A System Study on the Use of Public Transport Electricity Infrastructure in the Netherlands to Relief Grid Congestion

Integrated Technical, Legal, and Organisational Understanding and Guidance for Connecting Third-Party Energy Applications

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A System Study on the Use of Public Transport Electricity Infrastructure in the Netherlands to Relief Grid Congestion

Integrated Technical, Legal, and Organisational Understanding and Guidance for Connecting Third-Party Energy Applications

by

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Preface

With this master's thesis, I conclude my studies at the Delft University of Technology. Over the past eight years, I have experienced an incredible and rewarding journey that combined academic development in Civil Engineering and Construction Management & Engineering with significant personal growth. During the two gap years between my bachelor's and master's programmes, I had the opportunity to travel the world, meet inspiring people, and work at insane international sporting events. Those experiences shaped me as a person and influenced how I approach collaboration and problem solving.

With my graduation project, I wanted to contribute to a topic with tangible societal relevance. This thesis brings together several interests that I have developed throughout my studies: knowledge about how to manage and deliver complex infrastructure projects, working with diverse stakeholders, and understanding the technical foundations needed to make effective decisions and to think carefully about how complex problems can be addressed as effectively as possible. During the master's programme, I also explored a wide range of subjects, from programming, infrastructure developments and transitions to future public transport and mobility systems. That broad foundation proved valuable for this research, which investigates how public transport electricity infrastructure in the Netherlands could potentially be used more effectively to contribute to relieving electricity grid congestion, while safeguarding the reliability and growth of public transport operations.

The research topic was co-developed through conversations with Ibrahim, Independent Consultant and Researcher (GVB, TU Delft), who also acted as my company supervisor. I am sincerely grateful to Ibrahim for his continuous guidance and commitment throughout the project. He consistently made time to discuss progress, helped me navigate the technical and institutional complexity of the system, and supported me in building the electrical engineering knowledge that I initially lacked. I also want to thank him for the enjoyable moments along the way and for the effort he made to involve me in the organisation at GVB. I look back on a valuable and enjoyable learning period. I also greatly appreciated the open and welcoming environment at GVB, and the opportunity to conduct this research in close connection with practice.

I would like to thank my graduation committee for their support, critical feedback, and the time they invested in me throughout this project. They provided excellent guidance and created a supportive, constructive and enjoyable setting during our meetings, from which I learned a great deal, both as a student and as a person. I am therefore grateful to my chair, Wijnand, for his calm and structured guidance during progress meetings and for his ability to keep the overall direction clear while encouraging sharper reasoning. I would also like to thank my first supervisor, Magchiel, for his personal coaching, practical advice, and the confidence he gave me during a project in which I was continuously learning and exploring. Finally, I would like to thank my second supervisor, Pavol, for taking the time to review this work and contribute to its assessment.

I also want to express my gratitude to all interviewees and stakeholders who took the time to share their expertise, ambitions, and perspectives. Their input was essential for grounding this study in real operational and organisational realities.

On a personal note, I would like to thank my family, friends, and my girlfriend for their patience and support throughout this process. They listened to my enthusiasm, doubts, and frustrations for months, and their encouragement and feedback made a real difference.

As I conclude this chapter of my education, I look forward to the next step in my professional career. I am grateful for the opportunities TU Delft has given me, and I am excited to apply what I have learned in my first job in an industry that is also very close to my heart, the aviation sector, where I will be working on developing and implementing new innovations.

Finally, I hope you enjoy reading this thesis. I also hope this research contributes to a clearer understanding of the system's complexity and provides useful guidance for stakeholders seeking to use public transport electricity infrastructure more effectively to help relieve grid congestion.

Bart Frijling
Delft, December 2025

Executive Summary

Dutch electricity grids are increasingly constrained by congestion, while public transport operators (PTOs) and municipalities manage extensive electricity infrastructures that often have substantial unused capacity. This has led to the emerging idea that traction power networks and related PTO electricity assets could host additional (third-party) energy applications, thereby reducing pressure on the public grid without undermining reliable public transport operations.

This thesis clarifies what must be understood and organised, technically and institutionally, for such multi-use of public transport electricity infrastructure to be technically feasible, responsible, and societally valuable. While the initial ambition was to produce a broadly applicable prioritisation framework for selecting applications, the research shows that the sector currently lacks the required system understanding, knowledge, internal capacities and alignment to develop such a framework. Differences between network architectures, governance settings (PTOs with strong municipal embedding versus concessions with commercial PTOs), stakeholder roles, and legal constructions imply that a shared system understanding and a coordinated way of working are needed first. The thesis therefore contributes primarily by integrating and structuring this system understanding and providing guidance, and secondarily by proposing an outline for a future, MCDA-based prioritisation framework that should be adapted to the local context.

Methodologically, the study applies qualitative analysis across documentary sources, literature, legal and regulatory materials, expert consultations, and stakeholder interviews and surveys. These outputs are synthesised to answer the sub-research questions and ultimately the main research question. The design links each research question to specific evidence streams and uses triangulation to consolidate insights into an actionable overview of stakeholder roles, feasible application types, legal implementation routes, and decision-making themes. This synthesis also enables the later added research objectives, which focus on clarifying how the system functions in practice and what is needed understand and organised to effectively use the public transport electricity transport to relief grid congestions.

The main contributions of this research are:

- A structured overview of how traction power networks can be used beyond their core function, including the key technical constraints that must be safeguarded to protect public transport operations.
- A consolidated overview of legal connection routes and their practical implications, translated into an implementable decision logic for selecting the least complex viable route per case.
- A set of applications types and their integration-relevant properties.
- An outline for a modular MCDA-based prioritisation framework, including technically grounded themes and components, complemented by societal components that must be locally and democratically specified.
- Practical guidance that clarifies the system and translates it into an actionable process: it provides the key information stakeholders need to better understand how the system functions in practice and how the electricity infracture could be used, and it outlines how the process should be organised, including which stakeholders should be involved at which stage and how they can contribute.

The research identifies a broad set of candidate applications and characterises them by integration-relevant properties that matter for connection feasibility and system impact, including predictability, criticality, off-take versus feed-in, storage potential, and the ability to regulate grid stability. Candidate applications include, among others, stationary and mobile ESS, EV-charging, street lighting and public-space assets, charging for zero-emission construction equipment, applications in and around buildings, business parks and industry, local renewable generation (PV and wind), and bidirectional inverters as enabling technology.

A central result concerns legal feasibility. The thesis clarifies how applications can be connected under different legal constructions. These constructions strongly shape what can be done in practice, but should not be used to eventually prioritise applications. Instead, they should solely be used to enable technically and societally high scoring applications to be implemented. Four routes are most relevant in practice:

- **Installation**: often relatively fast and offers high control over the PTO network, but not suitable for connecting third-party WOZ-objects.

- **Cable Pooling**: sharing the main connection to the public grid (with max 4 WOZ-objects) under jointly agreed arrangements, potentially faster and less burdensome than Closed System recognition while maintaining more operational control.
- **Closed System recognition**: enabling up to 1000 third-party WOZ-objects, but with substantial operator obligations, longer timelines, and typically less direct control over network use.
- **Direct Line**: a dedicated link between a producer of renewable energy to an end-user.

In addition, the thesis explicitly distinguishes **congestion management** as an alternative pathway to relieve grid congestion. Rather than adding new external connections, congestion management focuses on freeing capacity within an existing connection.

Across stakeholders, one principle dominates: public transport operations must remain the first priority. If stakeholders jointly decide to use the network for connecting energy applications, the thesis recommends a staged decision logic in which a technical assessment precedes the societal assessment. This ensures that applications that cannot be connected without unacceptable operational risk, power quality concerns, or disproportionate impacts on the traction power network are screened out before broader societal objectives are evaluated. Stakeholders with technical responsibility, supported by technical experts, assign the highest importance to *Controllability* and *Grid Impact*, followed by *Installation and Maintenance*. *Scalability* was proposed by an expert as an enabling component for sector-wide uptake. Societal weighting results are indicative because they were answered by a small group and because several stakeholders emphasised that societal objectives should be specified through democratic decision-making and translated into local policy goals before being operationalised in a framework.

The proposed framework outline is organised around two main themes with underlying (sub-)themes and components, see Figure 11.2. The societal components included are as they were formulated based on input from a limited group of stakeholders and should ultimately be refined by the municipality and province/PTA. Care must be taken to ensure that certain aspects are not included twice in different (sub-)themes.

- **Technical theme**
  Core components
    - *Controllability*: assesses whether the application is controllable and evaluates technical impacts of the application and its connection type on the public transport electricity infrastructure.
    - *Effective Load Coefficient (ELC)*: captures efficiency and the influence of siting of the connection and its type.
- **Technical theme**
  Additional components, context dependent
    - *Installation and Maintenance*: assesses feasibility of installing, operating, and maintaining the application within the PTOs or municipalities asset management and operations.
    - *Scalability*: assesses phased scalability, cross-site replication, and knowledge creation and sharing to enable faster adoption by other PTOs and organisations.
- **Societal theme**
    - *Social sub-theme*
        - *Impact within the organisation (PTO)*: assesses how the application affects the PTO workforce and those who operate or maintain it.
        - *Additional Social component*: captures stand-alone aspects such as contribution to local air or water quality and siting in areas with severe grid congestion.
    - *Sustainability sub-theme*
        - *Prevention of pollution*: focuses on preventing harmful releases to air and water during installation and operation.
        - *Alignment with development goals*: assesses alignment with adopted municipalities or provinces/PTA objectives or SDGs.

   - *Additional Sustainability component*: captures stand-alone aspects such as prevention of harmful substances and local water and air pollution reduction.

To support practical decision-making, the thesis proposes that this modular outline should be applied sequentially: first the Technical theme as a feasibility screen, then the Societal theme to rank remaining candidates, followed by a legal feasibility assessment to choose an appropriate legal construction. Figure 11.1 provides the legal decision logic. For the highest-ranked applications, the recommendation is to select the least complex viable legal route.

Based on these findings, the thesis offers practical guidance for moving from isolated pilots to repeatable practice:

1. **Build a shared technical baseline**
   The (public) PTO or municipality, together with the DSO and where relevant the TSO, assesses what is technically feasible. This requires sharing data on load profiles, system capacities, and operational constraints of both the public grid and the traction power network. The aim is to identify suitable locations, required safeguards to protect core operations, and the feasibility of bidirectional inverters (to not waste regenerative braking energy). In parallel, required technical and administrative capacity is assessed and developed (engineering, asset management, metering, contracts, billing, data), when required.
2. **Align ambitions and deployment options**
   With a shared baseline, stakeholders (PTO, municipality, DSO and possibly TSO, province or PTA, and ideally legal expertise) jointly discuss whether and how the network should be used beyond transport, explicitly comparing connecting applications with alternatives such as congestion management.
3. **Choose the deployment**
   Per network, decide whether to connect applications, apply congestion management, combine both, or do nothing. If connecting applications is chosen, continue with the steps below.
4. **Operationalise the framework**
   The PTO or municipality and the DSO translate the Technical theme into concrete components, scoring rules, and minimum preconditions. Public authorities (municipality, province, PTA) specify the Societal theme based on adopted policy goals. Develop a standardised application fiche that captures the required technical, operational, and legal information.
5. **Enable implementation conditions**
   Explore funding and instruments that improve business cases. Where relevant, adjust concession requirements in future tenders to improve data access, clarify roles, and support cooperation on congestion management or application connections.
6. **Assess applications and select a legal route**
   Apply the framework sequentially (Technical first, then Societal). For the highest-ranked options, choose the least complex viable legal construct and update agreements and energy contracts with the DSO where needed, consulting the ACM when required.
7. **Iterate and share lessons**
   Document lessons and refine components, preconditions, and scoring rules over time. Build a small internal knowledge team and share experiences externally to accelerate cross-site learning.

Most importantly, the thesis concludes that using PTO electricity infrastructures for congestion relief is currently more an organisational and governance challenge than a matter of finalising a universally applicable prioritisation framework. Fragmented responsibilities, siloed practices, knowledge gaps, uncertainty about stakeholder involvement, and a limited shared overview of legal options constrain progress. The primary value of this research is therefore that it clarifies the system, provides a consolidated overview of options and decision logic, and offers structured, practical guidance that stakeholders can use to align expectations, put it into practice capacity, provide the necessary technical knowledge, and develop locally adapted decision-making that protects public transport operations while contributing to congestion relief.

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Nomenclature

Abbreviations

Abbreviation	Definition
AC	Alternating Current
ACM	Authority for Consumers and Markets (Dutch: *Autoriteit Consument & Markt*)
ATO	Connection and Transport Agreement (Dutch: *Aansluit- en Transportovereenkomst*)
BSP	Balancing Service Provider
CBC	Capacity Limitation Contracts (Dutch: *Capaciteitsbeperkingscontract*)
CPO	Cable Pooling Agreement (Dutch: *Cable Pooling Overeenkomst*)
CS	Closed System
CSP	Congestion Service Provider
DC	Direct Current
DES	Distributed Energy Systems
DSO	Distribution System Operator
EAN (Code)	European Article Number (Code)
ELC	Effective Load Coefficient
EMS	Energy Management System
ESS	Energy Storage Systems
EU	European Union
EV	Electric Vehicle
GDS	Closed Distribution System (Dutch: *Gesloten Distributiesysteem*)
GTV	Contracted power (Dutch: *Gecontracteerde Vermogen*)
GVB	The Public Transport operator of Amsterdam (Dutch: *Gemeentelijk Vervoerbedrijf*)
HTM	The Public Transport operator of The Hague (Dutch: *Haagsche Tramweg Maatschappij*)
HVAC	Heating, Ventilation, and Air Conditioning
IenW	Ministry of Infrastructure and Water Management (Dutch: *Ministerie Infrastructuur en Waterstaat*)
IPF	(World Bank) Infrastructure Prioritization Framework
ISO	International Organization for Standardization
KGG	Ministry of Climate Policy and Green Growth (Dutch: *Ministerie Klimaat en Groene Groei*)
MCDA	Multi-Criteria Decision Analysis
MIEK	Multi-year Program for Infrastructure, Energy and Climate (Dutch: *Meerjarenprogramma Infrastructuur Energie en Klimaat*)
MRDH	Metropolitan Region Rotterdam The Hague (Dutch: *Metropoolregio Rotterdam Den Haag*)
NS	Dutch Railways (Dutch: *Nederlandse Spoorwegen*)
OHL	Overhead Line
PAP	Primary Allocation Point (Dutch: *Primair Allocatiepunt*)
PTA	Public Transport Authority
PTO	Public Transport Operator
PV	Photovoltaic
RES	Renewable Energy Sources
RET	The Public Transport operator of Rotterdam (Dutch: *De Rotterdamse Electrische Tram*)
SAP	Secondary Allocation Point (Dutch: *Secundair Allocatiepunt*)
SDG	Sustainable Development Goal(s)
TBL	Triple Bottom Line
TSO	Transmission System Operator
V2G	Vehicle-to-Grid
VRA	Amsterdam Transport Authority (Dutch: *Vervoerregio Amsterdam*)
WOZ	Valuation of Immovable Property Act (Dutch: *Wet waardering onroerende zaken*)

Symbols

Symbol	Definition	Unit
I	Electric current	[A (Ampere)]
ELC	Effective Load Coefficient (dimensionless indicator used in technical theme)	[-]
P	Power	[W (Watt)]
V	Voltage	[V (Volt)]

1

Introduction

This chapter introduces the practical research undertaken as a necessary step towards using Dutch public transport electricity infrastructure more effectively to help alleviate congestion on the public electricity grid. At the start of the study, the aim was to design a prioritisation framework that infrastructure owners or operators could use to rank candidate (third-party) energy applications that seek connection to public transport electricity infrastructure (traction power networks), based on a set of evaluation criteria. As the research progressed, however, it became clear that a comprehensive, generally applicable framework cannot yet be developed, because several key technical, organisational, and legal conditions, as well as stakeholder roles, duties and responsibilities, are still insufficiently defined, aligned, or understood across the sector.

The focus of the thesis therefore shifted towards clarifying the system, including the enabling conditions, mapping the main ambiguities and practical barriers, and formulating recommendations that help stakeholders understand where to start, what steps to take, and how to collaborate. The aim is to support effective use of public transport electricity infrastructure in a way that safeguards core public transport operations, supports PTO objectives, and can contribute to local congestion relief. Based on the empirical data and insights gathered throughout the research, the thesis additionally derives an outline for a future prioritisation framework. This outline provides guidance on what to evaluate and structures this into themes and underlying components that practitioners can adapt to their context. It should be understood as a preliminary advise that can support later framework development once the underlying conditions are better defined and sector-wide understanding has improved. Accordingly, the thesis places greatest emphasis on the broader system insights that emerged from the empirical work, because these are prerequisites for any future framework to be realistic, actionable, and broadly usable.

1.1. Situational Overview

In the Netherlands, national and regional electricity grids are facing increasing congestion, while PTOs must electrify, decarbonise and expand their services, for example through the electrification of bus fleets, higher service frequencies, and longer rolling stock. These developments together increase electricity demand and put additional pressure on both PTO and public grid infrastructures. Municipalities increasingly express the ambition that public transport electricity infrastructures, which contain substantial unused capacity, should also be made available for connecting (third-party) energy applications that can help relieve local congestion.

The organisation and delivery of public transport services requires intensive collaboration between multiple stakeholders, long term planning, and continuous maintenance and renewal of infrastructure assets. Even under normal conditions, this creates a complex environment in which operational reliability, passenger service quality, safety, and cost efficiency must be balanced. When new requirements are added, for example related to sustainability objectives or the use of existing assets for new purposes, this complexity further increases and must be carefully managed.

This thesis focusses on one specific development in this broader context, namely the possibility of using the electricity infrastructure that powers PTO operations to also supply other (third-party) energy applications. Integrating such applications into public transport electricity infrastructures introduces new technical, organisational, societal, and regulatory questions. Stakeholders are confronted with unfamiliar roles and responsibilities, knowledge about what this new development entails is limited or not widely shared, and there is currently little research or practical experience that stakeholders can draw upon. As a result, it is not yet clear how these applications should and could be implemented in a way that is both operationally feasible for PTOs and beneficial for the wider public electricity system and society.

In this thesis, public transport electricity infrastructure refers traction power networks and related public transport electricity assets, grid connections to the public grid. Two types of actors can be responsible for this infrastructure: a PTO that operates and maintains the infrastructure, or a municipality that owns the assets and chooses to operate, control and maintain the network itself.

