either internally or externally. Internal reliability refers to the number of researchers that have worked on a study. The study's reliability is dependent on the number of observers; more observers reduce the chance of misinterpretations, which can influence the research conclusion to a great extent. This will occur more frequently with single researcher studies. External reliability refers to the replicability of a study. When the same research is performed under similar conditions, the results should be comparable. The choice was made to approach organizations with an affinity to ERS-OC technology to ensure that the respondents have knowledge about the subject to some extent. This aimed to prevent non-substantiated opinions from influencing the reliability of the results. While the working method is described step-by-step in this section, external reliability is questionable. The ERS-OC environment changes continuously, and the market will have evolved the next time someone aims to reproduce it. Also, the perceptions of various individuals will presumably not be identical, and the perception of an individual does not represent an entire sector. Also, the results are interpreted by one researcher, providing a unilateral view of the results. The interviews were conducted in Dutch with Dutch stakeholders, and in English with foreign parties. These foreign parties were from Sweden and Germany, and spoke fluent English. The language barrier would therefore not affect the reliability of the research findings. The transcripts were checked and corrected directly after the interview took place to prevent errors in the data.

4 RESULTS

This section discusses the findings of this study. It first elaborates on the perceptions of specific stakeholder groups, and subsequently the differences between stakeholder groups are discussed. Then it focuses on the enabling and disabling perceived factors of ERS-OC, divided into the PESTEL categories. Then, it will discuss the factors that directly influence the feasibility of a demonstration project. Finally, overarching themes that were found in the interviews are discussed.

4.1 STAKEHOLDER PERCEPTIONS

This section explains the perception of stakeholder groups with regard to ERS-OC demonstration projects. It will answer the following research question:

SQ1. What are the stakeholder-specific perceptions of ERS-OC?

The stakeholder-specific perceptions are derived from the interviews. The factors that were mentioned by the stakeholders and the corresponding definition can be found in Appendix A1. The division of those factors into the PESTEL categories, and how they are numbered is listed in Appendix A3. Appendix A4 provides an overview of the factors mentioned per respondent, and the corresponding frequency. The perceptions of individual stakeholder groups derived from the interviews will now be discussed.

<u>Truck manufacturers</u>

The truck manufacturers state that the need for electrification of trucks is high, and ERS-OC can be a significant contributor to accomplishing this. They state that ERS-OC is a mature technology, and that no new skills need to be acquired to produce catenary trucks. ERS-OC can provide a good business case for long-haul transport considering its market readiness and the lack of viable alternatives currently available. ERS-OC has the advantage that it can function also with partly electrified roads and signification emission reductions can be realized by solely electrifying the core network. The company explores all kinds of renewable trucks to ‘do something good for the environment’, while recognizing the political urgency as well as the advantages of being an early adopter of such renewable technologies. A mentioned opportunity is starting with shuttle routes for a demonstration project, which can then be gradually expanded. The electrification of railways is mentioned as an example that such a large-scale transition can happen, and that catenaries decrease the need for batteries. Constructing physical infrastructure will create public awareness of ERS-OC as a solution for decarbonization, which will attract potential users. They claim it is important to provide standards for ERS-OC to allow for transnational freight transport.

A perceived obstructing factor for ERS-OC progression is the lack of short-term gains for the involved parties, so stakeholders are hesitant to invest. The high initial investments will yield in the long term, but are considered risky without promises about large-scale rollout of ERS-OC. The catenary system might cope with an image problem, the public might find the infrastructure unesthetic or old-fashioned. Everyone is following technological development regarding ERS-OC or other technologies, so it is difficult to take strides and progress. There is currently no ERS-OC market present, making it hard to find suitable partners for an initial project. The challenge is to create international standards and public support through collaboration and dedication. When the infrastructure is in place, and the electricity price can be kept reasonable, it will be ‘very difficult to beat that’. ‘When you are through the first five years, and profitability of the system is proven, then it is a no-brainer to continue.’

<u>Freight operators</u>

The freight operators see ERS-OC as an interesting alternative for decarbonizing HDTs. They acknowledge its potential contribution to emission reductions and think that ERS-OC can potentially be a cost-saving measure, when properly scaled up. One freight operator says they want to decarbonize ‘as soon as possible, but affordable’. They claim, however, that it is too expensive for freight operators to invest in such a system individually, and that investment security from governmental entities is essential for the engagement of the freight operators. They state that they are willing to engage in an ERS-OC project when the right preconditions are in order. This can be enhanced by setting up policies that encourage the uptake of catenary trucks, making it more attractive to engage. However, freight operators need to comply with emission agreements to avoid fines, and alternatives are scarce, expensive, and inefficient. They highlight the possibilities for shuttle routes as an option for an initial project, since it would not be attractive for a freight operator to engage when catenaries are available on just a fraction of the journey.

Obstructing factors mentioned by the freight operators include the developments of other technologies, that are being followed closely and might be more suitable for their transition. Breakthroughs in battery technology are expected for HDTs. Looking at the total costs, they think battery-electric solutions are more feasible. The magnitude of the required investments, the risk of technological failure, and the lack of short-term gains make freight operators withhold. One states that the emission reduction targets 'will not be met at the current pace', and that the challenge is to take strides and move from theory to practice. This is possible solely when 'government and corporate businesses cooperate'. This is perceived as difficult due to an absence of leadership and perspective resulting from a lack of public and political support, and the absence of an attractive business case for the freight operators. While ERS-OC is considered a realistic carbon mitigation option, it is perceived to not be available large-scale in time to meet the goals of the Dutch climate agreement. The rollout of an extensive ERS-OC network will 'take decades'.

Governmental entities

ERS-OC is considered a sustainable solution that matches the ambitions of the governmental entities. Incentives to engage in an ERS-OC demonstration project are the ability to reduce emissions, and the upscaling pace that can be realized when the demonstration would be successful. It is acknowledged that alternatives are expensive and scarce, and that hydrogen for HDTs has become increasingly questionable in the past year. Also, using electricity from the national grid will make the country less dependent on foreign ICET fuel sources. ERS-OC is therefore considered a viable alternative for HDT decarbonization, which is confirmed by the founding of team 'VERS' ('Exploring Electric Road Systems'). This team explores the financial and technical feasibilities for ERS-OC in the Netherlands, commissioned by the government. Economically, ERS-OC can also become profitable fairly rapidly. ERS-OC has the advantage that it is ready to implement and can complement the few other technologies that are available for decarbonizing HDTs. In this way, smaller batteries and fewer resources are required to electrify the HDT fleet, decreasing dependency on foreign resources and products that are required for ZETs. To create greater awareness of the technology and a better understanding of how the ERS-OC SoS should be configured, it could be helpful to create a game in which stakeholders get assigned a similar task as they would in real life. In this way, the role and responsibilities of the different actors become clear. The opportunity of decreasing emissions by around thirty percent with the electrification of just the core network is considered a motivation to investigate the opportunities for ERS-OC more.

The governmental entities highlight that it is awaiting ERS-OC developments in other countries to learn how it should be done, before engaging in such a project themselves. Technological developments in other zero-emission technologies are also being watched. It is perceived as a challenge to configure the ERS-OC SoS, since this is a novelty and no examples are present. The regime, as explained by the MLP, needs to be reconfigured, which requires a holistic perspective. International developments of ERS-OC system configuration are being followed closely. It is also ambiguous what the future role of the government will be in an ERS-OC project, various constructions are being considered. It is vital to increase political and public awareness for ERS-OC being considered a significant player in the field of road decarbonization.

Road power component producers

The road power component producers mention that ERS-OC is an excellent measure to eliminate some of the biggest bottlenecks of other renewable powertrains, like battery size and weight, or range issues. It is highlighted that ERS-OC is a complementary technology, and is meant to support other drivetrains rather than compete with them. The technological maturity and scale-up pace of the technology are considered as opportunities for decarbonizing HDTs, and installation and maintenance works will not impose any major problems. Proof of concept is present and shows that an ERS-OC functions properly under real-world conditions. They mention that international collaboration is essential for the success of this technology, since freight operators often operate transnational, so standardization is required. The rapid upscaling potential is 'what you need for a European solution. You cannot wait until 2050 and then have everything ready'. However, infrastructure constructors and truck manufacturers are both waiting on each other, the chicken-and-egg story. 'That is why you should start with a corridor where you have a clear flow back and forth', a shuttle route. The increasing lithium price causes battery prices to not become as cheap as expected. The opportunity is mentioned that when ERS-OC hits the same TCO as alternatives, demand from that segment will boom. Fuel costs will be lower than alternatives and conventional fossil fuels, which can convince freight operators to engage. Using electricity from the national grid – which is the case with ERS-OC – also reduces dependency on foreign resources like clean hydrogen and batteries that are required for alternative ZETs. The visibility of the infrastructure is named as a marketing tool for the component producers.

When an ERS-OC network is rolled out, initial utilization will be low, which will 'make people ask if this taxpayer money is spent well', which is a challenge to overcome. Furthermore, 'someone has to pay for it', and it is not yet clear who that has to be. It would help to quantify sustainability gains into monetary values. Linking sustainability with profit can attract investors when governments are hesitant. Green investors might be convincible when the profitability of their investment is shown. Configuring the SoS is something that will take a great effort. Also, freight operators do not want to make concessions regarding range and flexibility, so the zero-emission powertrains should offer similar characteristics. Hybrid trucks could be a useful tool in the transition phase; when freight operators are told that they 'can drive electrically for 80-90 percent of their journey, while still having the same flexibility, that gives them comfort'. Lobbying of other sectors is perceived as a factor why ERS-OC is not getting the same amount of attention that other technologies get. The lack of consequences when emission agreements are not met is an obstructing factor for the progress of ERS-OC, or any zero-emission technology for that matter. Politicians tend to ignore sustainability goals and prioritize other subjects. The biggest challenge is to create a sense of political urgency to decarbonize HDTs, which can create support base for ERS-OC. This is essential for decision-makers to become dedicated to the technology and accomplish something.

Construction firms

Installation and maintenance of catenary systems is the core business of the construction firm. Adding ERS-OC activities to their portfolio would provide new market possibilities, since sustainability is one of the organization's key pillars. They recognize the advantages of engaging in early stages. They emphasize that such a project requires clear leadership and vision to force a breakthrough, and that it would be helpful to 'get all stakeholders into one room' and create a lobby that has sufficient support base to get things done. The potential financial and environmental gains for the involved parties should be better explicated to enthuse them. It would be useful to set up a test site where potentially involved parties could get a feeling of the technology. They see the potential of ERS-OC to complement other technologies, while reducing the need for batteries through dynamic charging. A thought worth mentioning is to assess the possibilities of railways and parallel running ERS-OCs exchanging energy to alleviate the pressure on the electricity grid.

The construction firm observes a lack of leadership and legislation that holds back the progression of ERS-OC in the Netherlands. Also, the effects of the catenary wear and tear need to be thoroughly assessed before dedicating efforts to the technology. They express some safety concerns for road users when the system is in use, and wonder if there would be any complications regarding grid capacity. They also acknowledge that configuring the system-of-systems is a big challenge.

Researchers

The researchers acknowledge the potential contribution of ERS-OC for decarbonizing transport, and state that it is an affordable solution compared to alternatives. However, dedication of stakeholders is required to enable upscaling and make the system profitable. They recommend starting with shuttle routes for an initial project to ensure system utilization. From there on, the infrastructure can be expanded over busy highways. An example mentioned is the Port of Rotterdam with expansion over the A15 highway. The investment costs are predictable, and the scarcity of resources for batteries makes ERS-OC a viable alternative to support HDTs.

The researchers highlight that, while being interesting for the future, many aspects of ERS-OC require further investigation before large-scale implementation should initiate. The biggest concerns regard grid capacity, voltage quality, and the sustainability of the system as a whole. The circularity of ERS-OC is questionable due to material use, wear and tear, and cupper scarcity. The voltage quality is affected by the number of trucks connected to the system on a certain segment, and quality could be lost when too many or too few vehicles are connected to the catenaries at one segment. Further research is required to elaborate on the specifications of electricity transfer from the grid to the vehicle under different circumstances. Also, organizing and executing such large-scale plans requires careful planning. For instance, the amount and size of additional substations required. They see challenges regarding system configuration. Stakeholder attraction should get more priority, and political urgency should be increased. There is also uncertainty expressed about the future success of ERS-OC, which is highly dependent on the developments in other zero-emission technologies.

No energy supplier was found that was able to respond. Their perception of ERS-OC can therefore not be analyzed.

In conclusion, the truck manufacturers are optimistic about the future of ERS-OC and highlight the lack of alternatives. They foresee issues with investments in the first five years, but are sure the technology will break through in the end. It seems that freight operators perceive ERS-OC as a viable alternative to decarbonize their fleet, but that it is only possible with financial support and clear leadership. The governmental entities also foresee a future for ERS-OC to decarbonize road freight. They are awaiting developments in other countries and with other technologies to learn about the configuration of the system. They highlight the advantages of dynamic charging and decreased resource dependency, while being economically justifiable. The road power component producers are certain about the advantages of ERS-OC to contribute to road freight decarbonization. They highlight the flaws of alternate zero-emission powertrains that can be eliminated by the rollout of an ERS-OC network. They insist on creating a standardized, pan-European network for the technology to flourish. They identify a lack of political urgency to achieve climate goals. The construction firms think that creating sufficient support base is a key opportunity when aiming to implement ERS-OC, and that the lack of leadership withholds progression. The researchers advise starting with a shuttle route, and say that stakeholders express their concern about the circularity of the system, and recommend further research on electricity transfer under different circumstances.

4.2 Enabling and disabling factors

Now that the stakeholder-specific perceptions are set out, the holistic perceptions can be analyzed. This section aims to answer the research question:

SQ2. What enabling and disabling factors are mentioned by stakeholders?

It focuses on the enabling and disabling factors for the implementation of ERS-OC that were mentioned by the stakeholders during the interviews, divided into the PESTEL categories to gain insights on what is required in the macro-environment to induce change. The extracted factors were divided into either the political, economic, social, technological, environmental, or legal category as described in section 3.3. In total, 317 stakeholder-mentioned factors were extracted from the interviews. The definition of the mentioned factors can be found in Appendix A1, and the categorization of the factors into the PESTEL categories can be found in Appendix A3. The frequency of the PESTEL factors mentioned per stakeholder can be found in Appendix A4. The mentioned factors will now be discussed.

<u>Political</u>

Political incentives mentioned by the respondents are decreased fuel dependency on foreign countries and political auxiliaries, displayed in green in Figure 6. ERS-OC usage will decrease the need for foreign oil, making the country less dependent on other countries' resources, which is considered an incentive for governmental entities. Political tools in the form of subsidies or fines are mentioned as motivations to engage in ERS-OC projects.

The most mentioned opportunity is decreased resource dependency through ERS-OC, displayed in blue in Figure 6. The Netherlands is currently highly dependent on other countries for its batteries, and demand for these batteries will rise as long as EV sales increase. ERS-OC uses electricity from the national grid. An extensive ERS-OC network will decrease the demand for foreign batteries, making the country less vulnerable to the availability and price fluctuations of certain essential resources for ICETs and ZETs.

The most frequently mentioned political barrier is a lack of leadership (yellow in Figure 6). To configure the system-of-systems that is ERS-OC, there has to be an organization that takes the lead and sets out a long-term plan. The government is often mentioned to be responsible for this role. Linked to this barrier is the lack of vision and perspective that is identified. Stakeholders indicate that long-term promises will stimulate engagement and investments in the technology. When this is not ensured, stakeholders are holding back because they are fearing loss of investment. Lastly, political lobbies are mentioned that may hinder the implementation of ERS-OC. Large corporations may prefer other ZETs to become dominant out of their interest.

The most frequently mentioned political challenges are political acceptance and the lack of political urgency (red in Figure 6). Political acceptance refers to dedication of decision-makers to invest in ERS-OC as a climate mitigation technology. According to the interviewees, the government is currently not concretely considering ERS-OC as an option for decarbonizing road transport, but is still in the exploratory phase. The urgency for politicians to realize vast emission reductions is absent, according to the respondents. Due to a lack of penalties when climate agreements are not met, the politicians do not appear to prioritize the decarbonization of HDTs and focus on other political issues. Another challenge for creating an ERS-OC demonstration project is to find suitable partners, freight operators in particular. These operators will not be interested unless it is economically attractive for them, which is difficult when starting with a small corridor since pantograph utilization will be low on a long-haul journey. These operators have to be lured in somehow to make them participate, requiring political tools. Another mentioned challenge is the chicken-and-egg story, meaning that all involved parties are waiting for each other to make a move. Freight operators will and cannot buy catenary trucks when they are not being produced. Truck manufacturers will not produce catenary trucks unless sales are assured through promises of the rollout of an extensive ERS-OC network. Meanwhile, governmental entities are not keen on doing large investments when utilization is not ensured. Breaking this circle is a challenge to overcome. Also, responsibility ambiguity is identified by the interviewees, meaning that it is unclear which (governmental) organization is responsible for realizing and financing such a project, since it can be categorized into sectors like transport, energy, environment, and so on.

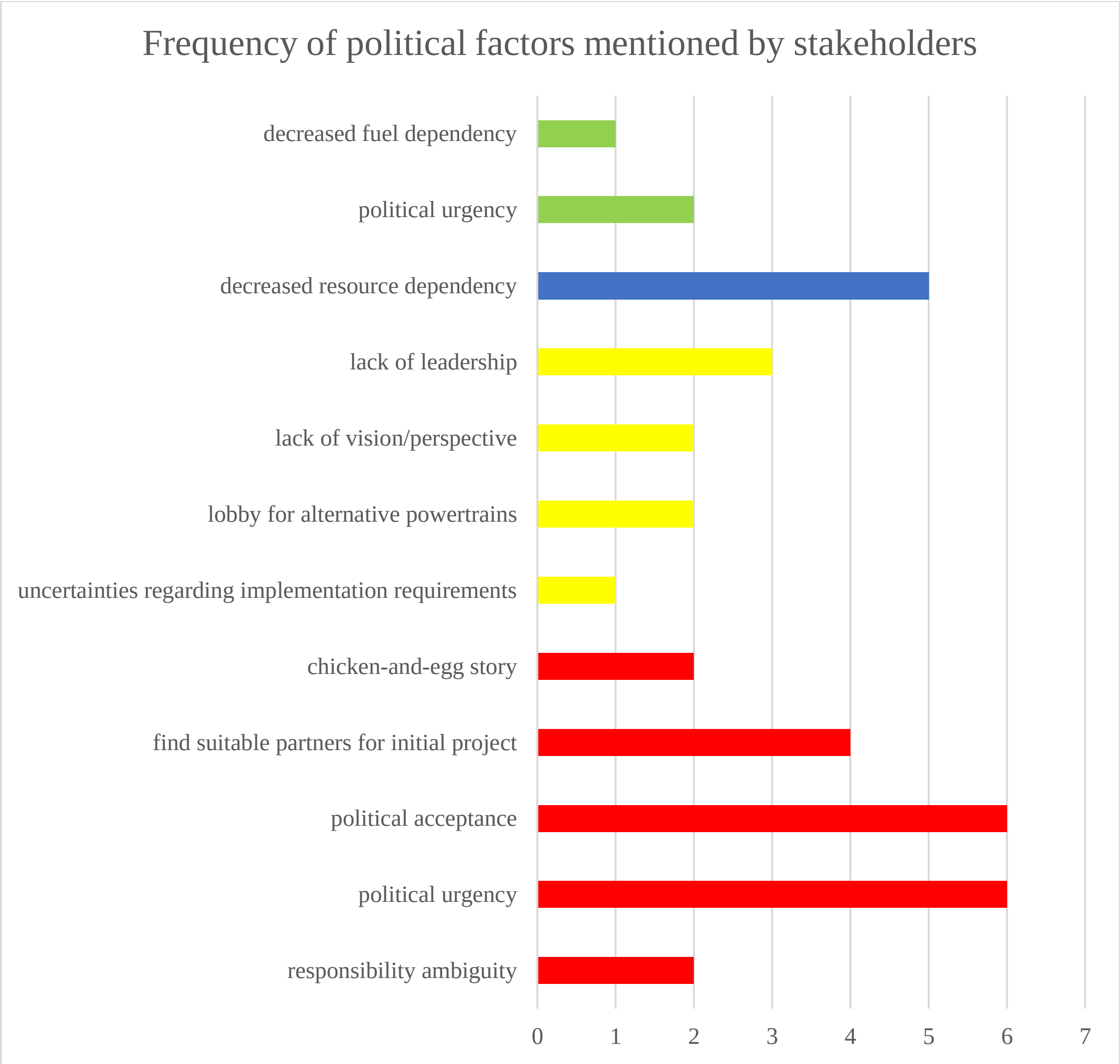

FIGURE 6 - FREQUENCY OF POLITICAL INCENTIVES (GREEN), OPPORTUNITIES (BLUE), BARRIERS (YELLOW), AND CHALLENGES (RED) MENTIONED BY STAKEHOLDERS

Economic

About a quarter of all factors extracted from the interviews regard economic statements (Table 18 in Appendix A5). The incentive that was mentioned most was the cost reduction that could potentially be achieved by switching to ERS-OC as a powertrain for HDTs, as can be seen in green in Figure 7. Cost savings in the long term can be achieved through lower fuel costs and lower maintenance costs for freight operators. Some stakeholders, like construction firms and road power component producers, mentioned that ERS-OC is interesting because their organization would enter a new market, with new customers, generating new revenue streams. Governmental entities could generate revenue through payment systems for the users that could pay back the infrastructure investment fairly quickly when the system is utilized properly, and through decreased foreign fuel imports.

Economic opportunities around ERS-OC are abundant, according to the stakeholders, and are shown in blue in Figure 7. They mention that security of their investment could induce rapid progression. Initiative from national governments through state-financed investments in infrastructure will create trust among other stakeholders, that will feel more secure about the investment they have to make to join the ERS-OC collective. These organizations are now holding back, because they fear the technology will not break through and their investments will be lost. The investment costs are predictable and with low risk due to the proof of concept present and the technological maturity of the system, which facilitates decision-making for investors. When considering the long term, ERS-OC can be the most cost-efficient alternative for zero-emission trucking. An extensive ERS-OC network will become cheaper when expanded through economies of scale. Also, it can be a useful tool to link investment costs with sustainability gains to attract organizations. By showing them that ERS-OC can be profitable both environmentally and financially, they will be more easily persuaded into engaging in a demonstration project. The catenaries lower the need for large and heavy batteries to achieve high ranges, which can reduce costs and provides a well-substantiated business case for long-haul transport. Also, engaging in an ERS-OC demonstration project can provide an early advantage for involved parties, since they will be pioneers in using such technology, providing the advantage of more experience and customer base when others choose to engage in ERS-OC. Other mentioned opportunities include the visibility of the physical system as a marketing tool, and using the increasing presence of green investors that want to magnify their capital through sustainable solutions by convincing them of the potential profitability of ERS-OC when gathering investments.

However, some significant financial barriers are mentioned for the implementation of an ERS-OC demonstration project, shown in yellow in Figure 7. This forms a risk for investors since network occupation is not guaranteed and investment will be lost if other technologies will become dominant. This is not desirable when investing public tax money or making long-term corporate investments. ERS-OC is a long-term decarbonization solution, that requires large upfront investments that may not be earned back quickly. Return of investment can take many years when the rollout is viscous. The lack of short-term gains is considered an obstructing factor for engagement in ERS-OC.

Economic challenges for ERS-OC that are mentioned are the high initial investment that is required for rolling out the demonstration project and eventually also subsequent corridors (red in Figure 7). Building the physical infrastructure, expanding the electricity grid, and financing the catenary trucks require significant investments. Gathering these investments to realize the rollout of an ERS-OC network is considered a challenge. Another bottleneck that is mentioned by various stakeholders is the complexity of composing an attractive business case for all parties involved. This is perceived as necessary to attract all stakeholders needed for a functional ERS-OC SoS. Another mentioned challenge is that the increasing electricity demand will affect future prices. Electricity should maintain at a competitive price to attract stakeholders.