The term *(third-party) energy applications* refers to any object, equipment, installation or facility that can be connected to the electricity infrastructure on which a PTO operates. Once connected, these applications are supplied with power via the public transport energy infrastructure and no longer require a separate connection to the public electricity network operated by distribution system operators (DSOs), such as Liander. (Third-party) energy applications can include, for example, EV charging stations, large-scale battery energy storage systems, and buildings such as offices, workshops or depots. The term is used as an umbrella concept for the wide variety of possible uses that can be connected to public transport energy infrastructure.

Background and context

Public transport networks in the Netherlands face increasing pressure due to rising passenger demand, ageing infrastructure that requires renewal, ambitious sustainability objectives, and evolving political and regulatory frameworks. At the same time, national and regional electricity grids are experiencing severe congestion challenges [1]. PTOs or municipalities manage extensive electricity infrastructures with substantial unused capacity and therefore have the potential to help mitigate these congestion issues [2]. Making more strategic use of public transport electricity infrastructures by connecting internal and external (third-party) energy applications is a relatively new concept, and some PTOs and municipalities do not know where to start. Furthermore, there are currently no established frameworks or decision support tools for evaluating and prioritising such energy applications.

Motivation

This research is motivated by the emerging opportunity for Dutch PTOs or municipalities to contribute actively to alleviating electricity grid congestion by connecting strategically selected (third-party) energy applications to their electricity infrastructures. The urgency of exploring this opportunity is reinforced by recent Dutch policy developments and sector initiatives.

On 21 July 2025, the Amsterdam City Council unanimously adopted a VVD motion supporting initiatives that leverage the electricity systems of GVB and ProRail as part of a multi-use strategy to relieve grid congestion. The motion explicitly refers to the “Sectordeal Netcongestie en OV” (English, *Administrative Agreement on Grid Congestion and Public Transport*) signed on 31 March and calls for active support for GVB energy congestion pilots [3]. In parallel, sector leaders have highlighted the immediate practical potential of PTO electricity systems. HTM’s CEO Jaap Bierman notes that HTM operates a dedicated electricity system in The Hague with a capacity of roughly 200 MW that on average is utilised at no more than 10%, and expresses, together with RET, the ambition to make public transport electricity infrastructures available to help alleviate urban grid congestion. Recently, RET and HTM have also achieved regulatory progress enabling (third-party) supply through several arrangements [4], which further strengthens the case for this development.

The combination of policy momentum, municipal expectations, and PTO willingness to help coincides with a high degree of complexity in the underlying operational and institutional settings. There is a clear need to understand the system more thoroughly, including the current state of developments, the governance arrangements, the operational and regulatory context in which PTO electricity systems are embedded, the interests and responsibilities of key stakeholders, and the range of candidate applications that are being considered. In addition, it is necessary to clarify the current maturity of the system, bringing together the available knowledge, and to identify which conditions must be in place before a full prioritisation framework can realistically be designed and applied.

1.2. Problem statement

To safeguard reliable public transport services while enabling public transport electricity infrastructures to contribute to grid congestion relief, stakeholders need a robust understanding of the technical and institutional system in which they operate. At present, however, stakeholders lack a shared picture of the conditions under which traction power networks can contribute to congestion relief and of what must be known and organised before (third-party) energy applications can be connected. Insight into available technical, legal and organisational options is fragmented, knowledge lacks, and roles, responsibilities and visions are interpreted differently across organisations. As a result, it is often unclear which stakeholders should be involved at which stage, what must be arranged before applications can be connected in effective way, and how core transport operations can be safeguarded.

This lack of shared understanding and knowledge also narrows the perceived solution space. Attention is frequently directed towards a limited number of pilot projects, which risks overlooking context-specific differences between PTO electricity infrastructures and governance settings, as well as alternative approaches that may be more suitable. Stakeholders are not always aware of what these differences imply for their own operations, obligations and available choices. Consequently, decision-making becomes difficult, collaboration is inefficient, and initiatives risk being suboptimal, unnecessarily risky, or misaligned with long-term objectives.

At the same time, PTOs cannot connect every candidate application and cannot assume the role of a DSO with universally accessible capacity. Choices are therefore required about which applications are technically feasible, legally implementable and organisationally manageable, and which applications should be postponed or not connected at all. Yet because the system and its constraints are not sufficiently understood, stakeholders lack a solid basis to decide where to start, what is feasible and desirable, and how responsibilities and processes should be organised.

The central problem addressed in this thesis is therefore not merely the absence of a prioritisation framework, but the lack of coordinated guidance, and a shared, integrated understanding of the system conditions under which (third-party) energy applications could or should be connected to public transport electricity infrastructures. This includes the technical, organisational, and legal understanding and prerequisites, the relevant stakeholders and their roles and contributions, and the way current arrangements shape what is realistically possible and desirable in practice.

Change in scope

As mentioned, the outset of this research was intended to develop a practical prioritisation framework that PTOs or municipalities could use to rank candidate (third-party) energy applications for a connection to their electricity infrastructures, based on a set of evaluation criteria. As the research progressed, it became evident that this objective was premature. Many foundational issues remain unresolved. These issues concern, for example, knowledge and data availability, clarity about permissible legal and contractual constructions and their associated burdens, alignment between PTO, DSO, and municipal objectives, mutual understanding of each other's roles, and basic insight into the impacts of additional external loads on traction power networks.

In this situation, attempting to specify detailed ranking criteria would be speculative and potentially misleading. The main added value of the research lies instead in revealing what is currently happening, organising the available options, identifying missed opportunities, highlighting where improvements are possible, and providing guidance to stakeholders on how to move forward in this complex situation.

Due to the change in scope during the study, some research objectives and questions were slightly adjusted to better support answering the main research question, but the underlying analyses and structure of the report is retained. The discussion chapter, the final part of the research, brings together and synthesises all the gathered insights and knowledge in order to answer the updated main research question. The newly formulated objectives are addressed in this phase and are used to derive a coherent set of results and conclusions. Overall, the research scope was reoriented from delivering a full prioritisation framework towards clarifying the problem space and identifying what needs to be organised and understood in order to eventually connect applications in a robust and effective way.

1.3. Research Objectives

The main objective of this thesis is to clarify what needs to be organised and understood so that public transport electricity infrastructures can be used in an effective and responsible way to reduce grid congestion and, where appropriate, connect (third-party) energy applications. Due to the change in scope, some research objectives were added during the research process and do not have corresponding research questions, since they were formulated at a later stage, these objectives are addressed and achieved in the discussion chapter of the report.

In addition to this primary objective, the research yields a useful secondary, additional contribution, an outline that PTOs and municipalities can use use as advisory input when they later develop a prioritisation framework to systematically assess (third-party) energy applications for a connection to their electricity infrastructure. This outline is based on information gathered throughout the research and is presented as advisory input. It offers a structured overview of decision-making themes and their constituent components, grounded in insights from internal and external stakeholders, experts, and academic literature, and clarifies why certain themes matter technically, operationally, and organisationally, and where in the PTO or municipal organisation the relevant expertise typically resides. It enables PTOs and their public partners to develop, tailor, and implement their own prioritisation approach.

Specifically, the research seeks to:

1. Develop an overview of the relevant stakeholders and examine their interrelations, influence, and responsibilities.
2. Compile an inventory of potential (third-party) energy application types and analyse their characteristic properties that are relevant to understand their technical, legal and societal impact, for comparison and future prioritisation.
3. Examine the legal and contractual constructions through which applications can be connected, including practical requirements and the advantages and disadvantages for PTOs.
4. Added after change in scope:
Identify and compare key differences between public transport electricity infrastructures and stakeholder contexts that affect the feasibility and desirability of connecting (third-party) energy applications.
5. Added after change in scope:
Identify knowledge gaps, clarify ambiguities, and institutional bottlenecks that currently hinder the systematic connection and prioritisation of applications.
6. Added after change in scope:
Formulate practical guidance on how the process of connecting applications should be organised, continued and prioritised, including roles, responsibilities, and collaboration arrangements between PTOs, municipalities, DSOs, and other actors.
7. Additional:
Identify key decision-making themes and context-specific components that PTOs and municipalities should consider when evaluating (third-party) energy applications, based on academic literature and expert advice, thereby providing structured input for a future prioritisation framework.
8. Additional:
Assess which components within these themes are considered most important and relevant by responsible external experts and experts within PTOs, municipalities, and provinces, and which actor is best positioned to evaluate each component, so that this knowledge can inform the design of future prioritisation tools.

1.4. Research Questions

The research objectives outlined in the previous section lead to the central question investigated in this thesis.

Main research question:

> *What needs to be understood and organised in terms of technical, organisational, and legal conditions so that Dutch public transport electricity infrastructures can effectively be used to connect (third-party) energy applications to help relief congestion on the public electricity grid?*

This main research question aims to uncover the most relevant technical, organisational, legal and societal conditions under which (third-party) energy applications can be connected to the electricity infrastructures of Dutch public transport operators in an effective way, and to clarify how these conditions, together with stakeholder roles and available knowledge, shape what is realistically possible and desirable in practice. It reflects the inductive and exploratory nature of the study and provides a foundation on which more detailed prioritisation and decision support instruments can later be developed once these underlying conditions have been clarified and understood.

To answer this question, the following sub-questions have been formulated. Each question addresses a different component of the main research question and contributes to a specific sub-objective.

Sub-questions:

The objectives of the sub-questions are stated briefly below, together with a concise description of the method used; the full method is detailed in *Research Design*. The mapping of questions to stages and sources follows the research design and thesis outline.

1. **Which stakeholders should be involved in order to effectively connect (third-party) energy applications, and what are their roles and influence?**

Objective: To identify the most relevant internal and external stakeholders based on their operational, legal, or strategic involvement in the process to connect (third-party) energy applications, and to understand their responsibilities, differences, interrelationships and decision-making power.
Method: Desk research of policy documents and government reports, complemented by exploratory consultations with legal and sector experts, to compile and validate a stakeholder overview.

2. **What types of (third-party) energy applications are currently being connected, or are viable candidates for connection, and what characterizes them?**

   Objective: To explore existing and potential (third-party) energy applications that may be connected to public transport electricity infrastructure, to understand their technical, spatial, and functional characteristics, to identify which characteristics and considerations are most important and relevant when assessing whether and how to connect (third-party) energy applications, and to inform future evaluation.
   Method: Literature review of academic and industry publications, together with recent government reports and sector news, to assemble and scope a catalogue of candidate applications

3. **Which legal constructions are available for connecting (third-party) energy applications to public transport electricity infrastructure, what requirements do they entail, and what are their main advantages and disadvantages?**

   Objective: To compile a comprehensive overview of feasible legal constructions for connecting applications, describe their what they imply for the PTO or municipality and summarize their advantages and disadvantages, and map application types to compatible legal constructs, so as to support PTOs ad municipality in selecting an appropriate legal approach for their context.
   Method: Analysis of national legislation and authoritative legal literature, supported by targeted consultations with legal experts, to identify the available connection constructs and their requirements.

   These questions were originally intended to help formulating a prioritisation framework, but are later adjusted to help answer the updated main research question.

4. **Which decision-making themes and corresponding components are relevant for understanding and assessing the feasibility of connecting (third-party) energy applications?**

   Objective: To create an overview and understand which themes and components are important and relevant to consider and eventually to asses which (third-party) energy applications could and should be connected.
   Method: A synthesised analyse of the gained outputs of the first three sub-research questions, academic literature and expert input, using interdisciplinary analysis to derive the evaluation themes and operationalise them into assessable components.

5. **How do internal, external stakeholders and experts perceive and assess these components, and where do perspectives align or diverge?**

   Objective: To analyse the consensus or divergence among stakeholders and experts, regarding the importance and relevance of specific components within each theme, and to uncover the underlying motivations, their present perception or constraints that motivates their opinions and approaches.
   Method: Semi-structured interviews with experts, those responsible within municipalities, provinces, and PTO/provincial technical departments, followed by qualitative analysis to get an overview of the most important and relevant components.

1.5. Research Design

In the research design, the research objectives and research questions are linked to specific data sources and analysis steps that together produce the research output. The main research question is answered through qualitative data analysis. This subsection explains how the elements of the study connect, which data types are used, and which techniques are applied to answer the main and sub-questions. Further details on data types and collection, and on the qualitative analysis procedure, are provided in Chapter *Research Methodology*.

A general overview of essential technical and legal background is developed from secondary sources to build a foundational understanding of the topic. In parallel, policy documents and governmental reports are analysed to identify the stakeholders involved and their interrelations. This yields a stakeholder overview that answers the first research question and achieves the first research objective.

Next, news articles, governmental reports, sector materials, and academic literature are used to compile an inventory of application types that could be connected to public transport electricity infrastructure. For each application, characteristic properties are documented, which will later support the development of the themes and their corresponding components. This addresses the second research question and the second research objective.

To answer the third research question and achieve the third research objective, statutory and regulatory documents, academic literature, and consultations with legal and regulatory experts are used to develop a consolidated overview of feasible legal and contractual approaches for connecting third parties. For each construction, the main requirements and responsibilities are described, together with advantages, disadvantages, and implications for PTOs. In this step, application types are also linked to compatible legal options for connection to the public transport electricity infrastructure.

With the knowledge and information gained from the first three research questions, an interdisciplinary synthesis will be done to produce insights for fourth research question and seventh (additional) research objective. The output is a set of synthesized insights that together with additional expert consultations and literature, formulates relevant themes and components, that answer the fourth research question and objective by developing the themes and associated components.

Eventually, the resulting themes and components are presented in semi-structured interviews with municipalities, provinces and PTO technical departments to answer the fifth research question and achieve the eighth (additional) research objective. The interview transcripts are the main data in this phase and are used to compare against the provisional themes and components, with respondents' reasoning captured to explain why specific components are more important.

Based on the accumulated knowledge and information, the study also progressively generates the insights needed to address the later added fourth, fifth, and sixth research objectives. As these objectives emerged in the later phases of the research and are grounded in the insights and knowledge built up in the preceding steps, they could not have been formulated and achieved in a meaningful way without the earlier work done. Together they contribute to answering the main research question and deliver the substantive insights that this study aims to provide. All these outputs are treated integrally in the discussion, where all inputs collected throughout the research, including documents, expert consultations, and interviews, are synthesised into coherent findings.

Analysis and synthesis

All documentary sources, literature, expert input, national legislation and interview transcripts are analysed qualitatively, as described in Chapter *Research Methodology*. First, it develops an overview of the relevant stakeholders and their roles, compiles and categorises potential types of (third-party) energy applications, and consolidates the legal constructions through which such applications can potentially be connected. The additional outline advises on decision-making themes and components that literature, stakeholders and experts regard as most important and relevant when assessing whether and how (third-party) energy applications could and should be connected. Finally, the integrative qualitative synthesis develops concise, practice-oriented insights and advice on what needs to be organised and understood so that public transport electricity infrastructures can be used in a responsible way to support PTO objectives, meet future demand and, where appropriate, host (third-party) energy applications that may help relieve local grid congestion. The combined insights from the preceding stages form a coherent system-level understanding and set of practical recommendations.

Figure 1.1 visualizes the Research Design, with the corresponding data sources, and their links to the sub-questions and objectives, including the feedback loops, that together with the objectives produce the main results and recommendations. It clearly shows that the newly formulated objectives have been added due to the change in scope.

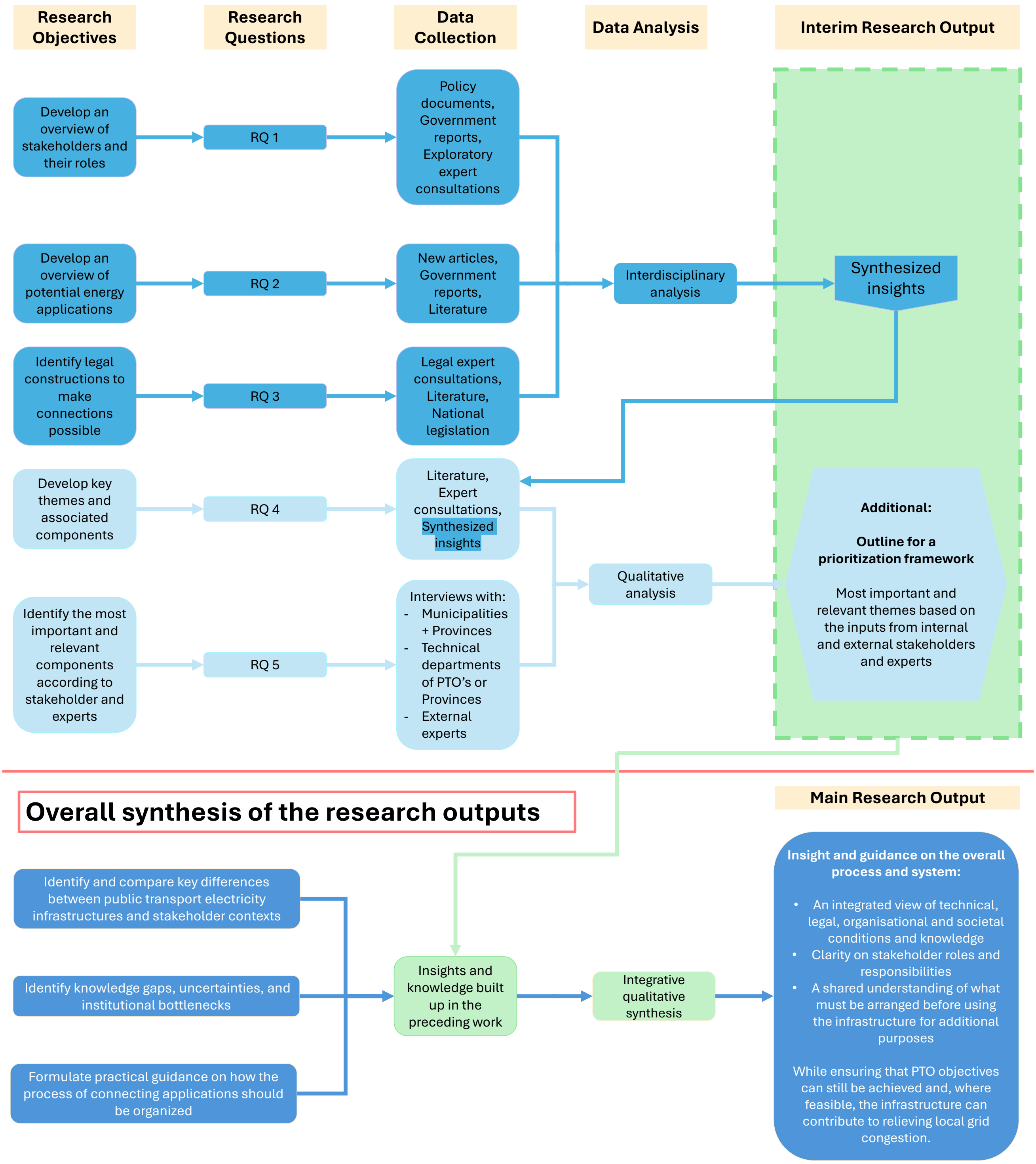


Figure 1.1: Schematic overview of the Research Design

1.6. Scope and Delimitations

This thesis is scoped to Dutch PTOs and municipalities with (public transport) electricity infrastructure in their area. At the same time, the study is intended to be relevant for other municipalities, provinces, and organisations that are willing to share their electricity infrastructure with third parties or to explore alternative ways in which their electricity infrastructure can contribute to relieving grid congestion.

The analysis is grounded in the Dutch legal and regulatory context and already anticipates the new Energy Act (Dutch: *Energiewet*), scheduled to enter into force on 1 January 2026, so that the recommendations remain applicable once the new legislation takes effect. The Authority for Consumers and Markets (ACM) is already preparing and giving permission according to the new *Energiewet* and the Energy Decree (Dutch: *Energiebesluit*), which suggests that earlier application of selected results are already feasible for PTOs or municipalities [5].

The legal and regulatory analysis is synthesised at a level relevant for PTOs and municipalities to understand what the legal options are, yet the applicability of specific conclusions may vary by organisational and contractual context. Given the stakeholder complexity, interviews are limited to municipal and provincial representatives and technical experts within the PTOs. In addition, a small number of experts from the ACM, a consultancy firm, and a researcher on traction power networks are consulted to assess particular themes within their expertise. The study does not evaluate every possible stakeholder perspective or niche application, nor does it carry out technical pilots or detailed quantitative modelling.

Since,the scope of the research has evolved, the focus was first concentrated on three substantive domains, technical aspects of connecting additional loads to public transport electricity infrastructures, legal and contractual options for enabling such connections, and societal value, that is, the social and sustainability benefits that municipalities and PTOs aim to realise through selected applications. Eventually, the scope shifted to clarify what needs to be understood and organised so that PTOs and municipalities can make effective and responsible use of public transport electricity infrastructures, both to maintain and expand public transport operations and, where appropriate, to support congestion relief.

1.7. Scientific and Societal Relevance

Scientifically, this thesis contributes to the emerging literature on the use of public transport electricity infrastructures for wider energy system objectives by adopting a system-of-systems perspective. It connects developments in traction power networks, and municipal decarbonisation agendas, and provides an integrated overview of the current situation, including its main hurdles and potentials. The study offers a stakeholder informed, qualitative analysis of how technical, organisational, legal, and societal conditions jointly shape what is feasible and desirable when connecting (third-party) energy applications to public transport electricity infrastructures. In doing so, it identifies knowledge gaps, institutional bottlenecks, and context specific differences between PTOs that are often overlooked in more technical or project specific studies. The results lay a conceptual and empirical foundation for future research on prioritisation and decision-making frameworks, including the development of more formal tools that build on the themes and components identified in this work.

Societally, the thesis supports municipalities and PTOs in making defensible, socially legitimate, and sustainable choices under grid constrained conditions. It provides practical guidance on what needs to be understood and organised before applications can be connected in a responsible way, clarifies available legal and contractual options, and highlights the implications of different choices for operational reliability and future public transport capacity. By offering a structured overview of relevant stakeholders, application types, and decision-making themes, the study helps align congestion relief efforts with long term decarbonisation objectives and the core public service mission of PTOs. The resulting insights can accelerate the effective use of underutilised capacity, foster more informed collaboration between public actors, and reduce the risk that scarce grid and investment resources are spent on suboptimal or fragmented solutions.

1.8. Thesis Outline

Figure 1.2 presents the structure of this thesis. The outline shows how the chapters are organised into six consecutive stages and how they connect to the research questions. Each stage builds on the results of the previous one, moving from context and exploration to synthesis and recommendations. The stages are described in more detail in Chapter *Research Methodology*, but are summarised here to clarify the overall logic of the thesis, see also Figure 1.2. The first five stages reflect the original ambition to work towards a prioritisation framework, the sixth stage brings together and reinterprets all outputs in light of the revised research aim, and develops the main discussion, conclusions, and recommendations.

The thesis begins with the *Introduction stage*. Chapter *Introduction* introduces the topic, formulates the problem statement, research objectives, and research questions, and positions the study in relation to its societal and scientific relevance. Chapter *Research Methodology* presents the research methodology, justifying the qualitative design, the stages of the study, and the methods for data collection and analysis.

The second stage is the *Exploration stage*, which provides essential background and addresses the first two research questions. Chapter *Contextual Framework* presents the contextual framework, consolidating the institutional, technical, and policy setting, and identifying key stakeholders, focussing on RQ1. Chapter *Applications* develops an inventory of potential types of applications, categorisations and describes characteristic properties of the applications, focussing on RQ2.

The third stage is the *Literature review stage*. Chapter *Literature review* surveys the academic and professional literature to deepen the theoretical and conceptual understanding of technical, legal, and decision-making components. Chapter *Legal Constructs* builds on this by consolidating the legal and contractual constructions available for connecting (third-party) energy applications to PTO infrastructure, highlighting their requirements, advantages, and disadvantages, focussing on RQ3.

The fourth stage is the *Expert consultation stage*, where Chapter *Focused Expert Consultations* is to obtain the last valuable knowledge to start developing the first themes and components.

The fifth stage is the *qualitative analysis*. Chapter *Themes Development* synthesises insights from the exploration, literature review, and expert consultations to define a coherent set of decision-making themes and their underlying components, focussing on RQ4. This step prepares the ground for empirical testing in the interviews. Evidence from the semi-structured interviews and survey with municipalities, provinces, and a PTO in Chapter *Stakeholder Perspectives* guides the development of grounded advice on the themes and components for the outline of a future prioritisation framework, focussing on RQ5. Chapter *Qualitative Analysis* conducts a qualitative synthesis of all empirical and literature findings to characterise the current system, clarify key problems and ambiguities, and derive the insights and generic themes needed for an outline prioritisation framework that can guide PTOs and municipalities when connecting (third-party) energy applications. Chapter *Outline for a Future Prioritisation Framework* presents the definitive outline for a future prioritisation framework, based on input of the stakeholders and the academic literature and expert inputs.

In the sixth and final stage, the *Implications and conclusions*, the outputs and results from all previous stages are brought together and synthesised to answer the main research question. In this stage, the thesis reorganises the findings around the revised research aim, namely clarifying the situational overview and the conditions that needs to be understood before a prioritisation framework can be effectively developed and applied. Chapter *Discussion* discusses addresses the added research objectives and put the findings in light of existing literature and practice, organises the diverse outputs into a coherent narrative, and explains how the accumulated evidence leads to a revised and more realistic understanding of the problem and the conditions of the current situation. Chapter *Limitations* addresses limitations and directions for future research, while Chapter *Conclusion* concludes the thesis by summarising the main conclusions and contributions and by revisiting the research objectives in the light of the changed scope. The final Chapter *Recommendations* translates the conclusions into practical recommendations for PTOs, municipalities, provinces, and other stakeholders, including guidance on how to continue the process of making connections possible and an outline for a future prioritisation framework.

In sum, the thesis proceeds through six stages, *Introduction*, *Exploration*, *Literature review*, *Expert consultation*, *Qualitative analysis*, and *Implications and conclusions*. Together, these stages provide the evidence and reasoning that culminate in a well grounded advice for PTOs and municipalities on how to organise the use of public transport electricity infrastructures in a responsible and effective way. As an additional outcome, the thesis proposes an outline for a future prioritisation framework and accompanying guidance that PTOs or municipalities can adapt to prioritise potential energy applications. This outline builds on the answers to the main and sub-research questions, but it does not in itself constitute a complete framework, it is intended as preparatory input for future work, see also Figure 1.2.

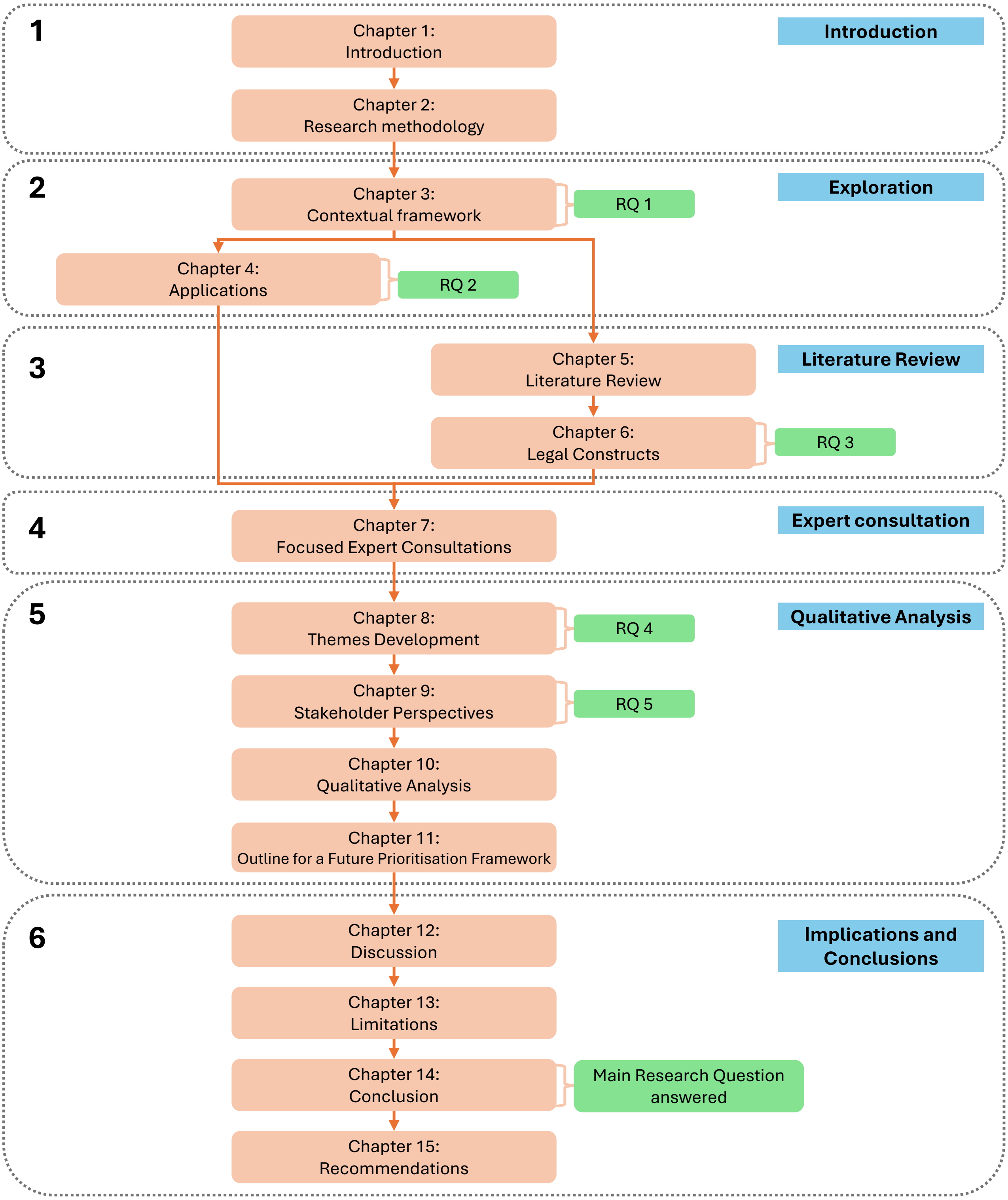


Figure 1.2: Schematic overview of the thesis outline, stages, and connection to research questions

2
Research Methodology

This chapter outlines the qualitative, exploratory research methodology adopted for this study and explains how the research was originally designed and carried out. It also briefly explains the relation to other decision frameworks currently existing. Although the scope was adjusted during the course of the research and the most meaningful outputs are presented in the discussion chapter, the underlying methodology remained unchanged, because the valuable insights were generated through this approach. Only at the end of this chapter a short paragraph explains how the shift in scope influenced the way the collected information was used to generate value for the study. The following sections describe the research approach in more detail.

The chapter also describes the data collection process, data management procedures, and analytical techniques used to uncover and validate these themes and components.

The research was aimed to produce a grounded and stakeholder-informed overview of themes and components that PTOs and municipalities with (public transport) electricity infrastructure can use to develop a decision tool to internally and systematically assess and prioritize (third-party) energy applications. To ensure the results are also valuable for other PTOs, municipalities, and third parties, the themes are treated in sufficient depth so that other actors can reason which components matter for their context, acknowledging that each network and connection has different characteristics, requirements, and stakeholders.

In this context, themes refer to overarching categories that reflect the most critical focus areas in the application prioritization process. Each theme is composed of several components, which are the specific elements, considerations, or sub-issues that give depth and meaning to the broader theme. The themes were pre-aligned based on discussions with experts and supervisors, and the research is therefore focused on these themes.

This research, therefore provides a comprehensive overview in which themes are developed based on expert input, a literature review, and a consolidated synthesis. This allows each operator and party to determine what is feasible, relevant, and strategically aligned within their own infrastructure and organizational context, and, in the case of PTOs, with the requirements set by their respective public transport authority (PTA) as defined in the concession agreements.

2.1. Research Approach and Justification

A qualitative exploratory research approach was chosen for this study due to its effectiveness in exploring and understanding the perceptions, motivations, and experiences of both internal and external stakeholders. Qualitative methods are particularly suitable for uncovering previously unknown or insufficiently explored themes and for gaining an in-depth understanding of complex, context-dependent issues. The flexible and iterative nature of qualitative research facilitates comprehensive data collection, allowing the study to adapt and delve deeper into emerging findings throughout.

In this research, a combination of literature reviews, policy document analyses, general technical and legal background research, expert consultations, and qualitative interviews is employed. The literature review, analysis of policy documents, and general technical and legal knowledge provide foundational insights and contextual understanding, enabling a clearer view of existing knowledge, key challenges, and stakeholder perspectives. This combined methodological approach ensures a thorough exploration of stakeholder knowledge, motivations, and priorities, making it highly appropriate when subjective experiences and detailed contextual understanding are critical [6].

The design proceeds in six linked stages, each with a clear purpose and output that feeds the next stage:

1. *Introduction*: Introduces the problem context and motivates the study, formulates the research objectives and questions, and outlines the qualitative methodology used in the remainder of the thesis.

2. *Exploration*: Develops the contextual framework by analysing policy and sector documents and consolidating essential traction power and legal fundamentals. It identifies stakeholders and their interrelations and compiles an initial set of candidate applications. This stage primarily addresses **RQ1** and **RQ2** and structures subsequent work.
3. *Literature Review*: Conducts a focused academic review on three strands, technical behaviour of traction and auxiliary systems under additional loads, legal and regulatory options that could enable dual use of PTO infrastructure, and decision support perspectives, including social and environmental value considerations. The review, complemented by national legislation and regulatory sources, answers **RQ3** and sharpens the inputs for theme development.
4. *Expert Consultation*: The knowledge gained in the initial phases of the research will be supplemented with additional input from experts. Together with the input from experts, there should be sufficient information available to further develop the preliminary themes in the next phase.
5. *Qualitative Analyses*: Using the knowledge from the previous stages, interdisciplinary synthesis yields a coherent set of preliminary decision-making themes and underlying components and answers **RQ4**. Theme-specific, semi-structured interviews are then conducted with responsible experts from municipalities, provinces/PTAs and technical departments of PTOs to determine which components are most important and why, which answers **RQ5** and produces the stakeholder-informed prioritisation overview. Finally, the results of the stakeholder survey are combined with the advice of the experts and the literature to develop a definitive recommendation for a prioritisation framework.
6. *Implications and Conclusions*: The final stage of the research focuses on delivering the intended outputs. It conducts an integrative qualitative synthesis of all collected data and insights and develops the overview needed to answer the **main research question** and to formulate recommendations. In this stage, the results are also discussed in relation to existing literature and practice, and the main conclusions of the study are drawn. The chapter presents the outcomes for the main research question, summarises answers to the sub questions, formulates practical recommendations for PTOs and municipalities, and reflects on limitations and directions for future research.

This design supports triangulation across documents, literature, and stakeholder knowledge to produce a grounded, PTO-oriented overview of themes and components.

2.2. Existing decision frameworks

Ranking candidate energy applications that could be connected to traction power networks is a multi-dimensional decision problem, because it involves technical performance, costs, risks, societal impacts, and legal or organisational constraints. Multi-Criteria Decision Analysis (MCDA) is widely used for exactly this type of problem, since it provides a structured way to combine quantitative and qualitative indicators, to elicit stakeholder preferences, and to document trade-offs in a reproducible way. In practical terms, MCDA methods help decision makers compare options when multiple criteria or objectives must be considered at the same time, for example when choosing between different infrastructure projects or energy applications.

The following subsections introduce several existing MCDA based prioritisation frameworks, to illustrate how such decision models are used in practice, how they are structured, and how they address challenges that are also present in this research. These examples provide a reference point for the proposed outline in this thesis and will later be used in the discussion to position the outline for the framework developed for public transport electricity infrastructures within the wider family of MCDA approaches.

World Bank Infrastructure Prioritization Framework

Marcelo et al. [7] introduce the World Bank's Infrastructure Prioritization Framework (IPF) as an alternative project selection-tool for governments that face large infrastructure needs, strict budget constraints and limited capacity to perform full social cost-benefit analyses for all candidate projects. IPF is designed as a systematic but pragmatic screening tool for large sets of small and medium sized projects. It synthesises project level information into two composite indices, a social environmental index and a financial economic index, and uses these to position projects in a two dimensional space that can be compared with the available sector budget. In practical terms, projects are scored on a set of normalised indicators, these indicators are grouped into the two dimensions with explicit weights, and the resulting index scores are plotted against each other and confronted with a budget line to identify feasible combinations of projects. Instead of selecting projects in an ad hoc or purely political way, the framework makes the decision space explicit, allows projects that have passed strategic pre-screening and basic appraisal to be compared, and creates room for technical deliberation based on a transparent set of criteria and weights. The graphical display of the results supports communication with stakeholders and encourages ministries to agree ex ante on the indicators and weights that reflect national priorities.

The literature on MCDA for sustainable development highlights several key requirements, namely that the method can handle complex situations with multiple criteria, scales, data types and uncertainties, that it allows the involvement of several decision makers, and that it facilitates stakeholder engagement to deepen knowledge and generate alternative solutions [8].

In this set up, projects are prioritised according to their performance on the two indices and their compatibility with the budget constraint. Decision makers can identify projects that perform well on both dimensions and fit within the budget, explore trade-offs between financial economic returns and social environmental benefits, and discuss whether projects with weaker performance should be redesigned or postponed. The authors emphasise that IPF is intended as a stepping stone approach, which structures decisions when information and analytical capacity are limited, while at the same time highlighting data gaps and appraisal weaknesses that can be addressed in future planning cycles.