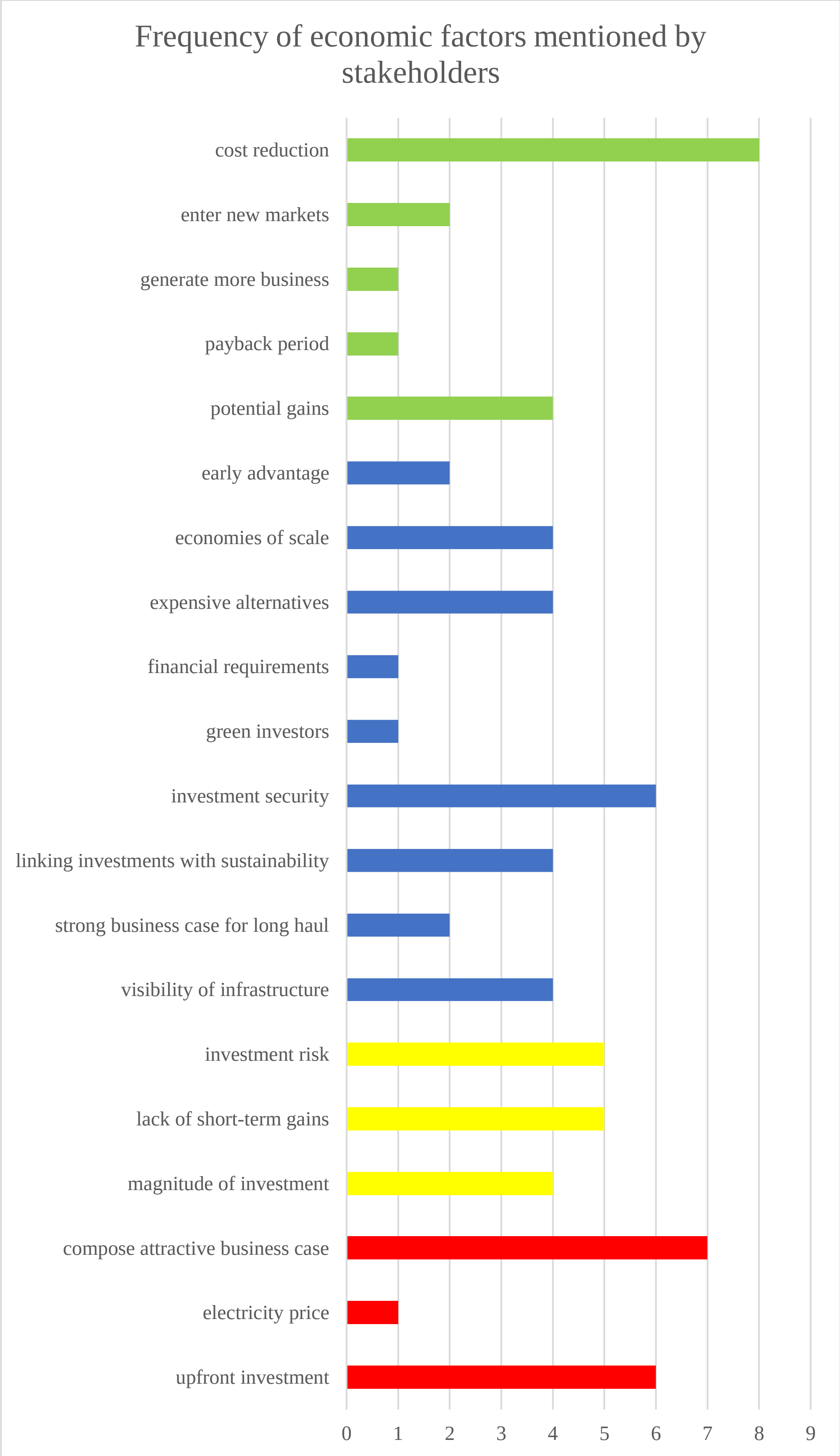

FIGURE 7 - FREQUENCY OF ECONOMIC INCENTIVES (GREEN), OPPORTUNITIES (BLUE), BARRIERS (YELLOW), AND CHALLENGES (RED) MENTIONED BY STAKEHOLDERS

Social

Social incentives (green in Figure 8) that are mentioned are social pressure and brand image. Social pressure refers to the pressure from society or organizations to make the transition towards ZETs to save the planet. By doing this, an organization can improve its brand image by appearing ‘green’ and committed to the environment.

The greatest social opportunity that is mentioned is lobbying for ERS-OC as a decarbonization measure, which is shown in blue in Figure 8. By gathering interested organizations into one room to discuss the opportunities of a demonstration project, a support base can be created that is capable of realizing a demonstration project. This can be realized by solutions that make the demonstration project more tangible. Stakeholder proposed solutions to achieve this are the creation of a test site on a full or smaller scale, or through a game that lets all the involved parties cooperate and get familiarized with their future role. Stakeholders mention that the sustainability trend that is currently going on facilitates attracting investors when governmental funding is not sufficient.

A mentioned social barrier is that organizations often act out of their interest (yellow in Figure 8). In this case, continuous and intensive cooperation between stakeholders is required, and selfishness can complicate progress. Another social barrier is the image problem that ERS-OC might have. People think it is an unesthetic solution that is undesired on highways, or they feel like catenaries have the sole purpose of providing energy for rail solution and it does not belong on roads.

The main social challenges, displayed in red in Figure 8, exist in gaining public support. Awareness and acceptance of the public will open doors for ERS-OC to penetrate the market. Now, the public is more aware of alternatives like BETs and FCETs. Other social challenges of ERS-OC that are mentioned are user attraction and international collaboration. Attracting ERS-OC users might be difficult, especially when no large network is rolled out. It is perceived to not be profitable for the short term, so freight operators might not purchase catenary trucks when they can only use ERS-OC on a fraction of their journey. While nations often follow their personal plans, the rollout of ERS-OC requires international collaboration. Standardization is required to support HDTs that often operate on transnational routes. While standardization is a problem with rail solutions, since all countries have developed their own rail systems in the past, ERS-OC can become standardized across Europe and even the world. However, this requires international collaboration which is not obvious.

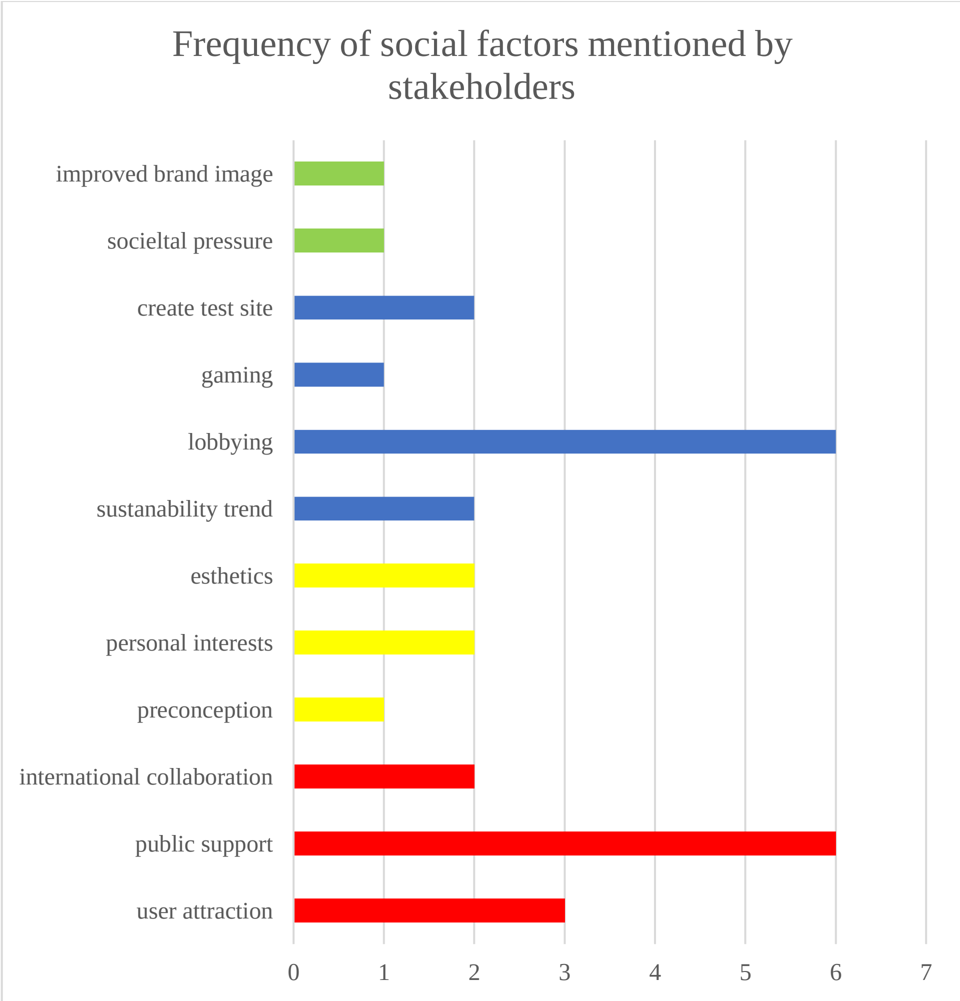

FIGURE 8 - FREQUENCY OF SOCIAL INCENTIVES (GREEN), OPPORTUNITIES (BLUE), BARRIERS (YELLOW), AND CHALLENGES (RED) MENTIONED BY STAKEHOLDERS

Technological

The vast majority of the factors mentioned by the stakeholders are technological in nature, as can be seen in Table 18 in Appendix A5. The technological incentives (green in Figure 9) that are mentioned are that there is a consensus that there is a need for electrification in road transport, and that ERS-OC can contribute significantly. Also, the pace at which ERS-OC infrastructure can be rolled out and expanded provides an incentive to invest. This can be achieved faster than an extensive hydrogen network, for instance.

The opportunity that is mentioned the most is the technological maturity of ERS-OC, shown in blue in Figure 9. Compared to zero-emission alternatives, ERS-OC has low investment and utilization risks. An extensive network could be rolled out instantaneously when investments are secured. The pilot segments in Germany provide proof of concept of the functionality of the technology in real-world conditions. Construction and maintenance skills are present in rail power technology firms, so no additional skills need to be obtained, according to the respondents. Another frequently mentioned argument is that alternative ZETs are currently expensive, while the TCO of ERS-OC is lower than BETs and FCETs when a proper network is rolled out. Also, the complementarity of the technology is considered a massive pro for implementing ERS-OC by many of the respondents. The catenaries do not have to be installed along the entire route of the truck, but can support other drivetrains on the busiest road segments, providing propelling power whilst charging the battery simultaneously. This enables long-haul transport without the need for heavy batteries. Also, the energy efficiency of ERS-OC is higher than alternatives, even ICETs. Having the lowest energy loss provides an interesting argument when transitioning towards sustainable powertrains. Vast carbon reductions can be realized when only the core highway network is electrified, so modest investments can induce significant emission reductions. Starting off with shuttle routes is advised by various stakeholders, so that freight operators that use this specific corridor daily can be approached for an initial demonstration project. ERS-OC is fit for gradual build-up, so the busiest corridors can act as a starting point, and expansion towards other busy segments can follow. This allows for gradual, modest investments to be sufficient for the rollout of an ERS-OC network. Another opportunity that is mentioned is that, because the catenary trucks use energy directly off the grid, it will lower the pressure on charging stations. Usage of ERS-OC will decrease the number of trucks at charging points, and therefore also the number of chargers required, offloading the grid. Lastly, arguments were mentioned that give ERS-OC an advantage over rail solutions. Some suggest that modal shifts are needed to realize the carbon reductions required to achieve the climate goals. However, rail solutions do not offer the same flexibility as ERS-OC. Furthermore, rail standardization is not possible anymore due to existing differences between countries. ERS-OC standards are being set up and can achieve standardization across the whole of Europe, or even the world.

The biggest hurdle for ERS-OC breakthrough, according to the respondents, is that decision-makers await landscape developments (yellow in Figure 9). Since decarbonizing road freight is a costly transition, there is the hope that technological breakthroughs in battery and fuel cell technology will lower costs significantly, which hinders the progression of implementing ERS-OC. Moreover, decision-makers wait for other countries, that are further in the development process of an ERS-OC network, to see how they will configure the ERS-OC SoS. In that way, Dutch decision-makers aim to avoid making mistakes, which obstructs progression. Another frequently mentioned barrier is the perceived feasibility of ERS-OC. Some stakeholders do not seem to believe that ERS-OC is a feasible solution to decarbonize road freight, and that other technologies will become dominant because of high initial investments, lack of infrastructure, and no personal experience with the technology, in contrary to battery-electric charging vehicles and infrastructure. Stakeholders mention that the initial usability of ERS-OC forms a barrier to stakeholder engagement. When just a couple of small segments are electrified, it is not profitable for users to buy catenary trucks when they can only use the catenary infrastructure for a fraction of the journey. Moreover, freight operators do not want to make concessions regarding route flexibility. Their sustainable drivetrain has to provide the same range and flexibility as current ICETs. The absence of sufficient ERS-OC infrastructure, and the absence of batteries capable of long haul journeys is considered a barrier for freight operators when transitioning to ZETs. Also, road users will see catenaries without trucks connected at the start, which can make them doubtful about the system's added value to society. The catenaries have to be replaced every once in a while, which is considered undesirable. The physical infrastructure might also have hindering effects on traffic flow. Also, since there currently is no market, there is no infrastructure and no catenary trucks. Stakeholders are not keen on engaging in ERS-OC projects when infrastructure is absent and no trucks are on the market. The stakeholders lack a sense of tangibleness.