Relevance for this thesis

Several design principles of IPF are directly relevant for this thesis. Grouping indicators into a small number of composite dimensions, in this case social environmental and financial economic, and in the financial economic dimension technical aspects can be implemented, is analogous to structuring a prioritisation framework into a limited set of themes with underlying components. IPF is explicitly designed as a screening tool when information is incomplete and analytical capacity is constrained, which is comparable to the situation in this research where choices must be made without full social cost-benefit analyses or when other relevant technical or organisational information is missing for each energy application. This supports the idea that multiple simple indicators can be combined within each theme or component, even when detailed data are not yet available. The emphasis on ex ante agreement about criteria and explicit weighting, and on transparent communication of results, also aligns with the need for objectivity and equal treatment when public transport electricity infrastructures are used, particularly in legal constructions where public bodies must be able to justify their decisions.

Dutch MIEK programme and its assessment framework

The Dutch Multi year Program for Infrastructure, Energy and Climate (Dutch: *Meerjarenprogramma Infrastructuur Energie en Klimaat*, MIEK) is the national programme that coordinates large energy infrastructure projects across electricity, hydrogen, heat and CO_2 It is explicitly designed for situations of structural scarcity in time, space, grid capacity and public funds, and therefore concentrates on selecting those projects that merit priority support because of their high societal value [9]. Projects are submitted using a standardised project fiche and are then assessed with the MIEK assessment framework (Dutch: *MIEK afwegingskader*). Applying this framework, projects are scored on a limited set of core criteria, namely their societal importance, spatial integration, contribution to the future energy system, scale level and urgency, as well as the presence of a concrete help request and the availability of suitable instruments to address bottlenecks. The individual scores are then brought together in a structured comparison of all candidate projects, allowing decision makers to rank projects and to identify a limited set of highest priority projects that should be accelerated under the prevailing constraints on time, capacity and public funds. Projects that score highly across these dimensions are granted a national MIEK status, which gives them priority in planning and access to additional support, for example accelerated permitting or coordination with grid operators.

Relevance for this thesis

MIEK shows how a multi-criteria assessment framework can be used to prioritise energy infrastructure projects under scarcity, based on a small set of transparent criteria that combine technical system considerations with broader societal goals. This is directly relevant for the present study, which similarly seeks to structure decisions on which energy applications should be connected first to public transport electricity infrastructures, by defining themes and components that allow operators and public authorities to justify priority in a consistent and traceable way.

MCDA for sustainability assessment in the food sector

Ferla et al. [10] present a systematic literature review of how multi-criteria Decision Analysis (MCDA) has been used to assess sustainability in the food sector. 42 empirical studies have been analysed along three main dimensions, namely the MCDA methods and tools that are applied, the type and role of stakeholder participation, and the indicators and sustainability dimensions that are used to evaluate performance. The review shows that a wide range of MCDA techniques is employed, and that these techniques are frequently combined with life cycle based environmental indicators and economic measures to support decisions on issues such as product choice, supply chain configuration and waste management.

A central finding of the review is that MCDA is particularly well suited for sustainability assessment, because it can integrate heterogeneous indicators that cover environmental, economic and social aspects within a single decision framework. The authors highlight that the most useful applications share several features, they make their criteria and weighting schemes explicit, they remain relatively simple and communicable for non-expert users, and they are designed to work with incomplete or uncertain data. The review further underscores the importance of stakeholder involvement. Many of the examined studies engage actors such as producers, retailers, consumers and public authorities to help define indicators, assign weights or validate the results, and the authors synthesise this into a stakeholder engagement map that clarifies who is typically involved, why, and at which stage of the MCDA process. Finally, the paper identifies challenges around harmonising indicator sets and balancing methodological sophistication against practical usability, and argues that future MCDA tools for food sustainability should aim for greater standardisation of indicators while preserving flexibility to adapt to local contexts.

Relevance for this thesis

The conclusions of Ferla et al. [10] are relevant for this thesis in several ways. First, their synthesis confirms that MCDA is an appropriate approach when decisions must account for multiple sustainability dimensions and qualitative as well as quantitative information, which is analogous to the situation of public transport operators that need to weigh technical, societal and organisational aspects when connecting energy applications to traction power networks. Second, the emphasis on transparent criteria, explicit weighting and ease of communication reinforces the design choice in this research to formulate themes and components in a way that practitioners can understand and explain, rather than relying on highly technical optimisation models. Third, the discussion of stakeholder involvement and the need to tailor indicator sets to specific supply chains provides a useful parallel for engaging PTOs, municipalities and regulators when defining and refining the components of a prioritisation framework for public transport electricity infrastructures.

Taken together, these frameworks and reviews show how MCDA can be used to structure infrastructure and sustainability decisions, from strategic national investment pipelines to sector specific regulatory assessments and supply chain evaluations. They also highlight design choices that are directly relevant for this thesis, such as the use of themes and underlying indicators, the balance between monetised, normalised and quantitative and qualitative criteria, the decision whether to calculate a single composite score or to present a structured dashboard, and the need to keep methods transparent and workable for practitioners. Comparing the proposed outline for prioritising and scoring energy applications on public transport electricity infrastructures with these established MCDA based approaches in the discussion chapter can therefore help to move beyond local institutional complexity and to draw on lessons from other sectors facing similar prioritisation challenges, and these lessons are distilled into a set of design principles listed below.

- **Work with a limited number of core dimensions** (IPF and MIEK)
  Structure the framework around a small set of clear themes (for example technical system, societal value, spatial integration and implementability) rather than a long list of ungrouped criteria.
- **Aggregate indicators and plot them** (IPF)
  Group indicators into composite indices (for example social environmental and financial economic), plot projects in this two dimensional space with a budget line, and use the visual overview to see at a glance which projects and combinations fit the budget and offer the best societal value.
- **Make scarcity and system constraints explicit in the assessment** (IPF and MIEK)
  Explicitly represent limitations in grid capacity, space, time and public funds and use the framework to identify combinations of projects or applications that fit within these constraints.

- **Use a standardised project fiche as the entry point** (MIEK)
  Require every energy application to be described in a common fiche with fields for location, technical profile, expected use, societal objectives and support request before applying the framework.
- **Allow for simple and partly qualitative indicators when data are incomplete** (IPF and Ferla et al. [10])
  Work with basic scales and semi-quantitative judgments where necessary, as long as definitions and assumptions are clearly documented and can be refined over time.
- **Normalise indicators and apply explicit weights** (IPF and Ferla et al. [10])
  Map indicators to a common scale and assign transparent weights to themes and indicators so that the influence of weighting on the ranking can be explained and tested.
- **Link technical requirements to financial and system impact** (IPF)
  Group technical aspects that drive costs, risks or grid impact in a financial technical or system technical component so that feasibility is assessed jointly rather than in isolation.
- **Design the framework for transparency and accountability** (IPF, MIEK and Ferla et al. [10])
  Formulate criteria, scoring rules and outputs in a way that is understandable for non-experts and usable to justify decisions towards boards, regulators and courts if needed.
- **Involve stakeholders in criteria definition, weighting and validation** (IPF, MIEK and Ferla et al. [10])
  Engage PTOs, grid operators, municipalities and regulators in the selection of indicators, the setting of weights and the interpretation of first results to increase legitimacy and practical relevance.
- **Treat the framework as an iterative stepping stone rather than a final model** (IPF and MIEK)
  Use the framework to structure current decisions and at the same time to reveal data gaps and design weaknesses, with the explicit intention to revise and improve it in subsequent application rounds.

2.3. Data Types and Collection Methods

This study draws on multiple qualitative data types that together provide a balanced view of theory and policy, as well as lived practices and organizational perspectives. The selected data types enable triangulation across open source documents, academic literature, national legislation, and stakeholder knowledge. Data are gathered through distinct methods, and each data type and its collection method are outlined below. Zotero is used to collect, organise, annotate, and cite sources throughout the research. This choice of data types aligns with the research design mapping from questions to inputs and outputs.

Secondary sources

A wide range of non-academic sources is reviewed to establish contextual understanding and to create an initial overview. These include policy and sector documents, governmental reports and portals, regulator publications, annual and programme reports, press releases and news articles, and other publicly available materials from PTOs, municipalities, PTAs, DSOs, and consultancies. The purpose is to obtain a clear picture of the institutional setting, the functioning of PTO electricity interfaces with emphasis on traction power systems, and the breadth of potential (third-party) energy applications. Insights from this exploratory work inform the stakeholder map and the search strings of the subsequent literature review, and they seed the applications inventory, primarily addressing **RQ1** and **RQ2**.

Data collection method

Documentary materials are identified through purposive web searches of PTO and stakeholder websites, public policy portals, and governmental databases. Selection follows inclusion criteria on relevance to third-party use of public transport electricity infrastructure, completeness, and provenance. Sources are logged in Zotero, and key information is saved in a structured data file that records data origin, scope, core statements, and implications for this research.

National legislation and regulatory documents

In addition to non-academic sources, primary legal materials are collected to determine feasible legal and contractual approaches. These include statutes and decrees, regulatory codes and orders, regulatory guidance and explanatory notes, and official consultations. The purpose is to identify available constructions, associated requirements, responsibilities, and compliance steps, and to summarize advantages and disadvantages for PTOs, addressing **RQ3**.

Data collection method

Authoritative versions are retrieved from official portals and consolidated collections. Where relevant, amendments and explanatory memoranda are tracked to understand intent and scope. Extracted provisions are logged in Zotero with citations, applicability notes, and cross-references to interview and literature evidence.

Literature review

The literature review provides the theoretical and conceptual foundation for the study. It synthesises academic work on the technical behaviour of traction and auxiliary power systems under additional loads, legal and regulatory options to employ public transport electricity infrastructure in alleviating grid congestion, and decision support perspectives, including triple bottom line approaches, for prioritising applications. The review refines the applications inventory and informs the development of themes and components, thereby support to answer **RQ4**.

Data collection method

Relevant literature is located through systematic searches in academic databases and scholarly search engines using tailored query strings per theme, technical, legal, social, and sustainability. Records are screened based on title and abstract, with full text inclusion determined by direct relevance to the research questions. Extracted findings and definitions are saved in a structured academic data file, while all sources are logged in Zotero.

Expert consultations

Targeted and scoping-oriented consultations are held to clarify significant thematic areas, surface unknowns, and refine the scope throughout the research. They help validate the preliminary set of themes and identify critical components that warrant deeper investigation in the main interview stage. Consulted experts include PTO specialists, ACM staff, and consultants with close links to municipalities, PTAs, and national government. These consultations help to get to **RQ1**, **RQ3**, and the theme formulation for **RQ4**.

Data collection method

Short semi-structured conversations are used to clarify ambiguities, interpret regulatory language, and assess the state of practice. With consent, sessions are recorded, then notes or transcripts are produced and stored in dedicated folders. Where appropriate, summaries included in the report are shared with participants for confirmation.

Stakeholders interviews and surveys

In-depth interviews or surveys are conducted with experts and representatives from relevant divisions within PTOs and the municipality or province/PTA. The interviews collect detailed insights on thematic relevance and allow respondents to articulate their professional views on critical components related to connecting (third-party) energy applications to public transport electricity infrastructures, and to express what their organisation considers most important when prioritising applications. Interviews and surveys are the primary data for stakeholder prioritization, addressing **RQ5**.

Data collection method

Interviews follow theme-specific, semi-structured guides tailored to each participant's role and expertise. Participants are recruited through purposive and chain referral sampling to ensure that only those with operational or decision-making responsibilities for a given theme are included. With consent, interviews are audio recorded and transcribed for analysis. Data are anonymised during transcription and stored securely. Short surveys are used as a fallback for invitees who are unavailable for interview, with survey data stored in separate folders.

2.4. Data management

All data gathered in this research, including interview transcripts, survey records, national legislation, and the documents that capture curated academic and non-academic knowledge, as well as other qualitative materials, are securely stored in TU Delft's Microsoft Teams environment. Access is restricted to the research team through institutional accounts. Personal identifiers are removed or pseudonymized during transcription and analysis, and any key linking files are stored separately. Data handling practices strictly follow TU Delft's ethical guidelines and fully comply with the General Data Protection Regulation (GDPR).

2.5. Data Analysis

The analytical process employed in this study is described below.

Qualitative Analysis

Following the approach of [11], the qualitative analysis proceeds in a clear sequence. First, all interviews and surveys are transcribed. The transcripts are then coded to obtain preliminary insight into salient topics, recurring notions, and illustrative quotations. Once coding is complete, the full set of coded interviews is reviewed again to extract important aspects and quotes, which are compiled into a structured catalogue. This catalogue functions as an intermediate evidence base that makes it possible to see overarching themes and patterns relevant to prioritising (third-party) energy applications on public transport electricity infrastructure.

Throughout, triangulation is applied by comparing interview-based insights with documentary, national legislation, and literature sources to check where evidence converges or diverges. This ensures that the final results are not only grounded in stakeholder perspectives but also consistent with the broader evidence base used in this study.

2.6. Outcome of Methodological Approach

By integrating findings from the literature and policy document review with expert consultations and stakeholder interviews, this research produces a structured overview of the most critical themes and components for prioritizing (third-party) energy application connections to public transport electricity infrastructures, primarily focused on PTOs whose owner is the municipality in which they operate. This synthesis provides PTOs with a foundational understanding of prioritization considerations and offers practical insights to support strategic decision-making processes.

2.7. Implications of the Change in Scope for the Research Approach

The empirical research was carried out as originally designed, since the change of scope only emerged at a later stage of the study. Therefore, data collection, document analysis, expert consultations, and interviews were conducted in line with the initial aim of developing a prioritisation framework for (third-party) energy applications on public transport electricity infrastructures. The change in scope ultimately affected how the collected material was interpreted, synthesised, and reported in the final stages of the study.

In the discussion chapter, an integrative qualitative synthesis of all collected data and insights was conducted. The synthesis focuses on assessing the overall state of the system, identifying key problems, stakeholders roles, clarify ambiguities, and knowledge gaps, and clarifying the technical, organisational, legal, and societal conditions that enable or constrain the connection of (third-party) energy applications. This shift in perspective allowed the same empirical basis to be used to formulate practical advice on what needs to be organised, which enabling conditions require attention, and what information is most relevant for stakeholders who wish to make more effective use of public transport electricity infrastructures.

For this reason, the research methodology itself was not changed. The original design and qualitative analysis, aimed at developing a prioritisation framework, generated the detailed system insights that ultimately revealed that neither the system nor the involved stakeholders are yet ready for a fully operational prioritisation tool. Instead of discarding this work, the study reframed and synthesised it to strengthen the understanding of the system and to provide well founded guidance. The adjusted scope therefore concerns the way the results are used and interpreted, not the methods by which the data were collected and analysed.

2.8. AI Statement

During the preparation of this thesis, ChatGPT [12] is used as a language support tool to improve the quality of the English writing, readability, and structure of the text. The tool was used to rephrase and streamline paragraphs that was written by the author of this thesis, to check grammar and consistency, and to suggest clearer formulations. ChatGPT was not used to design the research, generate ideas or arguments, analyse data, or draw conclusions. After receiving suggestions from ChatGPT, the author reviewed and edited all content as needed and the author takes full responsibility for the final text and its scientific content.

3

Contextual Framework

This is an exploratory chapter that aims to develop a broad and well-grounded understanding of the topic. The purpose of this exploratory phase is to contextualize the integration of (third-party) energy applications into the electricity infrastructure of public transport operators (PTOs). Rather than conducting a deep thematic analysis, this phase focuses on mapping the overall landscape in which such developments occur. By reviewing policy documents, technical reference materials, and conducting informal exploratory expert consultations, the chapter identifies the main opportunities, challenges, and stakeholder positions related to the integration of external applications. The outcomes of this exploration will guide and refine the research focus, define preliminary themes and relevant stakeholder groups, support the design of the subsequent research phases, and provide the technical and institutional understanding required to evaluate future scenarios and implementation strategies. Furthermore, this chapter provides an initial answer to first research question, identifying which stakeholders should be involved in the prioritization of (third-party) energy applications, and clarifying their respective roles and influence in the process.

3.1. Institutional and Policy Landscape

To have a proper understanding of which stakeholders should be involved in the prioritization of (third-party) energy applications it is important to have an overview that provides the institutional setting in which the integration of external applications into public transport electricity infrastructures takes place. It outlines the main stakeholders and their roles, the governing legislation, and the ambitions and measures set out in the recent Administrative Agreement on Grid congestion and Public Transport. Together, these elements form the policy context that shapes the opportunities and constraints for PTOs in enabling new connections.

Stakeholder Overview

Public transport operators (PTOs) in the Netherlands operate within a complex network of stakeholders. Understanding these actors is crucial, as each holds specific knowledge, responsibilities, or authority that influences how new applications can be connected to public transport electricity infrastructure. Some stakeholders provide the legal framework, others control technical access, while certain parties have the power to adjust regulations or concession terms. A clear overview helps to determine who should be consulted on specific issues, who can support decision-making, and who is best positioned to evaluate particular components. This section therefore highlights the main stakeholders involved, including the national government, the Authority for Consumers and Markets (ACM), regional public transport authorities (PTAs), municipalities, PTOs themselves, and national or regional grid operators.

3.1.0.1. National operating Government bodies

At the national level, the government acts as policymaker and facilitator. Two ministries are directly involved: the Ministry of Infrastructure and Water Management (IenW) for public transport, and the Ministry of Climate and Green Growth (KGG) for energy. Both ministries recognize grid congestion as a major barrier to mobility electrification and acknowledge that public transport can also be part of the solution [13].

Ministries (IenW and KGG)

Through these ministries, the government coordinates national agreements and initiatives to align the goals of energy and mobility sectors. Their role is to facilitate cooperation between stakeholders, provide funding or policy support for innovation, and adapt legal frameworks where needed. In 2024 an *Administrative Agreement on Grid Congestion and Public Transport* (Dutch: *Bestuurlijk akkoord Netcongestie en OV*) was signed, involving the State (IenW and KGG), grid operators, ProRail, NS, regional and urban PTAs, PTOs, DOVA, and the Municipality of Utrecht. In this agreement, parties committed to smart use of limited grid capacity, shared charging infrastructure, and the removal of regulatory barriers. In doing so, the ministries create the institutional conditions that enable PTOs and other actors to act [14].

Regulatory Authorities: Authority for Consumers and Markets (ACM)

The Authority for Consumers and Markets (ACM) is the independent regulatory body in the Netherlands responsible for sectors such as energy, and public transport [15]. In this study, ACM is a key stakeholder because it governs the legal and operational framework for electricity infrastructure access, particularly when Public Transport Operators (PTOs) seek to share their traction power networks with third parties [16].