The respondents have also mentioned several technological challenges, shown in red in Figure 9. The most frequently mentioned challenge is grid capacity; in order to function well, the electricity grid has to be able to handle the required extra energy needed for the usage of ERS-OC. Grid capacity is a broader problem in the energy transition. Additional substations need to be built when ERS-OC is rolled out in order to connect the system to the grid. Another argument mentioned is that voltage distribution problems might occur when too many or too few trucks are connected to an ERS-OC segment at once. The voltage quality could be affected negatively. Installation and maintenance of the system requires temporary (partly) road closure, which hinders traffic flow. This requires careful planning and calculations. There are also safety concerns among stakeholders. When the catenaries break, the loose cables form a hazard for road users. Stakeholders also mention that it is generally difficult to take strides from the hypothetic phase to the realization phase, especially in large transitions, and that this also applies to the implementation of ERS-OC.

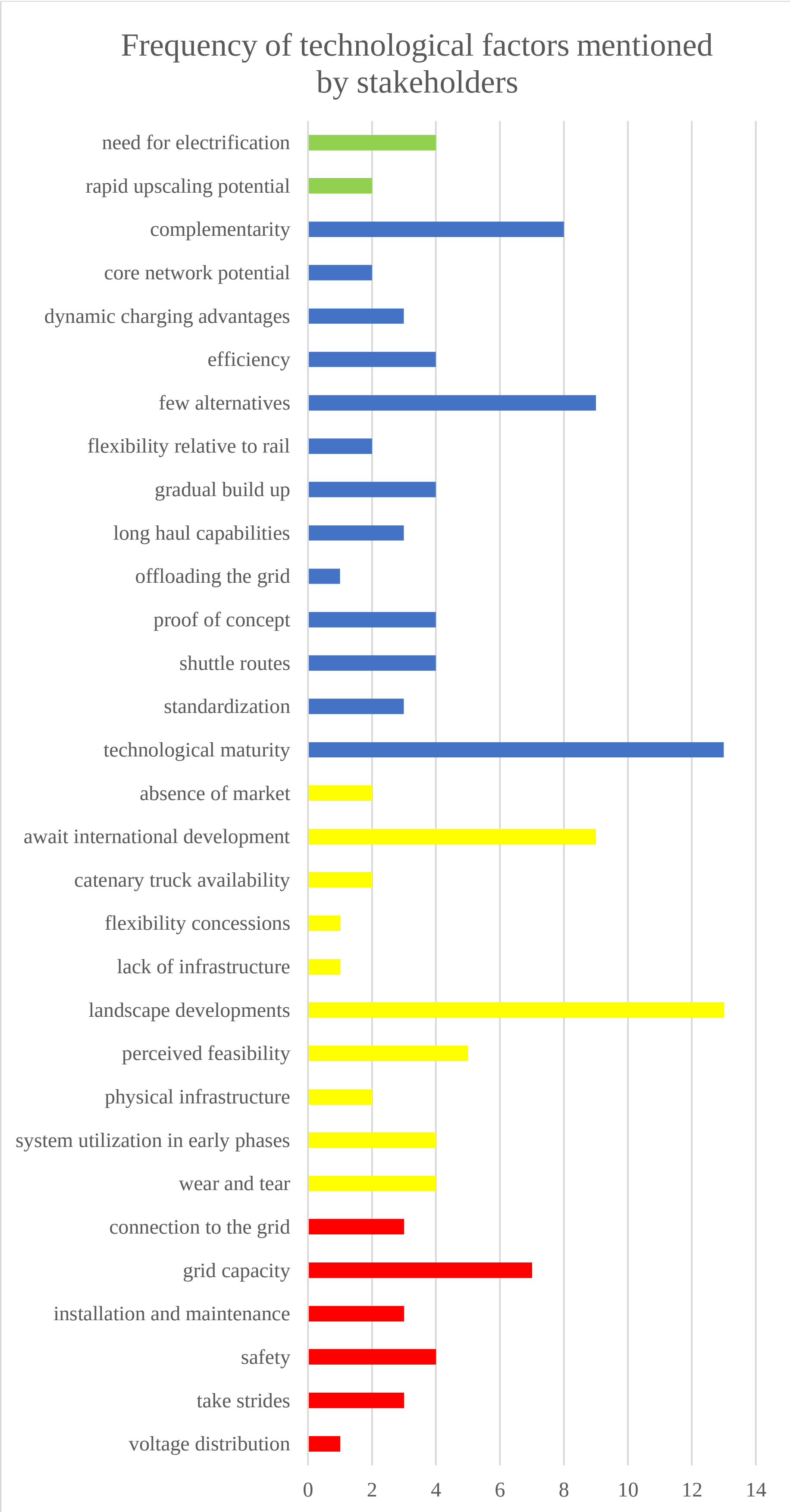

FIGURE 9 - FREQUENCY OF TECHNOLOGICAL INCENTIVES (GREEN), OPPORTUNITIES (BLUE), BARRIERS (YELLOW), AND CHALLENGES (RED) MENTIONED BY STAKEHOLDERS

Environmental

Just a few of the factors are environmental in nature. The most mentioned incentives are that ERS-OC complies with the ambitions of their organization, and that it can be used to reduce their carbon footprint (green in Figure 10). Engaging in ERS-OC projects is considered 'doing something good for the environment'.

Some concerns were expressed concerning the circularity of ERS-OC as a 'zero-emission' technology, shown in yellow in Figure 10. Contact between the catenaries and the pantograph causes friction, which causes wear of the copper wires, causing copper particles to scatter into the environment. These particles cannot be recycled, so the system is not entirely circular, something that is highly preferable for long-term sustainability measures. The catenaries also have to be replaced every few years. Furthermore, copper is a finite, scarce resource that is essential for the conduction of electricity from the grid to the vehicle. Long-term usage of ERS-OC can be affected by price and availability fluctuations of this resource. Others argue, on the other hand, that ERS-OC decreases the dependency on other scarce resources, like lithium used in batteries (blue in Figure 10). An extensive ERS-OC network enables for smaller batteries in trucks, thus, fewer lithium being required. Also, less gasoline would be required for hybrid HDTs in the transition period toward ZETs.

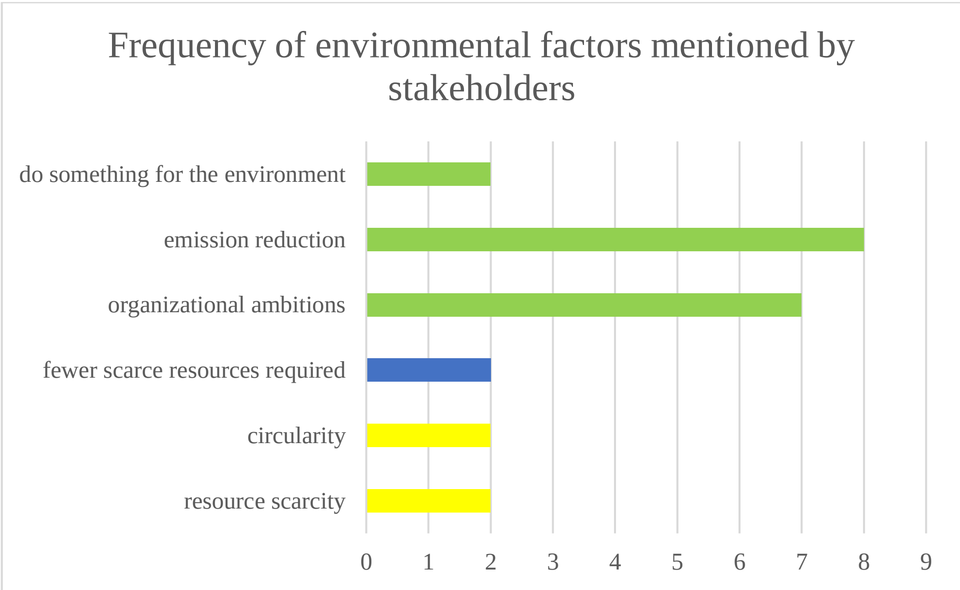

FIGURE 10 - FREQUENCY OF ENVIRONMENTAL INCENTIVES (GREEN), OPPORTUNITIES (BLUE), BARRIERS (YELLOW), AND CHALLENGES (RED) MENTIONED BY STAKEHOLDERS

Legal

Meeting climate agreements and avoiding fines are the legal incentives mentioned by the respondents and displayed in green in Figure 11. The respondents mention that it is a challenge to achieve the climate goals for the near and far future regarding HDTs. While some mention the climate agreements as an incentive to engage in ERS-OC, others argue that there is a lack of consequences when these agreements are not met, perceiving these agreements as more of a barrier (yellow in Figure 11). They mention that there is a lack of legislation that has to motivate organizations to switch to ZETs, and argue that it would be stimulating when the government would provide more incentives for them to switch to renewable alternatives. They acknowledge that binding policies would accelerate this transition by creating trust and perspective, and making the technology affordable for the affected parties (opportunity shown in blue in Figure 11). The biggest legal challenge is considered to be the configuration of the ERS-OC SoS, shown in red in Figure 11. Introducing ERS-OC to the national road system requires new infrastructure, new vehicles, and continuous interaction between stakeholders that have little to no experience with such a system. The interfaces between stakeholders have to be explicated, explaining concrete roles and responsibilities of the involved parties before engagement can be assured. This SoS is a novelty for all involved parties, and setting this up requires thorough planning with many legal aspects to consider. For instance, how will the payment system work? And who will be responsible for operating the system?

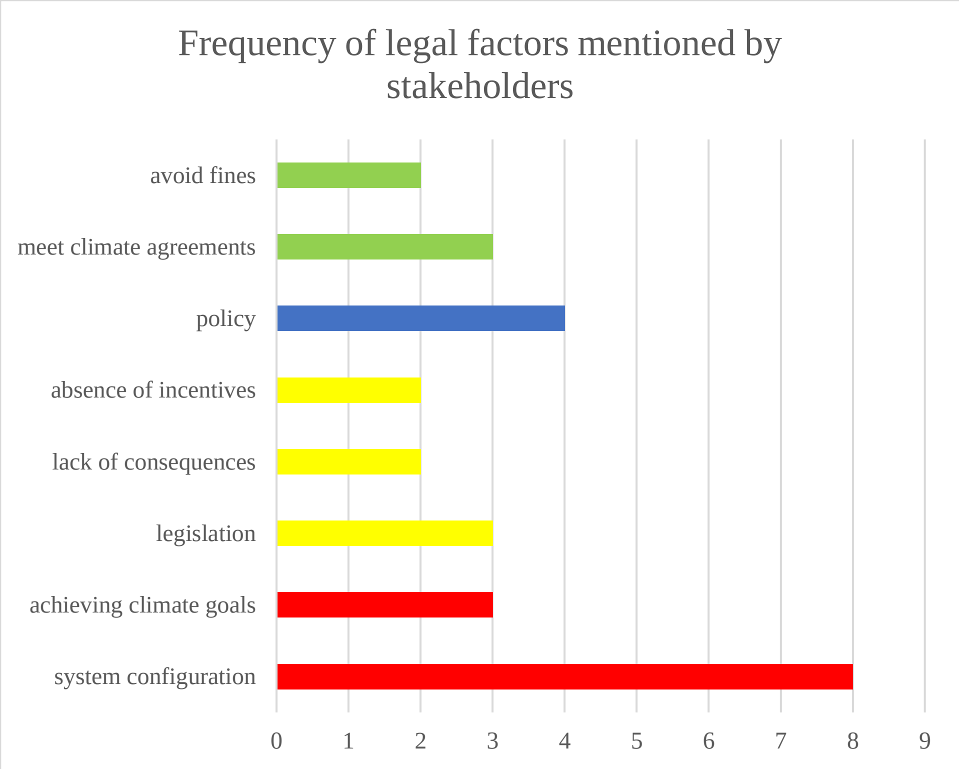

FIGURE 11 - FREQUENCY OF LEGAL INCENTIVES (GREEN), OPPORTUNITIES (BLUE), BARRIERS (YELLOW), AND CHALLENGES (RED) MENTIONED BY STAKEHOLDERS