ACM enforces the provisions of the Electricity Act (Dutch: *Elektriciteitswet 1998*), classifies electricity infrastructures, and assesses whether initiatives comply with current or upcoming legislation. Depending on the case, PTO systems may be defined as *regulated networks* (Dutch: *gereguleerde netten*), *installations* (Dutch: *installaties*), or *Closed Distribution Systems* (Dutch: *Gesloten Distributie Systemen*). Under Article 15 of the Electricity Act, ACM can grant exemptions that allow PTOs or other organizations to legally operate their internal networks without appointing a designated grid operator. The forthcoming Energy Act (Dutch: *Energiewet*) replaces the current GDS terminology with the broader term Closed System (CS) (Dutch: *Gesloten Systemen*). Therefore, in this research the term Closed System (CS) will be used instead of Closed Distribution System (GDS) and organisations are getting therefore the recognition of Closed System [16].

Beyond its regulatory function, ACM also plays an enabling role by informally supporting experimental projects that contribute to the energy transition, provided they serve the public interest and fit within evolving legal frameworks. In this context, ACM not only determines compliance and approves applications, but also offers practical geuidance on legal questions. For this research, ACM was consulted for legal clarification. Their role as both regulator and gatekeeper makes them one of the most influential stakeholders in enabling or restricting third-party access to public transport electricity infrastructure.

3.1.0.2. Energy Infrastructure Stakeholders

Electricity grids in the Netherlands are managed by two types of system operators. The national Transmission System Operator (TSO), TenneT, is state-owned and responsible for the high-voltage network [17], while regional Distribution System Operators (DSOs), such as Liander, Stedin, and Enexis, are publicly owned and manage the medium- and low-voltage grids [18].

Transmission System Operator (TSO)

In the Netherlands, the national electricity transmission grid (voltages of 110kV and higher) is managed by TenneT, the designated Transmission System Operator (TSO), which is state-owned and tasked with operating, balancing, expanding, and maintaining the high-voltage network and international interconnectors. Importantly, DSOs receive high-voltage electricity from TenneT [19].

Distribution System Operators (DSOs)

DSOs are responsible for providing and maintaining connections to the medium- and low-voltage grids, including those used by PTOs. Traction substations are usually connected at 10–20 kV, requiring dedicated capacity contracts. DSOs evaluate whether sufficient contracted and physical capacity is available [20].

PTOs and other large consumers must coordinate closely with both DSOs and TenneT, since grid congestion occurs on their networks and directly affects the feasibility of new connections. As electrification of public transport continues and (third-party) energy applications are integrated into PTO infrastructure, the load on regional grids can increase significantly, even though it falls within the capacity of the contract. Effective coordination between DSOs and TenneT is essential. This requires mutual insight into each other's load profiles and capacity constraints, in order to avoid unintended consequences such as causing or shifting congestion from the distribution level to the transmission level or vice versa. Only through this systemic coordination can congestion be managed effectively across all voltage levels [2].

3.1.0.3. Concession System in the Netherlands

Public transport in the Netherlands is organized through concession contracts granted by regional public transport authorities (PTAs) and, for most of the national railway network, by the Ministry of Infrastructure and Water Management (IenW). Concessions assign exclusive operating rights to public transport operators (PTOs) and set service, quality, and financing conditions. Concession arrangements define who grants the contract, who operates, and how infrastructure ownership and funding are organized. The precise allocation of responsibilities between municipalities, PTAs, PTOs, and the State varies by mode and region. In general the PTAs or IenW award and supervise while the PTOs operate.

Public Transport Authorities (PTAs)

A PTA is a public body that organizes bus, tram, and metro within a defined area. Under the Passenger Transport Act 2000 (Dutch: *Wet Personenvervoer 2000*), these responsibilities are decentralized to regional and local authorities [21]. In the Randstad, dedicated transport regions fulfil this role, such as Vervoerregio Amsterdam (VRA) [22] and the Metropolitan Region Rotterdam The Hague (MRDH) [23]. PTAs act as concession grantors, they formulate proposals and policy, execute projects and investment programs, and facilitate collaboration between municipalities, PTOs, grid operators, and national actors. Municipalities in the metropolitan region, except for Utrecht, often still own the local PTOs and also hold shares or otherwise exercise governance influence within the PTAs of their transport areas.

For the greater part of the national railway network, IenW is the concession grantor [24]. Outside metropolitan regions, provinces typically serve as PTAs, awarding exclusive operating rights, setting service and quality requirements, arranging funding frameworks, and generally awarding concessions to private operators that are not owned by, or integrated with, the local municipality or province. They usually award the management agreement and the Public Transport concession, (in-house), to a PTO, for the management and maintenance of infrastructure, and for facilitating the actual operation of the transport services.

Vervoerregio Amsterdam (VRA)

VRA is the contracting authority for bus, tram, and metro in its fourteen municipalities, responsible for awarding concessions and financing regional infrastructure improvements. The municipality of Amsterdam also has influence over the VRA via municipal representatives [25]. The VRA acquired a priority share in GVB Holding N.V.. This share provides legal influence over two subsidiaries: GVB Exploitatie BV and GVB Infra BV, without financial implications [26]. VRA tenders regional concessions competitively, while the Amsterdam urban concession is directly awarded in-house to GVB, consistent with EU in-house procurement requirements regarding sufficient control. In addition, VRA has expressed willingness to collaborate on the development, support, implementation, and promotion of smart methods that enable concession holders to facilitate shared use of bus, tram, and metro electricity infrastructure [27].

Metropolitan Region Rotterdam The Hague (MRDH)

MRDH acts as PTA for the Rotterdam–The Hague region, granting the metro, tram, and bus concessions to operators in the region, including RET, HTM, and EBS, and funding infrastructure renewal and innovation. The MRDH also holds shares in RET and HTM, the local PTOs of Rotterdam and The Hague [28, 29].

National Rail Concession

On the main railway network, the State grants a single concession to NS. The current concession runs from 2025 to 2033 [30].

3.1.0.4. Municipalities

Outside metropolitan regions, municipalities have also formal authority over public transport, they influence policy through participation in transport regions and via provincial governance. The municipalities of Amsterdam, The Hague and Rotterdam hold the legal title to tram and metro infrastructure, retain majority ownership of local PTOs such as GVB, HTM, and RET, and are represented in the governing bodies of their transport regions. As shareholders and asset owners, they exercise governance influence within Vervoerregio Amsterdam (VRA) and the Metropolitan Region Rotterdam The Hague (MRDH). For example, Amsterdam is a shareholder in Liander and is represented within VRA [25], while Rotterdam and The Hague hold shares in Stedin and have influence within MRDH [31, 32]. VRA is governed by its member municipalities, including the Municipality of Amsterdam, and MRDH is governed by 21 municipalities, including the Municipalities of Rotterdam and The Hague.

Beyond these ownership and governance roles, municipalities also fulfill a broader societal mandate. They set local policy to reduce grid congestion, and as earlier mentioned in the *Introduction* Chapter, the Amsterdam City Council unanimously adopted a motion supporting initiatives to address congestion and to enable multiple use of public transport electricity infrastructures, in line with national policy [3]. In general the municipalities do carry a broad statutory task package covering civil affairs, public order and safety, spatial planning and housing, environmental management and permitting, local roads and traffic, education facilities and youth care, social support and public health, economic development and retail policy, and culture, and initiate projects for residents and businesses in line with climate, air quality, and equity objectives. Because municipalities own key assets and hold social and environmental policy responsibilities, they are pivotal stakeholders in the use of local public transport electricity infrastructure; their decisions on spatial fit, permitting, congestion management, environmental impacts, and policy alignment directly shape feasibility and conditions for connection.

3.1.0.5. PTOs and their Governance: GVB, RET, HTM, NS

This subsection summarizes how each PTO is organised and how it relates to its concession grantor and public owners. The focus is on who grants the concession, who owns the company and infrastructure, and who operates or manages the assets. In the Netherlands, several traction power networks operate under distinct concessions: urban tram and metro systems in the metropolitan region, a trolleybus network in Arnhem, and the national and regional rail network.

Amsterdam: GVB and VRA

GVB is Amsterdam's municipal operator for tram, metro, bus, and ferry, organised as GVB Holding N.V. with several subsidiaries [33]. To enable an in-house award, Vervoerregio Amsterdam holds a priority share in GVB Holding N.V., providing governance influence without financial rights [26]. The municipality retains legal ownership of tram and metro infrastructure, VRA commissions and oversees investments and maintenance, and GVB Infra BV performs infrastructure operations under contract [34]. In short, VRA is the concession grantor, the municipality is the asset owner and shareholder, GVB is the operator.

Rotterdam: RET and MRDH

MRDH, a consortium of 21 municipalities, is the concession grantor in the region [23]. The Municipality of Rotterdam owns 99% of RET N.V., MRDH holds 1% [28]. Infrastructure assets are legally separated in RET Infrastructuur B.V., owned by the municipality, while RET N.V. is the economic owner and integrated operator [28]. In short, MRDH grants and supervises, the municipality owns the infrastructure and the company, RET operates the services.

The Hague: HTM and MRDH

HTM operates tram, RandstadRail, and bus. The Municipality of The Hague owns 99% of HTM, MRDH holds 1% [35]. MRDH acts as concession authority for tram, metro, and bus. HTM Railinfra B.V., owned by the municipality, holds legal title to the rail infrastructure, which HTM Personenvervoer N.V. uses under contract; in 2023 HTM Personenvervoer N.V. merged with its vehicle-owning subsidiary, consolidating operations and asset ownership [36]. In short, MRDH grants, the municipality owns the assets and the PTO, HTM operates on municipally owned infrastructure.

National rail: NS and ProRail

On the main railway network, the State owns NS through the Ministry of Finance, and the Ministry of Infrastructure and Water Management (IenW) grants the national concession to NS, currently for 2025–2033 [30]. The Ministry of Finance also owns NS Stations, which manages station retail [37]. ProRail acts as infrastructure manager and holds the management concession and manages, maintains, and controls the railway infrastructure as economic owner, while Railinfratrust B.V. holds legal title, both entities being state owned under IenW [38]. ProRail primarily supplies electricity to railway undertakings and consumes little itself, and it holds the connections with the DSO and TSO. In short, the State owns NS, ProRail, and Railinfratrust B.V. and grants the concessions, NS operates train services, ProRail manages the infrastructure and maintains the DSO and TSO connections.

Regional rail: private operators

For regional rail services, provinces act as concession grantors, and private operators such as Arriva hold the operating concessions. ProRail acts as infrastructure manager on these networks as well [2]. In short, provinces grant, private operators run the services, ProRail manages the rail infrastructure.

Utrecht: tram concession

The Province of Utrecht acts as PTA, granting the operating and management concession to U-OV, a private PTO, which holds its own grid connection with the regional DSO. The municipality is not a party in this governance arrangement, and the province is also a shareholder of the DSO [2]. In short, the province grants and oversees, U-OV operates and holds the DSO connection, the municipality stands outside this arrangement.

Arnhem: trolleybus

The Province of Gelderland is the concession grantor. The Municipality of Arnhem owns the trolleybus traction power network and has a use-of-infrastructure agreement (Dutch: *bruikleenovereenkomst infrastructuur*) with Hermes, the PTO. Hermes operates the system and is responsible for infrastructure maintenance. Hermes also holds its own grid connection with the regional DSO. The Province of Gelderland is a shareholder of the regional DSO, the municipality is not, and the province supports the municipality with infrastructure maintenance, which it outsources to Hermes [2]. In short, the province grants and supports, the municipality owns the infrastructure, Hermes operates, maintains, and connects to the DSO.

Bus concessions, private operators

Provinces or transport regions act as concession grantors for bus services, and they, sometimes together with municipalities, may hold shares in the private PTO. The PTO holds the grid connection with the regional DSO. Provinces or transport regions, and in some cases municipalities, may also be shareholders in the DSO [2]. In short, provinces or transport regions grant, PTOs operate and connect to the DSO, and local or regional authorities may hold shares in both PTOs and DSOs.

Note: Across the municipal cases (GVB, RET, HTM), the PTO effectively acts as the economic owner of the traction power network as it exclusively operates and maintains the infrastructure, even where legal ownerships rests with the municipality.

So in general, concessions are granted by regional transport authorities or provinces for urban and regional systems, and by IenW for the national network. Legal title to infrastructure typically rests with municipalities or the State, while PTOs act as economic owners through exclusive operation and maintenance; grid connections are held with the DSO or TSO depending on voltage level. In short, concession grantors set conditions, public owners hold the assets, and PTOs operate the systems and interface with the grid.

Legal Context

When a Public Transport Operator (PTO) considers allowing third-party connections to its electricity infrastructure, such actions must comply with the applicable energy legislation and concession conditions. The current framework consists of the Electricity Act 1998 and the upcoming Energy Act, which will enter into force on 1 January 2026 [39]. The new Act replaces the Electricity and Gas Acts of 1998, aims to better support the energy transition, and provides more opportunities for shared use of electricity connections [40]. Next to that PTOs will also have slightly more flexibility to refuse new requests to connect to their closed electricity systems, subject to the statutory conditions. Due to the new act, the ACM may already grant exemptions where needed to align with public objectives such as relieving grid congestion [5].

Legal constructions to make connections

A detailed treatment is provided in *Legal Constructs*. In brief, three to four principal constructions can be used to connect (third-party) energy applications, depending on ownership, location, and regulatory scope: installation-based coupling, where the application is part of the host(s' installation) or is a movable asset; connection via a closed (distribution) system that supplies multiple users behind a regulated private network; cable pooling, which allows several parties to share a single public-grid connection under allocation and control agreements; and a direct line from a nearby renewable generation site, complemented by a secondary backup link to the PTO's or host network to ensure continuity when the primary source is unavailable or sufficient.

Congestion Management

(Dutch: *Congestie Management*)

Congestion management is the set of temporary, market-based and operational measures that TSOs and DSOs (and Closed System operators) must apply in structurally constrained areas to prevent physical overload and unlock additional transport capacity until reinforcements are delivered. It includes requesting connected parties to increase or reduce injection or offtake against compensation, curtailment where needed, and transparency obligations laid down in the Dutch Netcode Electricity, which was updated in 2022 to strengthen rules for distribution grids as well [41, 42].

Priority Framework

(Dutch: *Prioriteitskader*)

The Priority Framework is a societal prioritisation regime established by the ACM so that grid operators must give priority to transport requests from projects that serve major public interests, instead of following first come, first served in congestion areas. The instrument governs the order in which *transport capacity* is granted, and only takes effect when capacity becomes available through congestion management or network reinforcement. The current framework distinguishes three categories, applied in descending order of priority, with first come, first served used within each category [43]:

1. *Congestion relievers*, applicants that demonstrably create additional room on the grid for others, for example, through batteries or combined heat and power units.
2. *Safety*, divided into six subcategories and applying to consumption capacity, namely emergency response, police and defence, critical security services, justice and prisons, water management, and acute healthcare.
3. *Basic needs functions*, divided into five subcategories and applying to consumption capacity, namely drinking water, education, heat supply, gas networks, and residential construction.

Applicants that fall within these societal categories are moved ahead of other parties in the queue, while applicants outside the categories retain their position. The framework was set by the ACM in Octorber 2024, however in March 2025 the ACM was instructed to adopt a better substantiated framework, which is now in review [44].

Connection, end-user and active customer

(Dutch: *aansluiting*, *eindafnemer*, *actieve afnemer*)
In legal terms, a (formal) connection refers to the part of a transmission or distribution system that links the public system to immovable property as defined in the Valuation of Immovable Property Act, that is, a WOZ-object [45]. An end-user is a connected party that buys or intends to buy electricity or gas for own use. An active customer is an end-user, or a group of end-users acting jointly, that within its own or a shared installation consumes or stores self-generated or shared electricity, sells or shares self-generated electricity, or uses flexibility or energy efficiency services, provided these activities are not its main commercial activity [40]. Under the new Energy Act, an undertaking whose main activity is the transport of persons or goods by rail is regarded as an end-user with a large connection, even if it does not in fact have a single physical connection, provided that multiple connections follow from the technical nature of the operations and the total available capacity exceeds 2 MVA [40]. However, each distinct system is a separate entity, for example, one for a tram system and one for a metro system, where applicable.

WOZ-object

A WOZ-object is an independently functioning unit of immovable property used for municipal tax valuation. Installations without an independent function are not WOZ-objects [46]. In practice, rail traction infrastructure used by one taxpayer and forming a functional whole can be treated as one immovable property. Jurisprudence on ProRail confirms that rail infrastructure may be regarded as a single immovable property, a view ACM followed in its exemption decision, which may by analogy apply to other Dutch PTOs [47]. If WOZ-objects are connected to a network, then they are considered as end-users.

A single WOZ-object does not necessarily coincide with a single physical structure. Separate buildings or installations can be combined into one WOZ-object if they are, judged on the circumstances, sufficiently connected in terms of distance, physical links, shared facilities, and, above all, a single organisational purpose. Recent case law on clustered school sites illustrates this, where several school buildings on three nearby locations with good mutual connections, shared facilities, and one educational organisation were treated as a single WOZ-object, resulting in one joint valuation and a lower overall tax burden. By analogy, different sites or segments of PTO electricity infrastructure that are operated as one functional and organisational whole may also be treated as a single WOZ-object for tax and regulatory purposes [48]. A traction power network can also be considered as one WOZ-object, but this further elaborated in *Legal Framework*.

Transfer point

(Dutch: *overdrachtspunt*)
The physical point that marks the boundary between two systems, or between a system and the installation of the connected party, at which separation can be realised [49].

Allocation point

(Dutch: *allocatiepunt*)
A virtual point at the transfer point of a connection, where energy exchanged between an installation and the

system is administratively attributed to a market party as if measurement had taken place at the transfer point [49].

Installation and Network (System)

(Dutch: *installatie*, *net (systeem)*)
If only one end-user is connected behind the transfer point, the set of connections qualifies as an installation. A network exists if two or more independent end-users use the set of connections [50]. The Electricity Act defines a network as one or more connections for the transport of electricity together with associated transformer, switching, distribution and substations and other auxiliaries, except where these are part of a direct line or lie within the installation of a producer or end-user. The Administrative High Court for Trade and Industry has held that if only the owner is connected, it is an installation, but if a third-party is connected, it becomes a network within the meaning of the Act [51]. The new Energy Act replaces the term network with system, the legal substance remains largely unchanged [52]. In this research the term system is therefore used.

Legal and organisational structure of a Closed System

In assessing a closed (distribution) system recognition, ACM considers not only the technical infrastructure but also the legal and organisational structure of the parties involved. Practice shows that ACM often treats entities within one corporate group, such as infrastructure companies, public transport operating companies and subsidiaries, as separate legal persons. In line with case law, the CBb's Salinco judgment, a set of connections can qualify as a network when multiple separate legal persons are connected as producers or end-users, when they belong to the same corporate group [53]. For PTOs, the presence of multiple legal entities within the organisation can therefore affect the legal classification of the system and the eligibility for a recognition. Any application should explicitly substantiate relationships between the subsidiaries and clarify whether a third-party connection exists within the meaning of the Energy Act. Therefore, in theory, tram, metro and trolleybus traction power networks should be able to qualify as a distinct Closed System if they meet all the other statutory criteria, but for tram and trolleybus networks it is in practice harder to get the recognition.

Supply licence

(Dutch: *leveringsvergunning*)
Under Article 2.17(2)(e) of the Energy Act, a supplier does not require a supply licence to deliver electricity or gas to end-users with a small connection located within a closed system, a rule that also applied under the previous Electricity Act for GDS operator. Related to metering boundaries, a transfer point is the physical boundary between systems or between a system and an installation [54].

Small connection

(Dutch: *kleine aansluiting*)
A small connection has a maximum capacity of 3 x 80 Ampere for electricity supply [54]. A supply licence is only required for parties that supply electricity to end-users with a small connection, with an exemption for a Closed Systems.

Multiple Suppliers at One Connection, MLOEA

(Dutch: *Meerdere Leveranciers Op Één Aansluiting, MLOEA*)
MLOEA allows contracting multiple suppliers behind one physical connection. At the request of the connected party, the grid operator adds multiple allocation points behind the same connection. Energy flows are metered and settled per allocation point, without the need for additional physical connections. Key points are: PAP, the primary allocation point for the main connection and supplier, SAP, a secondary allocation point for any additional supplier, and VAP, a virtual allocation point used for communication between the metering responsible party and the grid operator. All allocation points must be located on the same immovable property [55, 56]. This provides the administrative basis for cable pooling, enabling multiple installations to share the PTO's grid connection via separate allocation points with distinct metering and settlement.

3.1.0.6. Legal Precedents: HTM and RET

These two cases illustrate distinct legal constructions that two Dutch PTOs have used to connect (external) applications to their electricity infrastructure: (i) the *installation* route (HTM) and (ii) the *closed distribution system* route (RET). A more detailed description of both cases is provided in *Appendix - Legal Precedents: HTM and RET*.

HTM

In 2024, the Municipality of The Hague, HTM Personenvervoer N.V., and HTM Railinfra B.V. asked ACM to assess the use of existing tram traction infrastructure for EV charging [50]. ACM concluded that the assets qualify as an *installation* (not a network), with HTM Personenvervoer as the sole end-user; no supply licence is required to deliver electricity to the charging stations, as they are not considered end-users, since they are not WOZ-objects. HTM Railinfra owns the infrastructure but does not use it, while HTM Personenvervoer operates both the tram system and the chargers. ACM also noted that the cable between a charging point and an electric vehicle is not a legal connection because an EV is not immovable property. This case demonstrates an installation-based route for integrating EV charging without a supply licence where a single end-user uses the infrastructure and no third-party is connected.

RET

In 2024, ACM granted RET a closed distribution system exemption (Dutch: *GDS-ontheffing*) for the Rotterdam metro grid under Article 15 of the Electricity Act 1998 [57]. ACM found that the grid meets the statutory criteria for a closed distribution system: it is geographically bounded, sub–transmission in voltage level, and primarily serves RET and affiliated entities, with current non-household users being RET, RET Bus B.V., and the Municipality of Rotterdam (for emergency backup and future charging hubs). Although legal title to parts of the grid is shared with the municipality and Railinfratrust (RIT), ACM recognised RET as the economic owner with operational control. RET demonstrated compliance with data exchange and supplier switching requirements under the Netcode Electricity. This decision illustrates the closed-system route that enables shared use of PTO infrastructure by multiple non-household users, provided the legal, technical, and organisational conditions are met.

Conclusion: Governance and Institutional Relations

National ministries set the legal framework and funding parameters, and ACM provides the decisive legal classification and recognitions that enable or limit third-party access. PTAs act as concession grantors, they translate national aims into contractual conditions and investment programs. Municipalities often own local PTOs and rail assets, hold shares in DSOs, and steer spatial planning and permitting, which gives them practical leverage over local implementation. PTOs operate and maintain the traction power networks and function as economic owners in practice, they are the technical gatekeepers but must act within concession terms and ACM decisions. TenneT and DSOs control capacity and connection conditions, feasibility and timing depend on their approvals and congestion management. On the main rail network, the State owns NS and ProRail, with ProRail managing the infrastructure and NS operating services. In short, successful third-party integration requires alignment across five levers: ACM's legal green light, PTA concession conditions, municipal ownership and permits, TSO/DSO capacity, and PTO technical integration. Figure 3.1 shows an overview of the relations between the parties.

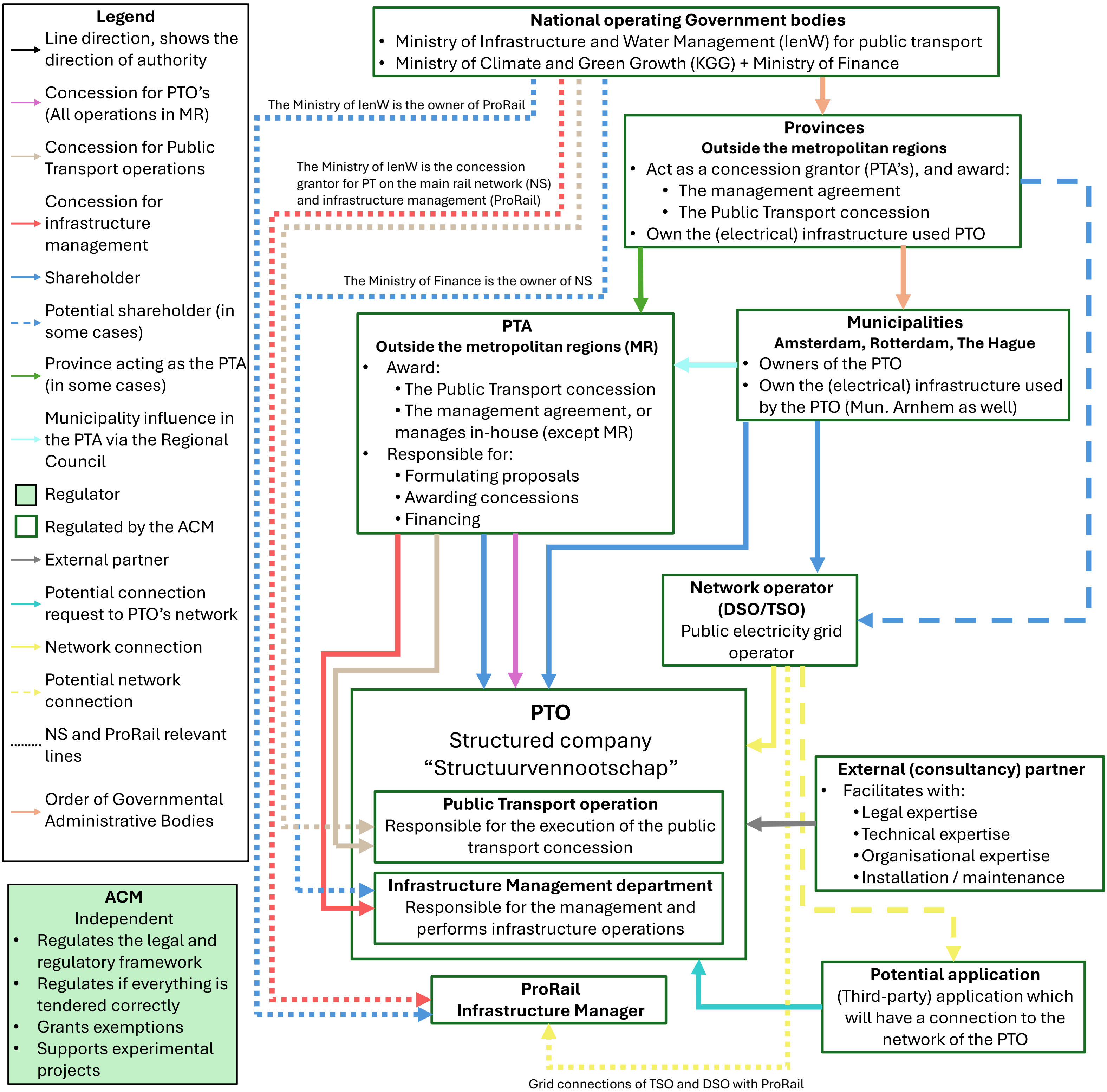


Figure 3.1: A schematic overview of relationships between stakeholders in Dutch public transport

A schematic overview of governance and operational relationships in Dutch public transport, showing who grants concessions, who holds shares over other stakeholders, and where regulatory oversight by the ACM applies, line direction indicates authority, and line styles distinguish standard relationships from case dependent ones, with separate lines for NS and ProRail. Provinces and PTAs in the metropolitan region act as concession grantors, municipalities in metropolitan regions can influence their PTAs, and in Amsterdam, The Hague, and Rotterdam the PTO also holds the concession for operations and the agreement for infrastructure management. The figure also shows where contractual network connections exist and where potential third-party connections may arise. The Ministries of KGG and IenW are mentioned since they signed together with the other stakeholders the Administrative Agreement on Grid Congestion and Public Transport.

Approached Parties

For this research interviews will be held to identify what matters, gain specific expertose, surface obstacles, and test feasibility. The selection covers legal, institutional, operational, tehcnical and municipal policy perspectives so that findings align with concession frameworks, municipal or provincial ambitions, and day to day practice. As earlier mentioned, experts will be interviewed for exploration phase and to develop the themes. Stakeholders from the PTOx, the municipalities and the provinces will be interviewed to rank the different components within the teams.

Approached experts

- **Regulator:** ***ACM***
  To clarify legal classifications and exemption pathways under the Electricity Act 1998 and the Energy Act, and to resolve ambiguities. Consultations will also map practical possibilities, and indicate where additional research or regulatory adjustments may be needed to enable timely and efficient third-party connections.
- **Private expert**
  An expert and independent consultancy firm will be consulted to provide practitioner insights into the institutional framework and current practice for sharing public transport electricity infrastructure, to help focus the scope, and to validate organisational and legal assumptions. This firm has earlier supported another PTO in applying for the exemption required to operate a GDS, primarily by providing legal advice.
- **Technical expert**
  A technical expert will be consulted to define the technical theme, identify the key issues to address, and specify which components should be included.

Approached stakeholders

- **Public Transport Operator (PTO)**
  As implementer, a PTO is interviewed to assess operational, legal, and technical feasibility, the availability of in-house expertise on key topics, and organisational capacity. The aim is to capture preferences, knowledge, and concerns, and to compare approaches and ideas both within the organisation and across PTOs.
- **Municipalities and Provinces/PTAs**
  Municipalities and Provinces/PTAs will be interview to assess the societal theme. Municipalities often own or hold shares in PTOs, together with provinces they may also be DSO shareholders, (and sit on PTA boards). Furthermore, they are also often the owner of the electricity infrastructure on which these PTOs operate. Crucially, both define local priorities for climate, air quality, equity, and spatial quality and control planning and environmental permits. Interviews will therefore also centre on the social and environmental (sustainability) outcomes that they want to achieve by connecting external applications (e.g., emissions reduction, noise abatement, public space quality, energy resilience), the trade-offs they consider acceptable, and how these aims can be embedded in concession conditions and permitting pathways; it will also identify knowledge gaps and local constraints.
  Furthermore, some technical departments within the municipalities will also be interview to asses the technical theme, just as is done with the technical department of the PTO.

3.2. Technical Context

Electric trains, trams, metros, and trolleybuses in the Netherlands draw power from dedicated traction power networks operated by PTOs. These systems comprise intake and traction substations, transformers, converters (rectifiers), switchgear, and either overhead contact lines or third rails. The traction substations are connected with the public grid or a self-owned distribution ring (AC), condition the power, and feed the traction power network. Although the examples in this section refer to traction power networks, the electrical concepts and definitions presented here, including AC and DC switchgear, intake and (traction) substations, metering arrangements under MLOEA, contracted capacity and quarter hour demand, reactive power, and grid congestion, apply equally to other high power electrical installations, such as depots and workshops, EV charging hubs, industrial facilities, large commercial buildings, and other types of electrical installations and substations. This generality is relevant for evaluating (third-party) energy applications that may be connected to PTO infrastructure, or perhaps other electrical installations since those connections are governed by the same technical principles.

Host electrical system

In this thesis, a host electrical system is the existing electrical installation that can physically and operationally connect a new application through an available connection point. While PTO traction power networks are a primary focus, the concept is intentionally broader so the methodology also applies to non-PTO contexts. Typical archetypes include: public transport traction power systems on the AC or DC side, municipal or regional energy hubs and (shared) municipal connections, campuses of public or private organisations such as universities, airports, and ports, industrial estates and logistics parks, data centres and water or wastewater utilities, large commercial complexes and multi-tenant buildings, and district energy or combined heat and power sites. These systems commonly comprise an intake substation to the DSO or TSO, internal distribution rings, AC and where applicable DC switchboards, local generation or storage, metering arrangements such as PAP and SAP under MLOEA, and defined transfer or allocation points. The gathered knowlegde in this research can therefore also be usefull across these archetypes.

AC and DC switchboard

An electrical switchboard is a central distribution apparatus with mounted switches, circuit breakers, fuses, and other protective devices that safely divides a single incoming power feed into multiple branch circuits for commercial and industrial facilities. In traction power systems, there are two types of switchboard, the AC and DC switchgear assemblies. The *AC switchboard* links the public grid to the substation transformer and distributes power to multiple feeders. The *DC switchboard* collects rectifier outputs and distributes power to the DC traction power network and other DC applications. Switchboards may include available connection points (Dutch: *vrije velden*) where additional feeders or connections for electrical applications, such as passenger station loads on the AC side or the traction power network on the DC side, and as well as external applications, can be connected to this switchboards.

Traction substations

Traction substations convert incoming grid power from the intake substation (Dutch: *inkoopstation*) to the voltage and current required by the traction power network. The AC and DC switchboards are part of the traction substation (Dutch: *onderdeel van het tractieonderstation*). Local PTOs typically receive medium-voltage AC from the DSO (ProRail may connect directly to the national high-voltage grid), step it down with a transformer, and convert it to DC using rectifiers for urban DC systems, or distribute high-voltage AC for mainline AC systems via the AC switchboard. Protection and control systems sectionalise the network for safety, continuity, and redundancy. Because of voltage-drop limits, low-voltage DC systems need closely spaced substations, typically every $\sim$2–3 km, whereas 25 kV AC systems can use wider spacing, roughly 30–50 km [58, 2]. In the Dutch context, mainline rail commonly supplies 1,500 V DC and urban systems 600–750 V DC [2]. Modern bidirectional converter substations can return surplus energy (e.g., regenerative braking) to the public grid where permitted. Substations are deliberately over-dimensioned to accommodate short-duration coincident peaks, such as multiple trams accelerating simultaneously, so the system can absorb these loads while maintaining voltage and protection margins. So, to conclude a transformer is a device that changes electricity from one voltage level to another, while a converter changes electricity from AC to DC or vice versa.

Intake substation (Dutch: inkoopstation)

The intake substation is the formal grid connection point at the distribution (DSO) or transmission (TSO) level for large consumers (Dutch: *grootverbruikers*). It forms part of the customer's installation and is under the customer's operational responsibility. From the intake, power is distributed to one or more traction substations (or other internal switchboards). Contracted capacity (Dutch: *gecontracteerd transportvermogen, GTV*) and technical connection conditions are enforced at this point, and metering as well as any rights or limitations for feed in to the public grid are set out in the connection and transport agreement with the DSO or TSO.

Catenary and third-rail systems

Once power is converted to the appropriate from the traction substation, power is delivered to vehicles through overhead contact systems (catenary) or third rail. Pantographs collect current from catenary, contact shoes from third rail. Return current flows through running rails back to the substation. Trolleybuses use two overhead wires, one for supply and one for return. Mainly these catenary and third-rail systems are operating on DC power.

DC versus AC electrification

Electric power is supplied as either alternating current (AC) or direct current (DC). Most buildings and appliances use AC, while batteries and electric motors operate on DC . In public transport, tram, train and metro networks

(Catenary and third-rail systems) typically supply DC. AC transmits efficiently over long distances with fewer substations, DC suits dense urban operation but requires higher currents and more feeders (substations). It is more efficient to connect applications on the native current to avoid conversion losses.

Energy Management System (EMS)

An Energy Management System, is a system of computer-aided tools used by operators of electric grids to monitor, control, and optimize the performance of the generation or transmission system. The supervisory control layer monitors and coordinates energy flows within the host electricity system. Its purpose is to keep operation safe and within contractual limits, controls electrical parameters, such as voltage, to ensure system stability and minimise peaks, controls electrical parameters, such as voltage, to ensure system stability, minimise peaks and costs, and align internal priorities with external signals from the grid or tariffs. The EMS measures key points, forecasts demand and generation, and sends setpoints to flexible assets, for example, chargers, storage, and shiftable loads, so core services remain guaranteed while connected applications follow agreed constraints.

Single-line schematic of a Dutch PTO power system

Figure 3.2 presents a compact single-line overview of a typical Dutch PTO electricity system. It shows the intake substation with the connection to the DSO (or TSO) towards the substation of the PTO, including the AC and DC switchboards, transformer and rectifier. Furthermore, it contains the traction sections, and the locations of available connection points on both AC and DC sides. The schematic also indicates where cable pooling can be applied at the intake and where external applications may be connected.