The factors are divided into enabling incentives and opportunities, and disabling barriers and challenges. Many arguments were given, the most mentioned will be shortly summarized now. The incentives varied in nature. The need for electrification is perceived as high. Emission reductions and pursuing organizational ambitions are frequently mentioned incentives. Potential cost reduction and other environmental gains are also considered as a motivation to engage. Opportunities were mentioned abundantly, especially the technological maturity of the catenary systems is considered an advantage. The possibility to reduce battery or hydrogen demand is mentioned often. Other technological characteristics also advocate the implementation of ERS-OC; the high efficiency, proof of concept, and the lack of viable alternatives are mentioned frequently. The gradual buildup of an ERS-OC network is also mentioned to abate the initial investment needed. Policy measures are frequently mentioned as essential for attracting users. These policies will create a sense of trust in stakeholders that are hesitant to invest. Also, creating support base through lobbying is considered a potentially effective measure to take strides and move from theoretical to practical. Politically, the use of catenaries decreases the dependency on foreign resources. On the other hand, ERS-OC is perceived as unfeasible, due to the risk of investment and the lack of short-term gains. Also, stakeholders are awaiting international developments and technological breakthroughs to make more well-informed decisions that are financially secure. Other barriers are the low initial utilization, which counteracts investments, and the wear and tear of the catenaries, which is considered as non-circular. The biggest challenge that was identified is that of configuring the system-of-systems, where all organizations must function as an overarching organization, interacting continuously. Other challenges are creating a sense of political urgency and public support. It is considered as a challenge to compose an attractive business case for all involved parties and justify the large initial investment. Technological challenges exist in grid capacity and safety issues when the system malfunctions.

4.3 FACTORS AFFECTING DEMONSTRATION PROJECT FEASIBILITY

After examination of the enabling and disabling factors for ERS-OC implementation, the factors that affect the feasibility of a demonstration project can be extracted. The stakeholders have stated that they are willing to engage in a demonstration project under the right circumstances. It is now that these 'right circumstances' should be identified and the demonstration should be realized. This section discusses the factors that were mentioned in the interviews, that can affect the creation of a demonstration project. It aims to answer the question:

SQ3. What stakeholder-perceived factors affect the feasibility of a demonstration project?

The factors that affect the feasibility of a demonstration project were extracted from the dataset. First, the enabling incentives and opportunities are discussed. Then, the disabling barriers and challenges are discussed. The definition of the factors can be found in Appendix A1.

Incentives

P	E	S	T	E	L
create political urgency	enter new markets	improved brand image	need for electrification	organizational ambitions	
		societal pressure		potential gains	

TABLE 2 - INCENTIVES AFFECTING THE FEASIBILITY OF CREATING AN ERS-OC DEMONSTRATION PROJECT, MENTIONED BY STAKEHOLDERS

The incentives that stakeholders mentioned (Table 2) have an overarching theme in that they are related to achieving climate goals and acting towards a zero-emission sector. The climate agreements work towards a sector that has zero net harmful emissions. The incentives that affect the feasibility of a demonstration project are related to complying with the final and intermediate goals of the Dutch Climate Agreement. Another incentive that can be used to increase the feasibility of creating a pilot is to show that engagement can provide more business for their organization, thus, more revenue and finally more profit. It is also perceived that engaging in a sustainable project – like an ERS-OC demonstration project – can improve the brand image of the organization.

Opportunities

P	E	S	T	E	L
	early advantage	create test site	gradual build-up		policy
	green investors	gaming	proof of concept		
		lobbying	shuttle routes		
		sustainability trend	technological maturity		

TABLE 3 - OPPORTUNITIES AFFECTING THE FEASIBILITY OF CREATING AN ERS-OC DEMONSTRATION PROJECT, MENTIONED BY STAKEHOLDERS

The stakeholders mentioned many opportunities that affect the feasibility of a demonstration project, listed in Table 3. The technological maturity of ERS-OC in comparison to alternatives is mentioned most frequently. Proof of concept is present, and the technology is ready to be implemented when resources and efforts are allocated correctly. Another theme that is found is the opportunity of gathering interested parties and creating support base in form of a lobby. The organizations can get familiar with the technology through measures like a full-scale test site, or a game that familiarizes the players with their future role and responsibility, and interactions with other stakeholders. This would make the demonstration project more tangible for stakeholders. A shuttle route is mentioned to be an excellent corridor for a demonstration project. From there on, the infrastructure can be gradually expanded. Policy measures provide an excellent tool to attract stakeholders, for example by providing tax exemptions or subsidies. When investments need to be secured from outside the organization, green investors can be approached that follow sustainability trends.

Barriers

P	E	S	T	E	L
lack of leadership	investment risk		await international development		absence of incentives
lack of vision/perspective	magnitude of investment				lack of consequences
uncertainties regarding implementation requirements					

TABLE 4 - BARRIERS AFFECTING THE FEASIBILITY OF CREATING AN ERS-OC DEMONSTRATION PROJECT, MENTIONED BY STAKEHOLDERS

On the other hand, some concerns were expressed about factors that hinder the creation of a demonstration project, as shown in Table 4. The biggest recurring theme was that there is currently no one taking the lead and showing the way. The lack of leadership and vision is considered an obstructing factor. A straightforward long-term plan would increase the feasibility of a demonstration project. This would lower the risk of investment for the involved organization, since long-term commitments are pledged. However, this is hindered by organizations awaiting international developments. Currently, incentives for engagement are lacking, according to the respondents. Other barriers that are mentioned are the initial investment that is required, and the lack of consequences when emission agreements are not met. Respondents also indicate that there are still uncertainties around the long-term added value of ERS-OC.

Challenges

P	E	S	T	E	L
chicken-and-egg story	compose attractive business case		take strides		system configuration
find suitable partners for initial project	upfront investment				
political acceptance					
political urgency					
responsibility ambiguity					

TABLE 5 - CHALLENGES AFFECTING THE FEASIBILITY OF CREATING AN ERS-OC DEMONSTRATION PROJECT, MENTIONED BY STAKEHOLDERS

The challenges that affect the feasibility of creating a demonstration project (Table 5) are mainly political in nature. It is considered hard to take strides from theory to practice. The main challenge is the configuration of the system-of-systems. A functioning ERS-OC requires cooperation between stakeholders in a new market. The interactions and interfaces between the stakeholders must be thought out well before creating a demonstration project to prevent failure of the project. Also, the lack of political urgency is perceived as a challenge. Decision-makers appear to prefer other zero-emission technologies and do not prioritize ERS-OC as a decarbonization solution. Moreover, it is unclear who should finance a demonstration project. Another recurring challenge is composing an attractive business case for all involved stakeholders that might engage in a demonstration project. This can eliminate the chicken-and-egg problem.

The incentives that affect the feasibility of a demonstration project are mainly based on achieving climate goals and generating more revenue. The opportunities lie mainly in exploiting the technological capabilities of ERS-OC, bringing the stakeholders together to increase understanding of the technology, and attracting green investors to secure investments. Setting up policies can attract potential stakeholders. The demonstration project should be a shuttle route and can be gradually expanded to other corridors. The feasibility of a demonstration project is obstructed by a lack of leadership, vision, and incentives. There is a lack of consequences when emission agreements are not met. Progression is hindered by awaiting international developments. Also, investments are considered a barrier to engagement. Configuring the SoS is the main challenge of ERS-OC before creating a demonstration project. There is no political urgency for sector decarbonization, or acceptance of ERS-OC technology. This should be enhanced to attract potential stakeholders and take strides.

4.4 Overarching themes

It seems that there is a thread present when assessing the perceptions of the stakeholders. While there is a consensus on the potential added value of ERS-OC for HDT decarbonization, there are frequently mentioned issues that have to be addressed first to comfort the stakeholders. It seems that there is a high level of uncertainty present in the stakeholders. At the time of writing, there are no statements made about the future implementation of ERS-OC in the Netherlands. Stakeholders are therefore hesitant to consider ERS-OC as a viable decarbonization measure, it seems perceived as an intangible and a far-fetched solution, while the in-use corridors in Germany prove that it is not. It is up to the policymakers to express confidence and dedication to ERS-OC, before catenary trucks will be approached as a serious business opportunity by the other stakeholders.

Hekkert et al. (2007) explained the main drivers for technological change in the TIS, as described in Section 1.4. The central point in his conceptual model is entrepreneurial activity, which induces change by stimulating lobbying, market formation, and guidance of the search. Schot & Geels (2008) state in their SNM approach that test site creation, like a demonstration project, is vital for technological development, and can be linked to the entrepreneurial activity of the TIS. Therefore, it would seem like a logical next step to create this demonstration project. This can aid policymakers in doing their job by familiarizing all involved parties with the technology, including themselves. This can reveal what policies and regulations need to be set up, which results in the creation of the vision that is so often mentioned by the respondents to be absent. Governmental entities are expected to execute this task and create incentives for the other stakeholders to engage, having the power to set up policies that enable disruption of the embedded regime. These entities are bound to environmental objectives and ERS-OC can aid in achieving those. The ball is in their court. When they provide perspective by ensuring the future application of ERS-OC, it will set everything in motion. Ensured construction of ERS-OC infrastructure will provide an incentive for the truck manufacturers, while freight operators will start investigating to what extent catenary trucks can yield, both financially and environmentally. Governmental commitment to ERS-OC for the long term allows for secure investments that have quasi-predictable payback periods.

So, it all starts with governmental dedication to ERS-OC alongside other zero-emission drivetrains, backed by substantiated findings of researchers on technological, financial, social, environmental, and legal aspects. When the findings comply with the road freight decarbonization approach of the governmental entities, the decision to engage in ERS-OC is justified and resources can be allocated to realize the construction of infrastructure. A logical first step would be a shuttle route that functions as a demonstration project, so stakeholders can familiarize themselves with the technology. This will provide the required incentives for freight operators and truck manufacturers. Their engagement will be sufficient motivation for the road power component producers, construction firms, and energy suppliers to engage, since ERS-OC provides them with an additional market to gain revenue from, rather than that they have to change their core business radically.

5 CONCLUSION

This research has investigated the perceptions of stakeholders on ERS-OC as a decarbonization measure for HDTs through a Dutch case study. The aim of this research was to answer the research question: *What are stakeholder-perceived factors that affect the feasibility of creating an overhead catenary electric road system demonstration project?* Three sub-questions are answered to provide a well-substantiated answer to the main research question. The first sub-question was used to elaborate on stakeholder-specific perceptions, and to compare their perceptions, aiming to answer the question: *What are the stakeholder-specific perceptions on ERS-OC?* Six stakeholder groups were examined. The truck manufacturers state that demonstration projects will prove the technology's added value and stimulate progress. Freight operators claim that they are not able to finance shifting to ERS-OC on their own, and expect infrastructure to be financed for them. The governmental entities say that they are seriously considering ERS-OC, but are awaiting feasibility reports and international developments before dedicating their efforts to ERS-OC. Road power component producers highlight the huge benefits of ERS-OC and the capabilities of eliminating certain flaws of other powertrains, but experience a lack of political support. The construction firms call for the creation of a test site and getting all the stakeholders together to create support base and induce change. The researchers state think more research is required before resources should be dedicated to ERS-OC. The second sub-question: *What enabling and disabling factors are mentioned by stakeholders?* aimed to create a holistic overview of the enabling and disabling factors for ERS-OC, divided into the PESTEL categories. Politically, the decreased dependency on foreign resources is an important enabling factor, while the lack of political urgency to decarbonize road freight is perceived as disabling. The potential cost reduction is the most important economic enabler, while the initial investment required is perceived as a significant barrier. Socially, lobbying can form a tool for inducing progression. Technological maturity is perceived as an enabling factor that should be exploited, allowing for predictable cost estimations and proof of concept. Also, the fact that ERS-OC complements other technologies is seen as a vital opportunity. On the other hand, the development of other zero-emission technologies is seen as an obstructing factor, as well as waiting on international ERS-OC developments. The environmental enabling factors are that ERS-OC reduces carbon emissions, and that it matches organizational ambitions, while the circularity of the system as a whole is questioned. Setting up enabling policies is seen as a legal opportunity, while configuring the SoS that explains all the stakeholder roles, responsibilities, and interfaces is perceived as the biggest challenge. The last sub-question identified the factors that affect the feasibility of creating a demonstration project. It aimed to answer the question: *What enabling and disabling factors affect the feasibility of a demonstration project?* The enabling factors for a demonstration project are either incentives or opportunities. The incentives for stakeholders to engage are mainly achieving their climate goals, and that ERS-OC matches their organizational ambitions. The opportunities lie in the predictable costs and requirements for a demonstration as a result of the technological maturity, setting up policies to stimulate engagement, lobbying to create support base, and using a shuttle route for the demonstration. The disabling factors are divided into barriers and challenges. Perceived barriers are a lack of leadership, vision and perspective, and the large investment that is required. Together, these form an investment risk, since no guarantees are present and investments are significant. Perceived challenges exist in configuring the system, including stakeholder roles, responsibilities, and interfaces. Also political factors, like acceptance of ERS-OC as a decarbonization measure, and creating the political urgency to decarbonize trucks. Gathering the initial investment required for a demonstration project is another perceived challenge.