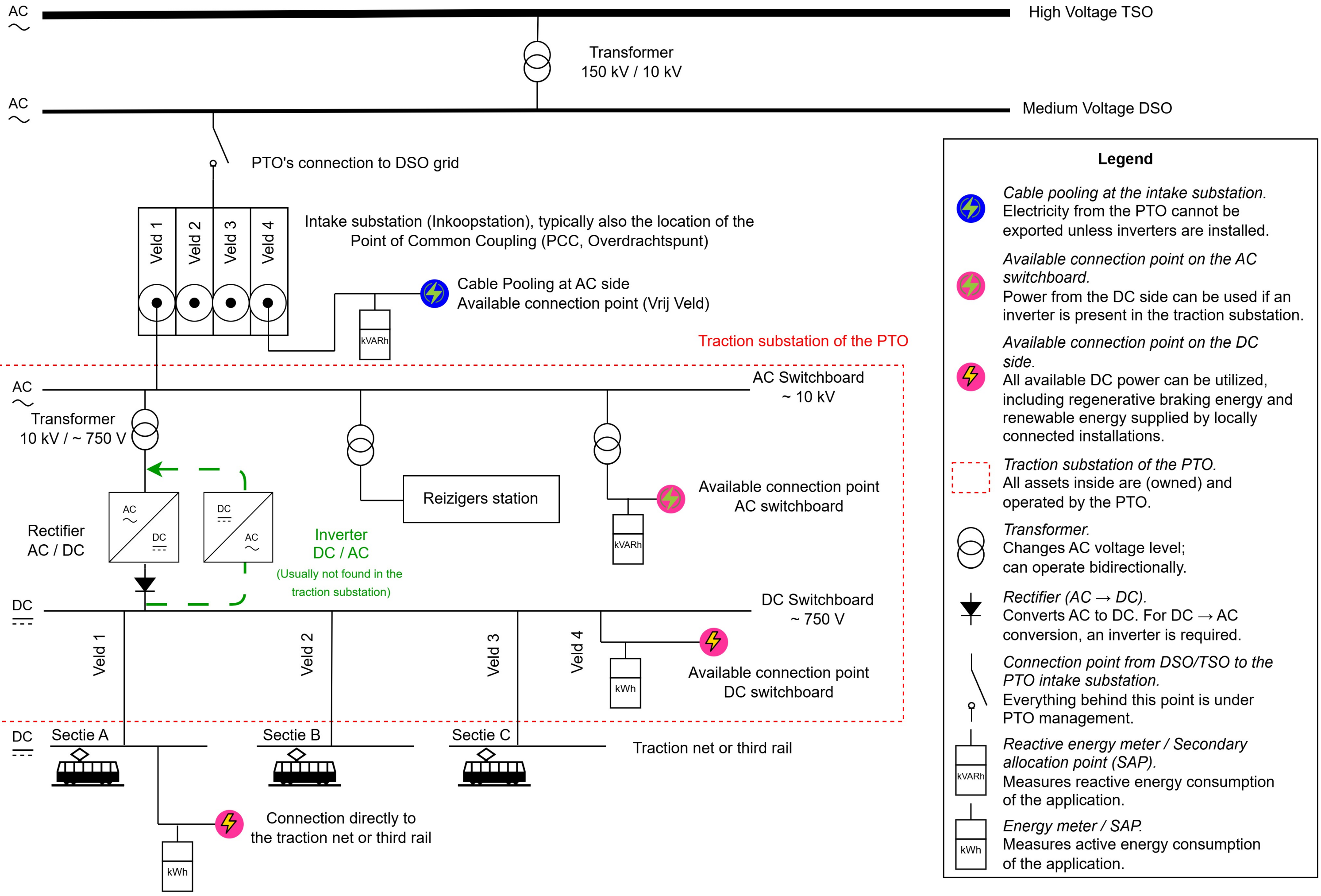


Figure 3.2: Single-line schematic of a PTO traction power system
Intake substation to DSO grid; AC/DC switchboards; transformer and rectifier; traction sections; available connection points; and indicative connection locations for cable pooling and external applications.

Preconditions for connecting third parties

PTOs are transport operators, not network operators. Their electrical systems are dedicated to traction and public transport operations, with only limited capacity that might be made available to third parties. Preconditions are needed to filter early requests and to ensure that a third-party connection does not compromise safety, reliability, or the PTO's core mission. Some conditions must and can be self-checked by the applicants, others should be verified by the PTO.

Step 1, applicant self-check

"The items that the applicant should check"

1. *DSO first principle*. The applicant should have already submitted a formal connection request to the local DSO and was refused due to grid congestion, the applicant is on the waiting list, and no timely alternative connection is available.
2. *Minimised power requirement*. The applicant should have already reduced its energy use and peak demand as far as reasonably possible.
3. *Scaled and justified demand*. The applicant should should provide an indicative load profile, operating hours, requested kW, and annual kWh that are proportionate to the use case, including whether demand

can be reduced in future if the PTO requires more headroom for its own operations.

4. *Public value and business case*. The applicant should demonstrate the societal value of its application, and provide an outline business case that does not shift unreasonable costs or risks to the PTO.
5. *WOZ-check,* installation method only. Is the application a WOZ-object? This check is relevant only if a third-party energy application is proposed via the *installation* method. If the application is an immovable property (WOZ-object), supply via installation is not permitted.

Stop rule, if any item is not satisfied, the request does not proceed to the assessment of the PTO.

Note: If the network holds Closed System recognition, the first step is in principle no longer valid since a Closed System operator must, in principle, assess all requests within the functional and geographical scope of the recognition on a non-discriminatory basis. Applications may still be declined on technical grounds, so then the assessment should proceed directly to Step 2.

Step 2, PTO verification

"The items that the PTO should check"

1. *Capacity headroom*. The requested demand should fit within the available headroom at the relevant traction substation or interface, and should fit within the contracted transport capacity (GTV) of the main connection.
2. *Technical compatibility*. The load may not adversely affect network stability or safety, and endanger the operational priorities for traction.

Stop rule, if any PTO-verified item fails, the request is rejected before it can be taking through the prioritization framework.

Note, these preconditions define minimum eligibility and do not create an obligation to connect. Only requests that pass the applicant self-check and the PTO verification, and that accept any context-dependent controls set by the PTO, proceed to the prioritization framework.

When the PTO starts checking the requests/applications, the prioritisation framework comes already in play. Does the application meet the technical requirements, and can it therefore potentially be connected to the network?

Key electrical concepts

Power (kW, MW).
Power denotes the rate of energy consumption and is defined as the product of voltage and current. In DC systems, power is calculated as $P = V \times I$. It varies dynamically depending on vehicle operation (acceleration, cruising, braking) and typically peaks during acceleration. Urban transit vehicles such as trams may consume 600–800kW at peak, while metro trains reach 2–3MW, and mainline electric trains may exceed 5–6MW [2].

traction power networks must be designed to supply both peak and average power demands reliably. The infrastructure, including substations and converters, must therefore accommodate transient and sustained power loads.

Voltage (V)
Higher voltage delivers the same power at lower current, reducing I^2R losses but requiring greater insulation and clearances. In DC traction, supply voltage can vary widely under load and regeneration, typically up to $\pm 30\%$. Equipment is therefore designed for a broad window, for example, a 1,500 V nominal system operating roughly between 1,100 V and 1,800 V. If voltage drops below design limits vehicles lose performance or stall, if it exceeds limits protection trips. Sustained abnormal voltages accelerate component wear and increase maintenance.

Current (A)
High currents raise I^2R losses, and can cause catenary sag due to heating. Sustained overcurrent accelerates wear and increases maintenance. Limiting current through higher supply voltage and more distributed substations improves safety and efficiency. When a vehicle draws a large current, it can cause a significant voltage drop over distance, meaning vehicles located farther from the substation may experience substantially reduced voltage under heavy load. This can lead to reduced traction performance, but this can be prevented by designing traction power networks to minimize these effects, through optimized substation placement and feeder sizing.

Contracted capacity (Dutch: gecontracteerd transportvermogen, GTV)

The maximum power draw agreed with the grid operator at the intake substation. Technical design often permits short peaks above GTV, while the contract constrains average demand [2]. Grid operators assess compliance in 15 minute intervals, the *Quarter-hour peak demand.*. Short spikes are usually acceptable if the 15 minute average remains within the contracted limit, otherwise renegotiation or reinforcement may be required. The electrical installation and grid connection are typically engineered to tolerate such short-term peaks, meaning their technical capacity can exceed the contracted GTV.

Series or parallel

If third parties are to be connected to the main connection, this can be achieved through *cable pooling*, which will be discussed later in this study. This may be implemented under the MLOEA framework, as discussed above. For additional allocation points within MLOEA, a secondary metering point, SAP, can be implemented *in series* with, or *in parallel* to, the primary metering point, PAP. Series configurations are generally simpler to implement, and the connection does not need to be taken out of service. Parallel configurations may require a temporary outage, and additional works at the intake. In both cases, export of electricity is permitted only if the physical installation, and the connection agreement of the main addressee, Dutch: *aangeslotene*, which will be the PTO. Figure 3.3 provides an overview of both variants.

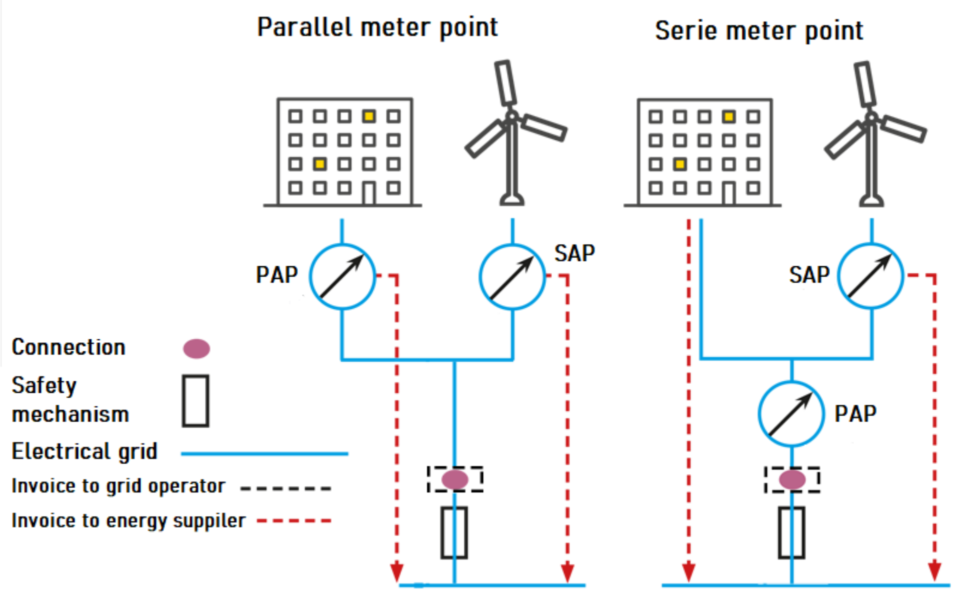


Figure 3.3: Overview of metering points in series or parallel [59].

Apparent power

In AC-systems results the combination of active and reactive power in *apparent power*, measured in volt-amperes (VA), which represents the total power that flows through the system. The active power performs useful work, measured in watts and the reactive power (VAR) arises due to phase shift between voltage and current. Although it does not perform useful work, it occupies capacity in cables and transformers and affects losses. Managing power factor limits penalties and preserves capacity for active power.

Regenerative braking

Vehicles can return energy to the traction power network through regenerative braking. If no loads are available at that moment, or if substations are unidirectional, the energy is dissipated rheostatically in braking resistors [60]. Bidirectional substations and suitable connection agreements can enable recovery to internal loads or the public grid.

Grid congestion

Grid congestion arises when there is insufficient capacity to transport electricity at the transmission or distribution level. Capacity must be assessed across the whole chain, from TenneT's high-voltage grid, DSO medium-voltage networks, and the low-voltage grid. Adequacy at one level does not guarantee adequacy at another. Congestion increasingly constrains large consumers and producers in the Netherlands [61]. In some cases, substations still have the capacity for additional load, but a practical hardware constraint applies: a lack of available connection points at the substations of the grid operators, which prevents new connections [2]. Moreover, off-take and feed-in capacity are not identical; it may be possible to feed in while additional off-take is restricted, or vice versa. Figure 3.4 indicates that constraints predominantly affect electricity off-take from the public grid, while in some cases there is still capacity to feed electricity into the grids of the DSOs and TSO, particularly in and around Amsterdam, The Hague, and Rotterdam. Therefore, it should be possible for PTOs to feed electricity back via bidirectional substations to the public grid.

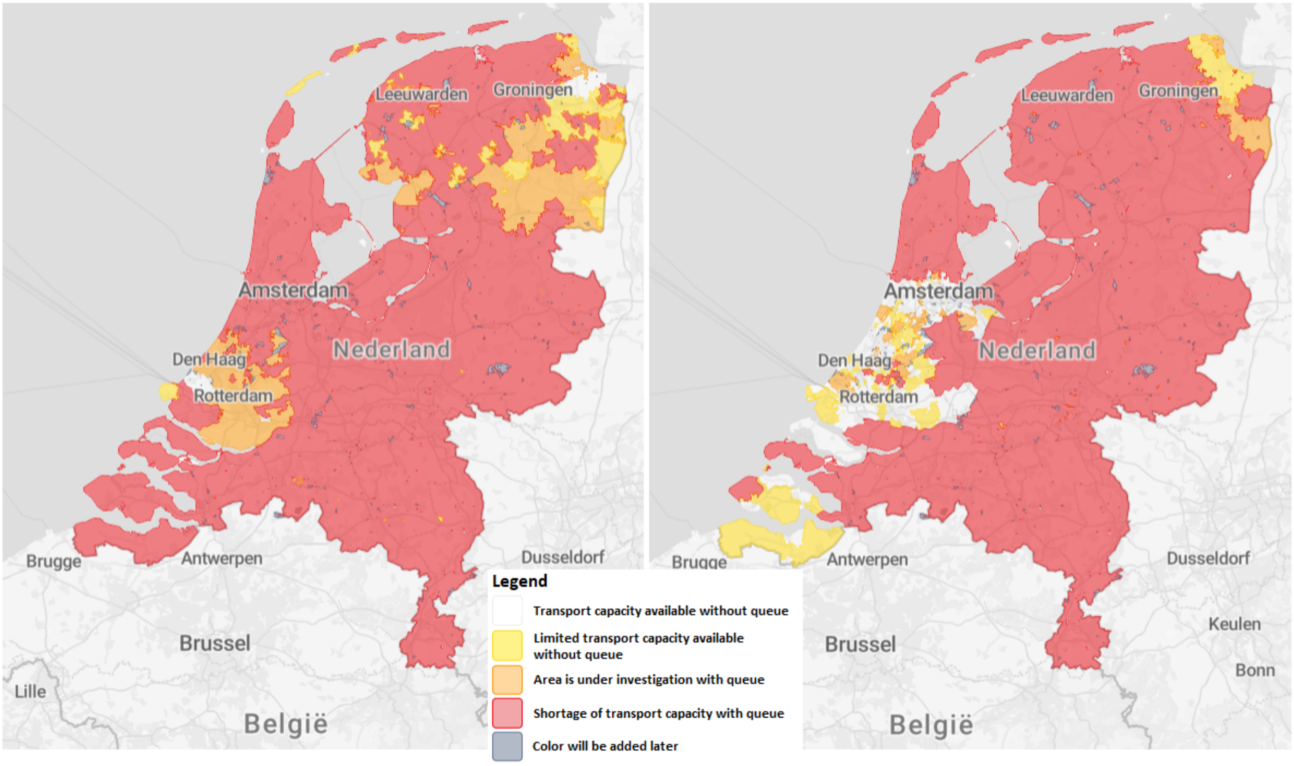


Figure 3.4: Illustrative capacity map indicating transport scarcity for off-take (left figure) or feed-in (right figure) in the Netherlands of both TSO and DSO nets [62].

3.3. Exploratory Expert Consultation

To ground the study in current practice and to refine the set of stakeholders that need to be included and the provisional set of themes and components, two exploratory, non-structured expert interviews were conducted at the beginning of the research. The objectives were to verify the state of play regarding third-party connections to public transport electricity infrastructure, to surface emerging opportunities and constraints, to clarify stakeholder roles and responsibilities, and to identify noteworthy aspects that should be considered when prioritising candidate applications. Insights from these interviews were used to narrow the scope of the study, inform subsequent interview guides for PTO and municipal respondents, and formulate preliminary assumptions for later validation. The interviews also yielded several provisional ambitions and needs that informed component design so that it reflects what practitioners actually require.

Exploratory consultation

Profile

The interviewee operates at the interface of policy and implementation. At a Dutch transition-oriented organisation, they co-develop transition solutions with market actors, this includes a role focused on sustainable energy at a regional public transport authority. Next to that, they are active as a researcher and have contributed to recent reports commissioned by national ministries, which have been frequently consulted for this thesis and map how public transport networks can help relieve congestion and how the sector can keep growing and decarbonising without worsening grid congestion [63].

Focus and key insights
Inclusive stakeholder involvement:

The interviewee stressed the importance of involving all core public stakeholders (PTO, Municpality, Provinces and where possible the PTA) in the analysis and design of the prioritization, because they co-determine the feasibility, sequencing, and prioritisation as the owners, or operators and concession providers.

Thematic lenses beyond technical, legal, and societal:

On the thematic setup, the interviewee considered the technical, legal, and societal lenses broadly appropriate, yet stressed two additions, an *organisational* lens that makes explicit what must be arranged across actors to move from idea to implementation, and a *benefits* lens that specifies how benefits are identified, and revenue models can be achieved.

Capacity and information gaps:

The interviewee also underlined persistent capacity and information gaps across the system. According to this expert, there is probably not enough knowledge capacity within PTOs and the sector to make this transition possible, and that even DSOs struggle with the information they need, and have to provide to the PTO's, and that they depend heavily on TenneT. And in general, there is a limited understanding of the potential that PTOs can offer keeps the system vague, which in turn causes indecision.

Framework design priorities, scalability and shared knowledge:

For framework design, the interviewee advised focusing on *scalability* so that similair types of applications can be connected at different types of networks, and that learned knowledge travels across PTOs, assembling a knowledge platform to consolidate cases, data, and procedures. Furthermore, the expert highlighted that it is important that the applications should be *financial* feasible and that from a *societal* perspective the application should make a positive impact, but still should be technically also the right type of application for that specific network. The expert cautioned that aligning interests is difficult in practice, noting that many organisations and companies approach this transition with one or very few solutions, which risks giving every problem the same answer; upscaling is valuable, but it must follow a deliberate trade-off, is this the best fitting solution in this situation. Beyond scaling technologies, the expert argued to scale the method for applying knowledge in new settings.

Initiating roles in practice:

The expert further observed that public transport authorities (PTAs) often act as stronger initiators than municipalities, due to their knowledge base and experience with mobility.

Additional information from a colleague of the transition expert
Realistic legal constructions for third-party connections:

A colleague of the interviewee [64] clarified which legal routes are realistically available for connecting third parties. In the current Dutch context, two routes stand out, namely the Closed (Distribution) System (GDS/CS) and Cable Pooling. In principle, tram or trolleybus traction power networks could be recognised as a CS, yet the practical value is doubtful due to high costs, limited available capacity, and the difficulty of demonstrating the required conditions to qualify for a closed system. Cable pooling, is a behind-the-meter arrangement, the PTO decides who is connected on the pooled connection, there is no interface at a DSO substation, which offers more freedom.

Closed System, feasibility and tariffs:

Furthermore, it was specified that under a CS, differentiated network tariffs per connection are permissible if they are transparent and non-discriminatory, for example, a different tariff for 50kW versus 100kW connections, not different tariffs for otherwise equivalent connections based on party identity.