Taking everything into account, the enabling and disabling factors affecting the feasibility of creating an ERS demonstration are set out. The factors are divided into internal and external factors for the organizations. Enabling internal factors are that engaging in the demonstration can help in achieving their climate goals, and that it matches their organizational ambitions. On the other hand, there is a perceived lack of incentives, leadership, vision, and perspective. The chance that other powertrains will become dominant is therefore perceived high, which puts a risk on their investments. Externally, the proof of concepts leaves the technology with few technical uncertainties. A demonstration project will prove the technology also in the Netherlands, create awareness and attract stakeholders. Stimulating policies can support ERS-OC in becoming an accepted and affordable decarbonization measure. To accomplish that, efforts have to be put into overcoming the challenges that exist in configuring the system, gathering the required investment for the infrastructure, and gaining political acceptance.

6 DISCUSSION AND RECOMMENDATIONS

6.1 DISCUSSION

This research has investigated the perceptions of stakeholders on ERS-OC as a decarbonization measure for HDTs through a Dutch case study. Initiating ERS-OC activities through a demonstration project is determined to be a logical starting point in various countries, as stated by the TIS approach of Hekkert et al. (2007), that explains how entrepreneurial activities drive change. Identifying the perceptions of stakeholders is considered an essential step when aiming to implement an ERS-OC demonstration project, according to Bourne (2006) and Scherrer et al. (2020). Semi-structured interviews were conducted to capture qualitative data of stakeholder-perceived factors that affect the feasibility of creating an ERS-OC demonstration project. Nine interviews were conducted with organizations that have shown interest in the technology as a business opportunity. The respondents were able to talk freely to avoid biases through suggestive questioning, but the conversation was guided when necessary. The moderate amount of nine respondents results from the non-probability sampling approach, which aimed to approach only the organizations that had some affiliation with ERS-OC. Despite that nine interviews is a moderate amount, the respondents have provided more valuable information than organizations that have no affiliation with ERS-OC would have, since these are expert opinions. The data derived from the interviews can therefore be considered valid.

The frequently mentioned opportunity to start with a shuttle route is obvious and meets expectations. This has also been the first step toward large-scale implementation in other countries that experiment with ERS-OC. It is a logical first step to increase awareness and understanding of the technology among politicians and stakeholders. The lack of leadership is a recurring theme that was also discovered by Tongur & Sundelin (2017). All respondents have stated in the interviews that they are willing to engage in such projects, if the conditions are right; it should be affordable, and investment risks should be minimized through documented long-term commitments to the technology. Stakeholders need a leading entity that creates a long-term vision for ERS-OC, securing investments, this will create trust among stakeholders in the future of the technology, and defines and delegates stakeholder roles. The respondents foresee the leadership and investor role for the governmental entities, since they are the problem owner and are responsible for achieving their climate goals. This is backed by the findings of Scherrer et al. (2020), who found that the lack of support from actors and the absence of lobby for improvement is perceived as a barrier to ERS-OC implementation among stakeholders. This corresponds with the findings of this research, which discovered that the other stakeholders perceive a lack of leadership, perspective, and incentives to engage in ERS-OC projects. However, the governmental entities in this research state that they are waiting on 'big brother Germany' to take strides and make decisions on how to commercialize ERS-OC and configure the SoS. The freight operators declare that they cannot afford to switch to ERS-OC on their own. This is backed by the findings of Börjesson & Gustavsson (2018) that freight operators expect other stakeholders to finance the infrastructure. It is imaginable that organizations are not able to finance the physical infrastructure on their own and still run a profitable business. Wang et al. (2019) also concluded that financial and planning aspects are the biggest concerns. The respondents of this research have stated that, despite the potential profitability, the required investments are also considered a significant challenge. Planning aspects are similar to the vision and perspective factors that are mentioned by the stakeholders in this study. Another recurring theme is that the decarbonization of HDTs should get more priority. The road power component producers declare that they perceive a lack of political urgency, while others perceive a lack of incentives for themselves to engage. Despite the clear statements that world leaders make about addressing climate change, it seems that efforts and resources are focused on more profitable cases. ERS-OC progress is dependent on the available resources, that might become available when a solid, profitable business case is constructed. This can be substantiated by the record-breaking global carbon emissions in 2021, displayed at the start of this paper (Figure 1). To take strides, responsibilities need to be explicated to manage stakeholder expectations. Wang et al. (2020) found that financials, safety, service, environment, and social influence were the biggest concerns for the long-term development of ERS-OC. This research has also identified financial (investments), safety (hazard for road users), environmental (circularity), and social influence (public support) challenges that are perceived by stakeholders. Service factors were not identified in this study. The findings of Gadgil et al. (2022) concern wireless ERS, but had similar results. Uncertainty about the dominant powertrain in the future, the availability of infrastructure, and energy distribution over a high occupancy ERS-OC network are concerns that were also mentioned by the respondents of this research. Vehicle functionality was not mentioned in this research, which is due to the lower technological maturity of wireless ERS, which induces more technological doubts than with ERS-OC.

This research is subjected to some limitations that have to be taken into account when assessing the results and concluding remarks. The absence of an energy supplier leaves a gap in the results of this research, since they are vital to the functioning of the system. Their perception would likely affect the results, since they represent an entirely different sector with other expertise and goals. This stakeholder might have also provided answers to the uncertainties about grid capacity and voltage distribution that were addressed by the researchers. It must be noted that some stakeholder groups have solely one representative. This representative might have a different opinion than someone else in the organization, making what is now stated as the perception of an entire sector, more like the opinion of an individual. In practice, however, this concerns the people that will be responsible for hypothetical ERS-OC projects in organizations that have shown interest in engaging in ERS-OC projects. So, their opinion is valuable when creating a real-world demonstration project. The truck manufacturer was Swedish, while the scope was set for the Netherlands. This could not be avoided, since Scania is currently the only catenary truck producer in Europe. Their opinion is of great value, since they have a significant portfolio of all types of electric trucks. Furthermore, because there are few organizations having experience with ERS-OC, the respondent pool was limited and might be too low to make reliable quantitative statements from. Also, factors mentioned multiple times are counted as multiple data points. This might have an exaggerated effect on the results, making the argument seem more important than it is perceived in real life. The choice has been made to allow factors to be mentioned multiple times, since this indicates the importance of an argument for the respondent. A second round of interviews with the same respondents could increase the internal validity of the results, by assessing the perception of the respondents with a pre-made list of factors, based on the findings of the first round of interviews, that increase the validity of the coding process. Also, some mentioned factors can be divided into more than one PESTEL category, based on interpretation. While this might affect the reliability of the results when discussing the division into the PESTEL categories, this does not influence the perceptions of the individual stakeholder, nor the holistic perception of the respondents of the technology. Whether a factor is either an incentive or opportunity, or barrier or challenge is also based on interpretation of both the author and the respondent. It is, however, clear whether factors are enabling or disabling, so the conclusions of this research have not been affected by interpretation. Future studies could aim for more quantitative methods to draw conclusions, and use the data of this research to set up preliminary questions for, for instance, Q-method research. Using this method was not possible for this research, since literature of factors affecting demonstration projects was absent. Also, ERS-OC is an innovation acting in a niche within a large-scale transition, where circumstances change continuously. The results are relevant at the time of writing, but might lose their relevance throughout the years as a result of progression. The limited time frame is also considered as a limitation of this research, more interviews and a second round of interviews could have been conducted.

What stands out when interpreting the results are the benefits of ERS-OC as a complementary technology. It can eliminate the weight and range constraints of BETs, help to compensate for absent hydrogen refueling infrastructure, and can decarbonize ICETs on electrified corridors. Another advantage is that electrification of solely the core highway network could induce huge carbon reductions. Electrification of the Dutch core network, between Amsterdam, Rotterdam, Eindhoven, and Utrecht, could achieve a thirty percent emission reduction in HDTs, according to the governmental entities. The sidenote is that this requires all passing trucks to connect to the catenaries. Ergo, this system will only function properly when all parties are dedicated to this technology. Without the participation of manufacturers, energy suppliers, and freight operators, the technology will fail. It is therefore the task of governmental entities to provide incentives for engagement for all parties. This also accounts for the governmental entities themselves. Progress will lag if incentives are absent. Currently, imposing high fines when emission agreements are not met can be interpreted as an incentive to engage. But, these punishments for neglection of the agreements are too soft and go almost unpunished, according to the road power component producers. This is the crux of the problem that goes wider than the transportation sector. Decarbonization of HDTs requires significant investments, no matter what alternative powertrain is chosen. It seems like decision-makers do not prioritize HDT decarbonization in this phase of the energy transition. While it seems costly, ERS-OC can become profitable over time, and decrease alternative ZET requirements and costs. Ignorance and insignificance are two terms that might be bold, but true statements that explain why ERS-OC does not get the dedication from policymakers that it deserves. Further research is required to investigate how the urgency for HDT decarbonization can be increased, for instance by performing research on how electrification of the core highway network in western Europe would contribute to achieving climate goals. It would be useful to explicate the financial and environmental potential gains of electrifying the core network, to make the potential profits for all involved parties more explicit. This analysis should include a combination of technologies, so, ERS-OC together with BETs or FCETs. This can aid in explicating the corresponding costs, material use, and other requirements, clarifying what the term 'dedication' concretely requires for all involved parties.

6.2 RECOMMENDATIONS

In the end, it has become clear through the interviews with stakeholders that many expect governmental entities to initiate the rollout of ERS-OC. The suited ministry can and should induce ERS-OC activities by announcing clear statements that guarantee dedication of efforts and resources to the technology. A plan should be set up that describes the decarbonization of the entire HDT sector, where ERS-OC is complementing other technologies, like BETs and FCETs. This plan should include all requirements, including materials and financial resources. This should be made tangible by setting goals and deadlines, and defining and assigning roles and responsibilities of the stakeholders; configuration of the SoS. That guidance will create a sense of trust and initiate processes with all other stakeholders. The consensus among the respondents is that someone should take the lead and create a long-term vision. This leader should be from a governmental entity, since they are the problem owner. They should provide guidance and clarity about the future of ERS-OC. This will generate trust among stakeholders that are now too fearful to invest due to the many uncertainties about the future use of ERS-OC. Creating trust among stakeholders is essential before the ERS-OC SoS can be configured. Dedication from all sides is required for proper functioning of the system. It is therefore important to gain political and public support for the implementation of ERS-OC. An, preferably international, ERS-OC project team – like the existing Dutch 'VERS' – should make assertive steps towards governmental entities, freight operators, and potential truck manufacturers. A demonstration project can create a sense of tangibleness, which will increase political and public support when successful. Also, stakeholders can become familiarized with the technology, so the demonstration can help to create support base made up of organizations that can together form the SoS.

While technological breakthroughs cannot be ruled out, it is not likely that BETs or FCETs and their infrastructure are available for a competitive price before the 2030s or even later. ERS-OC can aid in electrifying long-haul transport instantly when efforts are dedicated to this technology. It is, however, important to create clarity about stakeholder roles and responsibilities, especially those of the governmental entities. It would be helpful to get all stakeholders that compose the SoS into one room to discuss what their expectations and concerns are. Creating a demonstration project will not directly have a significant impact on carbon emissions, but is vital in the creation of awareness among potential stakeholders. International counterparts that are responsible for decarbonizing road freight should keep in touch and discuss developments and potential international corridors. Because in the end, the energy transition is a global issue that affects us all. To push plans for a demonstration project, the following steps are recommended:

- The appropriate ministry should express dedication and resources to set up the demonstration project, and create a vision and a long-term plan including funding schemes and stakeholder roles and interactions.
- Stakeholders should be attracted by bringing them together and familiarizing them with the technologies, and what will be expected from them.
- Then, a suitable corridor should be identified where potential users shuttle back and forth daily.
- When investments are secured and stakeholders are found, it is time to take the plunge and go for it.

In further stages, beyond demonstration projects, it seems that dedication from decision-makers is the major challenge that needs to be addressed. ERS-OC can be economically justifiable, it has proven to work, and no major technical issues are found. It should be made explicit to what extent the rollout of an ERS-OC network would contribute to the decarbonization process of HDTs, and how this relates to long-term cost reductions. It is important that ERS-OC should not be approached as a singular alternative for ICETs, but as a complementary technology for other zero-emission technologies. This is where the potential added value of ERS-OC technology lies. Given the enormous fleet of vehicles that need to be electrified through batteries or fuel cells, it could make a huge difference in carbon emissions, but also overall costs, if a big chunk of the required resources for electrification can be eliminated because the core highway network is equipped with catenaries using renewable electricity from the national grid. Then, BETs, FCETs, or hybrid trucks can dynamically charge and use a modest battery, fuel cell, or ICE to reach their destination, without having to make concessions on payload or flexibility.

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APPENDIX

A1. DEFINITIONS OF THE MENTIONED FACTORS

A1.1 INCENTIVES

Accelerate implementation process – Aiming to accelerate the implementation of (more) ERS-OC segments in order to create more business.

Avoid fines – ERS-OC can help to prevent future fines that are being imposed when emission agreements are not being met by reducing an organization's emissions.

Cost reduction – ERS-OC is considered as a viable alternative for fossil fuels when it will have a lower TCO than the current powertrain.

Create political urgency - The pressure from law-imposing instances creates an incentive for stakeholders to do more to meet the climate agreements

Decreased fuel dependency – Using the national electricity grid decreases foreign fuel dependency, like oil and gas, and less tangible for fluctuating prices induced by political unrest.

Do something for the environment – Engage in sustainable projects in order to mitigate the effects of climate change.

Emission reduction – Considering ERS-OC to mitigate the carbon footprint of the organization.

Enter new markets – ERS-OC is a new business opportunity for certain stakeholders that are more involved in rail than in road, for now.

Improved brand image – ERS-OC can improve the organization's brand image by the sustainable nature of the technology.

Meet climate agreements – An incentive for ERS-OC is the aim to meet the climate agreements that are signed.

Need for electrification – Policy reports have stated the shift away from fossil fuels. The need for electrification is seen as a transition that is inevitable.

Organizational ambitions – ERS-OC is a sustainable solution for transport. Sustainability as an organization's key pillar creates an incentive to invest in ERS-OC.

Payback period – The payback period of an ERS-OC is calculated to be relatively short when an extensive network is rolled out.

Potential gains – What the investment will eventually yield on a business level.

Rapid upscaling pace – because of the technological maturity and proof of concept, scaling up small ERS-OCs can be executed rapidly**.** Pilots in Germany have proven that an ERS-OC can be set up rapidly compared to alternatives, allowing for quickly realizable emission reductions.

Societal pressure – Organizations and societies can exercise pressure on decision-makers that makes them invest to achieve certain goals.

A1.2 BARRIERS

Absence of incentives – The triggers for freight operators to switch to BETs are scarce. While there are subsidies, this is perceived as too low to induce a market shift.

Absence of market – since there is no market yet for truck manufacturers, they are not producing ERS-OC-compatible trucks.

Await international developments – breakthroughs in other countries will act as a guidance for countries in more early stages of ERS-OC development. However, seeing how the wind blows hinder progression.

Catenary truck availability – Since no infrastructure is in place yet, the truck production for ERS-OC is also absent – except specific orders for the ERS-OC corridors in Germany.

Circularity – Because the catenaries wires are subject to wear, particles – including the scarce cupper – are being scattered into the surrounding environment. These particles cannot be recycled, making the catenaries not entirely circular, which is desired for long-term sustainability measures.

Esthetics – the physical infrastructure is perceived as not very esthetic.

Flexibility concessions – Freight operators do not want to make concessions regarding flexibility of their routes. Their sustainable drivetrain has to provide the same range and flexibility as current ICE trucks. The absence of infrastructure in form of catenaries, and the absence of batteries capable of support long haul journeys is considered a barrier for freight operators when operating on long, transnational routes.

Investment risk – Investing in a large ERS-OC network is a risk for infrastructure investors, because the network occupation is not guaranteed and investment will be lost when other technologies become dominant. This is not desirable when spending public taxes or making long term corporate investments.

Lack of consequences – the absence of fierce punishments when climate goals are not met is perceived as a barrier for the progression of sustainable alternatives

Lack of infrastructure – Stakeholders are not keen to engage in ERS-OC projects when infrastructure is absent.

Lack of leadership – there is a perceived lack of leadership with ERS-OC projects that hinders progression and implementation of the system.

Lack of short-term gains – The roll out of an extensive network that will realize significant carbon reductions will take many years, so short-term gain in terms of emissions is questionable.

Lack of vision/perspective – The absence of long-term vision and dedications with electric roads is considered a hindering factor for stakeholders to engage.

Landscape developments – Other technologies will be considered if ERS-OC developments lag and other technologies see breakthroughs. Also, modal shifts are perceived as carbon mitigation options. This leads to reticence among stakeholders.

Legislation – current legislation does not promote the transition to ZETs sufficiently to induce significant changes.

Lobby for alternative powertrains – lobbying by proponents of other technologies for HDTs – like hydrogen - can form a barrier for the progressions of ERS-OC.

Magnitude of investment – The large investment that is required to realize ERS-OC is considered as a hindering factor. ERS-OC will only be considered when it is realizable within the organization's price range.

Perceived feasibility – Stakeholders may perceive low feasibility of the technology becoming dominant since initial cost are high, experience with the technology is absent, and no infrastructure is in place, in contrary to battery electric charging infrastructure.

Personal interests – Setting up an ERS-OC requires cooperation of stakeholders. Stakeholder acting solely from their own interests can be an obstructing factor for progression.

Physical infrastructure – the physical infrastructure may have hindering effects on traffic flow.

Preconception – some parties are biased about the concept of catenaries on the road and think that it belongs solely on the rail, or that it looks unusual.

Resource scarcity – Copper is an essential element of the catenaries. This is a finite resource and long-term usage of catenaries will be affected by price and availability of this scarce resource.

System utilization in early phases – when only a couple of small segments are electrified through ERS-OC, it is not profitable for users to use ERS-OC-compatible trucks when they can only use the pantograph for a fraction of the journey. Also, road users see catenaries with no trucks connected, which can make them doubtful about the system's utility.

Uncertainties regarding implementation requirements – Current research on implementation of ERS-OC in the Netherlands is scarce and requires more attention in order to convince stakeholders that are currently uninformed, for instance in the field of environmental gains, material requirements, and system configuration methods.

Wear and tear – The contact of the pantograph with the catenaries causes friction, which causes wear of the copper wires. This in undesirable and not circular, since the particles will end up in the environment surrounding the catenaries. Moreover, the catenaries have to be replaced every once in a while.

A1.3 Opportunities

Complementarity –ERS-OC does not have to be present along the entire route but can support other drivetrains on specific segments, without being the primary powertrain of the vehicle. The catenaries can provide energy for propulsion and charge the battery simultaneously.

Core network potential – An opportunity for ERS-OC is the emission reduction potential that can be realized when electrifying the most frequently used highway segments - the core network - through catenaries.

Create test site – Building a test site where the physical system is presented can help in engaging stakeholders by enhancing their understanding of the system.

Decreased resource dependency – Because catenary systems allow for dynamic charging and smaller batteries, the need for certain (scarce) resources, like lithium, that are required for electrification of the transport sector is reduced. ERS-OC can make investing countries less dependent on foreign countries for the supply of (scarce) resources that are required for the production of e.g. batteries and green hydrogen.

Dynamic charging advantages – One of the main opportunities for freight operators is that they can dynamically charge their operative vehicles while underway, eliminating long charging stops with current BETs.

Early advantage – The opportunity to gain significant market share when investing in ERS-OC as a pioneer.

Economies of scale – For all stakeholders, the more parties are participating in ERS-OC projects, the lower the overall costs will become.

Efficiency – The energy efficiency of ERS-OC is higher than alternatives, like battery-electric or fuel cells. This means the lowest energy loss, which should be used as an argument for ERS-OC over alternatives.

Expensive alternatives – The TCO of ERS-OC is lower than other zero-emission technologies like BETs, but especially FCETs.

Few alternatives – Momentarily, there are only three technologies considered to sustainably replace ICE-powered HDTs, of which ERS-OC is one, alongside BETs and FCETs.

Fewer scarce resources required – Catenaries reduce the need for large batteries, that are dependent on lithium availability. Smaller batteries require less lithium, thus, use fewer scarce resources.

Financial requirements – Because of the proof of concept and technological maturity, the investment costs that are required for infrastructure are calculated with high certainty.

Flexibility relative to rail – An advantage of ERS-OC relative to rail is its flexibility in terms of accessibility, the trucks can reach remote places. Also, rails require catenaries along the entire track, which is not required when using ERS-OC.

Gaming – Developing and playing a game that simulates the development of ERS-OC implementation can aid in understanding the complex system that has to be designed and the roles that each stakeholder will possess.

Gradual build-up – The roll out of ERS-OC can be performed gradually, start with e.g. 10 km and expand gradually towards the entire core network, which can facilitate gathering investments since smaller amounts are required at once.

Green investors – The sustainability trend makes more and more investors put their money in sustainable initiatives, which could also be ERS-OC.

Investment security– Initiative from national governments will provide investment security for the other stakeholders. Promises about future implementation of an ERS-OC network – through government statements or international developments – and state-financed investments will induce trust with stakeholders that are now holding back investments because of the fear of failure of the technology, and losing their investment.

Link investments with sustainability – By showing potential stakeholders that ERS-OC can be profitable both environmentally and financially, they will be more easily persuaded in engaging in ERS-OC.

Lobbying – Bringing powerful stakeholders together and including them in the process will create a support base that is capable of launching an ERS-OC project.

Long haul capabilities – ERS-OC facilitates electrified long haul transport when a large network is rolled out. This is currently difficult due to the current BET (e.g. range) and FCET (e.g. infrastructure) characteristics.

Offloading the grid – ERS-OC as future main powertrain for HDTs will result in less demand for superchargers and less HDTs having to charge statically, because they charge dynamically, reducing the grid capacity needed at charging stations.

Policy – Setting up policies that create incentives for stakeholders and enable ERS-OC to be implemented in an affordable manner will create trust and accelerate the process.

Proof of concept – The presence of in-use corridors in Germany can persuade skeptics about the functionality of ERS-OC in real-world situations.

Shuttle routes – An opportunity when introducing ERS-OC to Dutch roads is to start off with a shuttle route that certain freight operators use every day. This facilitates attracting users in the first phases of ERS-OC implementation. They can subsequently be expanded gradually towards the hinterland.

Standardization – Because trials are performed before the technology is rolled out internationally, standards are present that can allow for transnational use of the system, facilitating international freight transport supported by catenaries.

Strong business case for long haul – ERS-OC can eliminate certain obstructing characteristics of alternative long haul sustainable vehicles, like battery weight and range, which is considered as a mean to deliver a substantiated business case for the electrification of long haul transport.

Sustainability trend – Using the global trend of making the world more sustainable in your advantage by presenting ERS-OC as a solution to make the world more sustainable to gain political and public acceptance.

Technological maturity – Compared to alternatives, ERS-OC is a matured technology that has low investment and utilization risks. An extensive network could be rolled out instantaneously when investments are secured. The pilot segments in Germany have proven the functionality of the technology under real-world conditions. Skills are already available in companies that work with ERS-OC concepts.

Visibility of infrastructure – The presence of ERS-OC infrastructure and compatible trucks will be publicity ERS-OC as a mean for electrification, which increase public awareness and will attract potential users.

A1.4 Challenges

Achieving climate goals – The agreements for 2050 and intermediate steps in 2030 are difficult to achieve when current pace is maintained.

Chicken-and-egg story – Truck manufacturers will not produce and freight operators will not buy catenary trucks while no infrastructure is in place. Meanwhile, governmental entities are not keen on investing in infrastructure when utilization is not ensured. This resembles the chicken-and-egg story.

Compose attractive business case – It is perceived a challenge to make a business case out of ERS-OC that benefits all involved parties, something that is required when aiming to make all involved stakeholder cooperate.
Connection to the grid – When a large network is rolled out, extra substations have to be built in order to connect the entire ERS-OC with the electricity grid. This requires careful planning and calculations.

Electricity price – in order to attract users, the fuel price should be competitive. The projected increase in electricity demand will affect the price of electricity, which will affect the price of using the ERS-OC infrastructure.

Find suitable partners for initial project – The right organizations have to be approached to facilitate an initial ERS-OC project. The challenge lies in finding organizations that will utilize the ERS-OC as much as possible.

Grid capacity – In order to function well, the grid has to be able to handle the required extra energy needed for the usage of ERS-OC.

Installation and maintenance – Installing and maintaining the ERS-OC requires temporary (partly) closure of the road, which hinders traffic flow.
International collaboration – Because long haul transport is often transnational, it is important that countries collaborate and set standards for ERS-OC systems to enable international road freight transport.
Political acceptance – Investments in an ERS-OC network require political backing. Otherwise, few incentives will be created to attract early adopters.

Political urgency – despite the agreements made on emission reduction, the lack of binding penalties and other political developments may degrade climate issues lower on the political agenda, hindering progress.

Public support – Creating public support for ERS-OC as a measure for emission mitigation.

Responsibility ambiguity – Because ERS-OC falls into various categories like transport, energy, and environment, organizations might have trouble allocating ERS-OC.

Safety – Malfunction of the system can form a hazard for road users. Loose electricity cables are dangerous.

System configuration – Implementation of ERS-OC does not only require infrastructure and vehicles, but stakeholders have to interact continuously. In order to facilitate that, a new system has to be configured that explains these interactions and its interfaces.

Take strides – it is difficult to proceed from the hypothetic phase to the realization phase, especially in large transitions.

Upfront investment – The large initial investment that has to be made for constructing an ERS-OC network is considered as a hurdle.

User attraction – When initiating the roll out of an ERS-OC network, it might be difficult to attract users. When these potential users can only make use of the catenaries for a fraction of their journey, they will not invest in catenary vehicles.

Voltage distribution – Claims are that the proximity of trucks connected to the catenaries could negatively influence the voltage quality

A2. Overview of conducted interviews

Stakeholder group	Organization	Job title of respondent(s)	Date of interview
Freight operator	Heineken	Manager Projects Customer Service & Logistics	14 March 2022
Governmental entity	Ministry of I&W	Innovation Manager	16 March 2022
Researcher	Movares	Innovation Manager and Mobility Advisor	22 March 2022
Freight operator	Transport & Logistiek Nederland	Policy Maker for Sustainable Logistics	29 March 2022
Road power component supplier	Siemens Mobility	Head of eHighway Business Development, Business Development Manager	29 March 2022
Researcher	Movares	Energy Transition Advisor	30 March 2022
Construction firm	BAM Infra Rail	Acquisition Manager, Ing. Tender Manager	1 April 2022
Truck manufacturer	Scania	Project Leader Vehicle Electrification	1 April 2022
Road power component supplier	Railtech	Business Developer	5 April 2022

TABLE 6 - OVERVIEW OF THE CONDUCTED INTERVIEWS, INCLUDING STAKEHOLDER GROUP, COMPANY NAME, JOB TITLE, AND DATE OF INTERVIEW

A3. Coding of mentioned factors and division into PESTEL categories

*) F = financial = economic

A3.1 Incentives

#	Incentives (I)	Theme
1	accelerate implementation process	F*
2	avoid fines	L
3	improved brand image	S
4	cost reduction	F*
5	do something for the environment	E
6	emission reduction	E
7	enter new markets	F*
8	decreased fuel dependency	P
9	meet climate agreements	L
10	need for electrification	T
11	organizational ambitions	E
12	payback period	F*

13	political urgency	P
14	potential gains	F*
15	societal pressure	S
16	rapid upscaling potential	T

TABLE 7 - INCENTIVES MENTIONED BY STAKEHOLDERS, WITH CORRESPONDING PESTEL-CATEGORY

A3.2 Barriers

#	Barriers (B)	Theme
1	absence of market	F*
2	await international development	T
3	circularity	E
4	esthetics	S
5	flexibility concessions	T
6	absence of incentives	L
7	system utilization in early phases	T
8	investment risk	F*
9	magnitude of investment	F*
10	lack of consequences	L
11	lack of infrastructure	T
12	lack of leadership	P
13	lack of vision/perspective	P
14	landscape developments	T
15	legislation	L
16	lobby for alternative powertrains	P
17	perceived feasibility	T
18	personal interests	S
19	physical infrastructure	T
20	preconception	S
21	resource scarcity	E
22	lack of short-term gains	F*
23	catenary truck availability	T
24	uncertainties regarding implementation requirements	P
25	wear and tear	T

TABLE 8 - BARRIERS MENTIONED BY STAKEHOLDERS, WITH CORRESPONDING PESTEL-CATEGORY

A3.3 Opportunities

#	Opportunities (O)	Theme
1	strong business case for long haul	F*
2	complementarity	T
3	core network potential	T
4	create test site	S
5	dynamic charging advantages	T
6	early advantage	F*
7	economies of scale	F*
8	efficiency	T
9	expensive alternatives	F*

10	long haul capabilities	T
11	few alternatives	T
12	flexibility relative to rail	T
13	gaming	S
14	gradual build up	T
15	green investors	F*
16	financial requirements	F*
17	investment security	F*
18	link investments with sustainability	F*
19	lobbying	S
20	offloading the grid	T
21	policy	L
22	proof of concept	T
23	decreased resource dependency	P
24	fewer scarce resources required	E
25	shuttle routes	T
26	standardization	T
27	sustainability trend	S
28	technological maturity	T
29	visibility of infrastructure	F*

TABLE 9 - OPPORTUNITIES MENTIONED BY STAKEHOLDERS, WITH CORRESPONDING PESTEL-CATEGORY

A3.4 Challenges

#	Challenges (C)	Theme
1	achieving climate goals	L
2	chicken-and-egg story	P
3	compose attractive business case	F
4	connection to the grid	T
5	electricity price	F*
6	find suitable partners for initial project	P
7	grid capacity	T
8	upfront investment	F*
9	installation and maintenance	T
10	international collaboration	S
11	political acceptance	P
12	political urgency	P
13	public support	S
14	responsibility ambiguity	P
15	safety	T
16	system configuration	S
17	take strides	T
18	user attraction	S
19	voltage distribution	T

TABLE 10 - CHALLENGES MENTIONED BY STAKEHOLDERS, WITH CORRESPONDING PESTEL-CATEGORY

A4. Factors mentioned by the respondents, divided into incentives, barriers, opportunities, and challenges

A4.1 Respondent numeration

#	Stakeholder	Organization	Respondent's job title
1	Freight operator	Heineken	Manager Projects Customer Service & Logistics
2	Governmental entity	Ministry of Infrastructure & Water Management	Innovation Manager
3	Researchers	Movares	Innovation Manager and Mobility Advisor
4	Freight operator	Transport & Logistiek Nederland	Policy Maker for Sustainable Logistics
5	Road power component producer	Siemens Mobility	Head of eHighway Business Development, Business Development Manager
6	Researchers	Movares	Energy Transition Advisor
7	Infrastructure supplier	BAM Infra Rail	Acquisition Manager, Ing. Tender Manager
8	Truck manufacturers	Scania	Project Leader Vehicle Electrification
9	Road power component producer	Railtech	Business Developer

TABLE 11 - STAKEHOLDER GROUPS AND THEIR NUMERATION, ORGANIZATIONS, AND RESPONDENTS IN CHRONOLOGICAL ORDER

A4.2 Incentives

#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	TOTAL
1		1	1	5		3					1							**11**
2						1		1				4	1			1	1	**9**
3															1			**1**
4				1		1				1								**3**
5	1	1		1		2				1	2			1			1	**10**
6																		**0**
7											1	1			2			**4**
8					1	1								1	1			**4**
9				1	1		2			1		2						**7**
TOTAL	1	2	1	8	2	8	2	1	0	3	4	7	1	2	4	1	2	**49**

TABLE 12 - INCENTIVES MENTIONED PER RESPONDENT (X-AXIS IS ARGUMENT NUMBER, Y-AXIS IS RESPONDENT NUMBER)

A4.3 Barriers

#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	TO
1									1					1			1									**3**
2		4						1						3			1	1	1							**11**
3				1			1	2						2				1							1	**8**
4		2		1		1	1	2	2		1	1	1	3								2				**17**
5		1			1	1	2		1	2			1	1		2	1			1			2			**16**
6			2											1			2		1		2			1	1	**10**
7												2			3										2	**7**
8	2	2												2								3				**9**
9																										**0**
TOTAL	2	9	2	2	1	2	4	5	4	2	1	3	2	#	3	2	5	2	2	1	2	5	2	1	4	**81**

TABLE 13 - BARRIERS MENTIONED PER RESPONDENT (X-AXIS IS ARGUMENT NUMBER, Y-AXIS IS RESPONDENT NUMBER)

A4.4 Opportunities

#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1					1		2	2		1					
2		3	1				1	1	1		3		1		

3							1								
4					2			1	1		3				
5		3							1		2	2		1	
6										1					
7		2		1		1									
8	2		1			1			1	1	1			1	
9				1										2	1
TOTAL	2	8	2	2	3	2	4	4	4	3	9	2	1	4	1

TABLE 14 - OPPORTUNITIES MENTIONED PER RESPONDENT (1/2) (X-AXIS IS ARGUMENT NUMBER, Y-AXIS IS RESPONDENT NUMBER)

16	17	18	19	20	21	22	23	24	25	26	27	28	29	TOTAL
	4				1							1		**12**
	1			1			3	1				3		**20**
									1					**2**
	1				2				1			1		**12**
					1	1	2	1	1	1		2	1	**19**
1														**2**
			3			2								**9**
									1	1		3	1	**14**
		4	3			1				1	2	3	2	**20**
1	6	4	6	1	4	4	5	2	4	3	2	#	4	**110**

TABLE 15 - OPPORTUNITIES MENTIONED PER RESPONDENT (2/2) (X-AXIS IS ARGUMENT NUMBER, Y-AXIS IS RESPONDENT NUMBER)

A4.5 Challenges

#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	TOTAL
1		1				1	1	2										1		**6**
2											2		1	2		2				**7**
3	1			2		1	1					1				3		1		**10**
4	2		2				1	1			2		1				1			**10**
5		1	2							1		3	2					1		**10**
6				1			2									1			1	**5**
7			2			1	2		1				1		3	1				**11**
8					1	1		1		1			1				2			**7**
9			1					2	2		2	2			1	1				**11**
	3	2	7	3	1	4	7	6	3	2	6	6	6	2	4	8	3	3	1	**77**

TABLE 16 - CHALLENGES MENTIONED PER RESPONDENT (X-AXIS IS ARGUMENT NUMBER, Y-AXIS IS RESPONDENT NUMBER)

#	Total
1	**32**
2	**47**
3	**21**
4	**42**
5	**55**
6	**17**
7	**31**
8	**34**
9	**38**

TOTAL	317

TABLE 17 - TOTAL NUMBER OF MENTIONED FACTORS PER RESPONDENT (Y-AXIS IS RESPONDENT NUMBER)

A5. FREQUENCY OF FACTORS MENTIONED PER STAKEHOLDER GROUP, DIVIDED INTO PESTEL-CATEGORIES

	Truck manufacturers	Freight operators	Governmental entities	Road power component producer	Infrastructure supplier	Researchers	TOTAL
Political	2	6	8	14	3	3	**36**
Economic	11	26	5	20	5	5	**72**
Social	2	4	4	11	5	3	**29**
Technological	17	25	22	34	14	18	**130**
Environmental	2	4	6	6	1	4	**23**
Legal	0	8	2	8	4	5	**27**
TOTAL	34	73	47	93	32	38	317

TABLE 18 - TOTAL NUMBER OF MENTIONED FACTORS PER STAKEHOLDER GROUP, DIVIDED INTO PESTEL-CATEGORIES