Important take-aways from both interviews

This interview motivates two additional components in the framework, *Organisational Readiness* and *Economic Benefits & Value Capture*, alongside the technical, legal, and societal components. Given scope, lack of available information and time constraints, *Organisational Readiness* is not further developed in this thesis, since it does not materially support prioritising applications relative to one another. *Economic Benefits & Value Capture* is likewise not operationalised, because quantification of the costs and benefits would be premature, the evidence base is still evolving, only a limited number of pilots have been executed, and comparable cost–benefit data are not yet available. As a practical recommendation, future users of the framework can apply a benefits theme by scoring each application on expected costs and benefits, using indicative ranges or brackets rather than precise figures. With this orientation, the results of the report are designed to be reusable across PTO contexts and by other electricity networks operators.

- Involve all core public stakeholders early, PTO, Municipality, Province, and where applicable the PTA, since they co-determine feasibility, sequencing, and prioritisation.
- It is advice to complement the technical, legal, and societal lenses with: *Organisational readiness* and *Economic benefits & value capture*, yet due this is not implemented in the research.
- Address capacity and information gaps across the system, PTOs and even DSOs face knowledge constraints and data dependencies on TenneT and establish a shared knowledge platform.
- Prioritise *scalability* of both solutions/applications and the method.
- PTAs often act as stronger initiators than municipalities due to domain knowledge and experience with mobility.
- Legal constructions for third-party connections: *Closed (Distribution) System* and *Cable pooling*.
    - *Closed System*: in principle possible for tram or trolleybus networks, yet practical value is often doubtful
    - *Closed System tariffs*: different network tariffs based on objective technical criteria can be permissible if transparent and non-discriminatory.
    - *Cable pooling*: a behind the meter arrangement without a DSO substation interface, the PTO decides who to connect

3.4. Chapter Conclusion

This section includes the answer to the first research question of this research.

> *Which stakeholders should be involved in order to effectively connect (third-party) energy applications, and what are their roles and influence?*

Based on the review of policy documents, government reports, and the report *Raakvlak openbaar vervoer en netcongestie* by Pennings [2], the stakeholders that must be included in designing a prioritisation framework are the **PTOs**, **municipalities**, and **provinces/PTA**. These actors hold the decisive mandates, sit closest to implementation, and are responsible for balancing what is socially desirable with what is technically feasible and possible. The interview with the transition expert 3.3 supports the need to include these stakeholders. Therefore, this research will interview PTOs, municipalities, and provinces to develop the prioritisation framework and to incorporate their inputs.

For the *societal* dimension, municipalities and provinces/PTA are essential: the framework must be generalisable across Dutch PTOs, and municipalities, provinces/PTA. The PTO must be centrally involved for the *technical and operational* dimension, since it possesses system knowledge, connects the applications on (its) network, and remains responsible for the operations of the concession, together with the DSO who has valuable technical information on the Public Grid.

The prioritisation of (third-party) energy applications should be led by two core actors: the **Municipality** and the **PTO**. **Provinces** should be incorporated where the municipality is not the PTO's shareholder, where responsibilities are regional or where the province is the owner of the electrical infrastructure. Because the framework must apply across all Dutch PTOs and provide a general overview of key components, the municipality, the province, and the PTO will be jointly involved in its design. Together, these parties hold the mandate, information, and instruments to design a workable framework. The municipality defines societal and sustainability objectives, typically owns traction assets (and often the PTO), can influence the PTA and DSO, and controls levers such as spatial planning and permits. The PTO, as operator and maintainer of traction and auxiliary systems, judges technical feasibility, safety, operational impact, and implementation logistics. Accordingly, the municipality and the PTO should jointly establish the framework and take final prioritisation decisions.

Other stakeholders are involved in a targeted manner rather than as co-designers of the framework. The **DSO** (and, where relevant, the **TSO**) should be consulted early to assess headroom, connection conditions, and interface constraints, and to co-define *preconditions* that screen out infeasible applications (e.g., incompatible profiles or insufficient capacity). DSOs/TSO are consulted again if contractual adjustments are required; clear preconditions in the framework can limit such needs.

The **PTAs** are not primarily tasked with setting local societal priorities, and neither own the infrastructure and typically lack the technical remit to co-design the framework; moreover, municipalities/provinces steer PTAs, so their perspectives enter via municipal/provincial governance. However, since they are the concession provider they should be incorporated with the development of a framework. Concession compatibility remains a standing precondition. Once the framework is established, the PTA can help align or revise concession requirements to facilitate PTO implementation. It should be noted that PTAs can be biased and focus too much on prioritising applications that positively contribute to the public transport service within the concession region, by connecting applications for other operating PTO in that area.

The **ACM** and **National Government** may be consulted for regulatory interpretation, legal feasibility, or exemptions, but they do not need to sit in the core group; they are not the technical decision-makers on what aspects should drive prioritisation.

Interest groups and other external parties are likewise not members of the design team; in this municipal-ownership setting, the municipality represents the public interest and balances societal priorities.

Conclusion

For clarity, accountability, and efficiency, constitute a lean decision group comprising the municipalities, provinces and PTOs to develop and apply the prioritisation framework, with structured consultations of DSO/TSO (capacity and interface checks), PTA (concession alignment where needed), and ACM (legal feasibility) at defined decision points. This concentrates technical appraisal with the PTO and public-value appraisal with the municipality/province, keeps the process governable, and ensures that the necessary authorities are engaged when their mandates are triggered. See Figure 3.5 for roles and information/decision flows. The qualitative analysis will examine this figure in more detail, providing additional explanation, read the *Stakeholder involvement*.

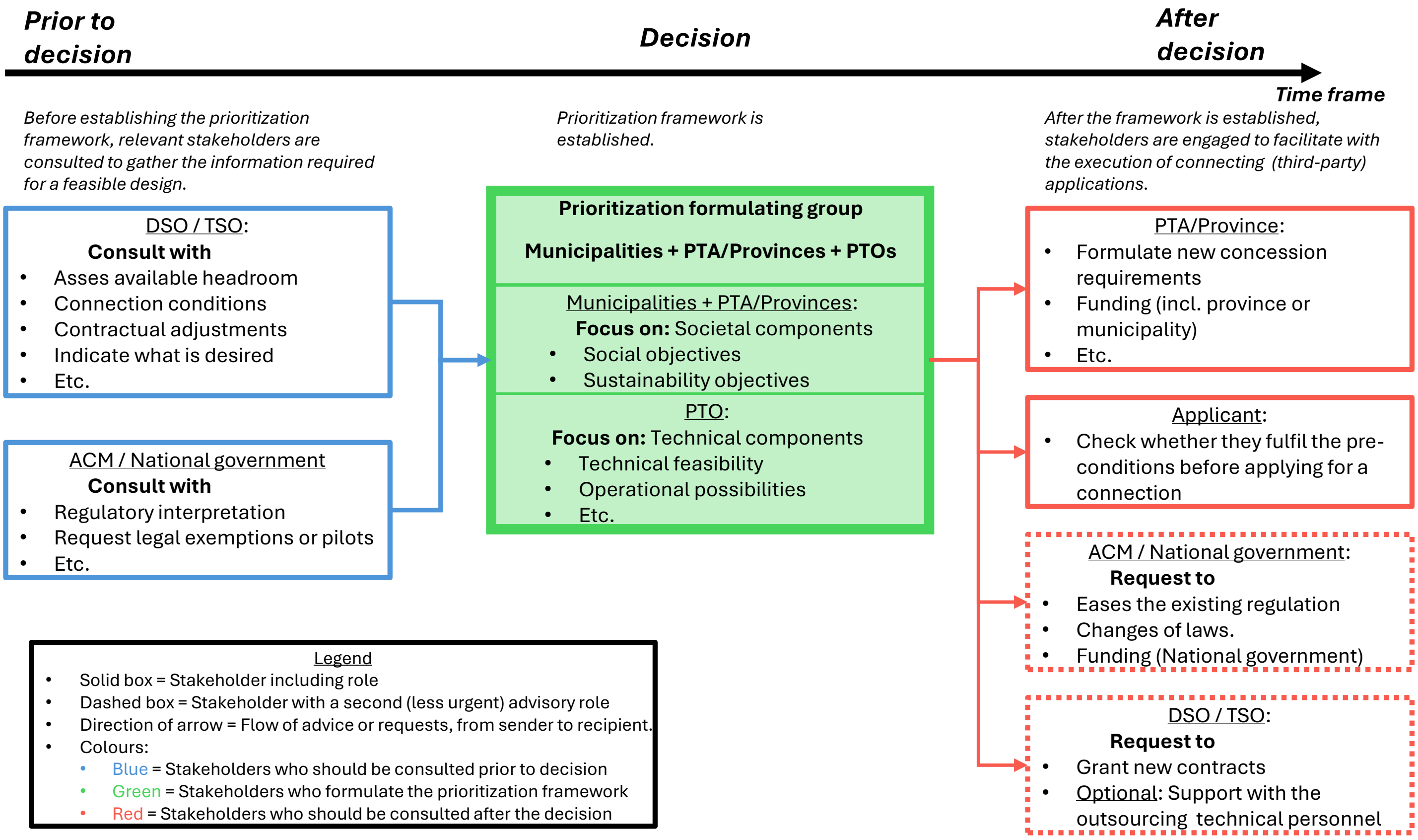


Figure 3.5: Stakeholder roles and decision flow for establishing the prioritisation framework

4

Applications

Having a clear overview of potential (third-party) energy applications is essential for identifying which evaluation themes are most relevant and useful when assessing them. This understanding supports the development of appropriate prioritization criteria. Moreover, by discovering the different characteristics of these applications, highlighting similarities, an overview can be created which helps to uncover important components to rank applications on and discover challenges that may arise when comparing or ranking them. Therefore, this chapter presents a range of commonly mentioned applications, based on relevant academic and technical literature, to lay the groundwork for defining practical prioritization themes and components.

4.1. Applications

Energy Storage Systems

Energy storage systems (ESS) balance supply and demand, support grid stability, and enable higher shares of variable renewables. Behabtu et al. [65] distinguish six categories by stored energy form and conversion: mechanical, electrochemical, electrical, thermal, thermochemical, and chemical. Mechanical options (e.g., flywheels, water storage) are typical for large, long-duration use; electrochemical batteries serve distributed, shorter-duration, or mobile use; electrical storage (e.g., supercapacitors) offers very high C-rates but low energy density; thermal/thermochemical store heat; chemical stores energy in bonds (e.g., hydrogen). This taxonomy provides a structure for assessing relevance to PTO infrastructure. However, in practice batteries are the most widely deployed electrical storage technology, valued for scalability, modularity, and rapid response. Among the available chemistries, lithium ion batteries offer comparatively low cost and a flat discharge profile that supports consistent power delivery, which explains their dominance in both stationary storage and electric vehicles [66].

Each of these technologies varies significantly in terms of energy density, response time, scalability, and cost-effectiveness. For example, mechanical systems are typically used in large-scale applications for long-duration storage, while electrochemical batteries are more suitable for distributed, short-duration, or mobile use cases. Electrical storage, like supercapcitors have very high C-rates due to their rapid charge and discharge capabilities, but have way lower energy-density making them space inefficient. They are ideal for applications demanding high-power density and fast cycling, such as regenerative braking systems or power buffering in public transport systems. Batteries have moderate C-rates, are relatively compact, and offer high-energy density, but they are more expensive. Batteries are more suitable for long-duration applications like electric vehicles. The C-rate is a measure of the rate at which a battery is charged or discharged relative to its nominal capacity [67].

Coupling can be AC or DC depending on host topology and application placement. Mechanical and thermal systems usually couple on the AC while electrochemical and electrical systems can couple on either side, with DC-side coupling attractive for traction power networks to reduce conversion steps and capture regenerative energy.

Operationally, different ESS have different charging profile dependencies. Lithium-ion batteries generally tolerate curtailed or paused and resumed charging, since they exhibit no memory effect, although aggressive fast-charging and repeated high C-rate starts can accelerate ageing. By contrast, thermal energy storage often relies on steady heat-transfer conditions and thermal stratification, so frequent power interruptions reduce the effective capacity and efficiency of these systems. Similarly, water electrolysis for hydrogen can follow rapid electrical set-point changes, however efficiency losses during temperature transients, minimum load constraints, and lifetime penalties from frequent shut-downs mean that buffering or sustained operation is often preferred when coupling to variable sources [68].

An ESS can also function as an energy bank, effectively operating as a mobile substation that reinforces the power supply for passing vehicles on the existing rail network without requiring a new grid connection. The energy bank stores electricity directly from the overhead line and releases it again to vehicles as they pass. This “unplugged substation” is flexible, quickly deployable, and easy to connect to the overhead line. It can provide structural reinforcement of the traction supply, regulate voltage drops, deliver temporary boosts during diversions or events, or serve where the DSO or TSO cannot offer capacity for a new substation connection. This concept has already been implemented in practice at RET, where energy banks were successfully deployed [69]. In principle, ESS applications of this kind are most directly beneficial to the PTO or the asset owner, for reinforcing their own network or providing additional capacity. Where internal reinforcement is not needed, the ESS can also be made available to third parties, for example to charge vehicles or support temporary works, provided that technical constraints, concession conditions, and local permitting are respected.

From a legal perspective, supplying power to most ESS units is relatively straightforward when the assets are movable, that is, when they do not qualify as immovable property under the Dutch Valuation of Immovable Property Act. In such cases, the link to the ESS is generally not regarded as a formal connection to immovable property, so compliance can typically be arranged through private contractual agreements and an installation-based connection method. This interpretation was informally discussed with the Authority for Consumers and Markets (ACM), although no unequivocal confirmation could be provided because case-specific assessment is required. More complex legal frameworks, such as recognition as a closed system or the use of cable pooling arrangements, are only necessary when the ESS is owned by a third-party and the supply qualifies as delivery to immovable property.

Categorization of Energy Storage Systems (ESS)
To support structured decision-making, energy storage systems can be classified not only by their technological principles but also by their functional characteristics and suitability for specific grid contexts. Behabtu et al. [65] identify several dimensions for categorization. One approach is to group ESS based on their intended use case and performance profile, such as short-term versus long-duration storage, or high-power versus high-energy applications. For instance, technologies like lithium-ion batteries and supercapacitors are well suited for fast-response, short-term services (e.g., frequency regulation), while systems like PHS and hydrogen-based storage are more appropriate for bulk, long-duration energy shifting. Therefore, the PTO, municipality, or province should first define the purpose for installing ESS, then specify the criteria by which particular ESS types will be prioritised over others.

In addition to these dimensions, Behabtu et al. [65] also highlight a range of technical and economic indicators that can be essential when comparing different storage technologies and to prioritise some ESS over others. These include: total capital cost, divided into power cost ($/kW) and energy cost ($/kWh), environmental impact, technology maturity, discharge time (from milliseconds to hours), response time, system lifetime (in years), daily self-discharge rate, power range (MW), energy density (Wh/L), power density (W/L), and round-trip efficiency (%). Each of these parameters can play a critical role in assessing the feasibility and performance of a given storage solution.

Pennings [70] describes multiple PTO relevant variants, for example, additional, including mobile, storage on the DC side, local generation combined with storage such as batteries or hydrogen, second life battery systems, and storage in other vehicles that can return energy when needed. Capturing braking energy with batteries requires substantial capacity, because battery C-rates are lower and short high current bursts would otherwise not be absorbed. Such applications can supply peak demand, reduce simultaneity, lower overall energy use, enable supply to third parties where allowed, reduce dependence on the regional or national grid, and relieve congestion [70].

EV-chargers

Bartłomiejczyk, Jarzebowicz, and Hrbáč [71] proposed an innovative solution to mitigate peak load limitations in AC distribution grids and reduce network congestion by supplying electric vehicle (EV) charging stations through urban traction power supply systems. He also stated that traction power networks typically possess substantial peak power reserves, which can be utilized to meet the energy demand of additional devices. Given that EV charging facilities are frequently located near transportation hubs, their integration with traction power infrastructure often requires only short cable connections. Charging stations may be connected either directly to the DC traction overhead line or via a traction substation.

This configuration enables optimal synergy between the traction and charging systems, particularly through the potential use of regenerative braking energy to supply the charging infrastructure. Furthermore, the extensive spatial reach of overhead contact lines enhances the accessibility of traction power for charging applications. However, the amount of power that can be drawn by a charging station from the overhead line depends on factors such as the distance from the traction substation and the specific design of the traction power network.

In Pennings [70] are several charging systems identified that can be connected to public transport electricity infrastructures. These include, among others, EV chargers that may be combined with the direct integration of local renewable energy sources, as well as general charging infrastructure for electric vehicles. Such applications contribute to key objectives such as relieving pressure on the electricity grid, enabling the use of locally generated energy, and reducing peak simultaneity in energy demand.

From a legal perspective, EV charging benefits from a simplifying point: the connection between a charging point and an EV is legally not a formal connection, because a vehicle is not an immovable property, that is, not a WOZ-object. As in the *HTM* case, this interpretation, confirmed by ACM in the HTM case, means that supplying power to vehicles via charging stations does not trigger the same connection rules as supplying another premises, which eases compliance routes for pilots and deployments. However, the EV charger must be owned by the same entity that owns the host electrical system.

Multiple types and sizes of EV chargers can be integrated into the electricity infrastructure of PTOs. These chargers vary in power output and purpose, ranging from slow chargers for private vehicles to ultra-fast chargers for heavy-duty buses and trucks. In general, chargers can be grouped into three categories, based on charging speed, target vehicle types, and usage purpose (commercial or PTO-only). Some types of chargers are also more suitable to connect to the AC side or DC side, dependent on the charger and its power output.

Table 4.1: Overview of EV-charger types

Charger type	**Power**	**Charging time**	**Applications**
Slow Charging (AC)	$\sim$10 kW	6-10 h	Commercial use (public parking lots) PTO-only (support fleet)
Fast Charging (DC)	$\sim$100 kW	30 min - 1.5 h	Commercial use (public fast-charging stations) PTO-only (bus depots)
High-Power Charging (DC)	$\sim$1 MW	30 min -2 h	Commercial use (logistics hubs, truck stops) PTO-only (dedicated depots)

Street lighting (and public spaces)

Street lighting represents a promising smart system application, as it can function as a grid interactive, demand responsive node rather than merely a passive energy consumer, just like a regular ESS application. The distributed nature of street light poles offers a natural platform for deploying micro distributed energy storage systems (ESS), enabling local peak shaving, bidirectional energy flow, emergency backup, and enhanced grid stability. As shown by [72], such systems can also support micro grid participation and demand management. Street lighting draws most of its energy in the evening and night, with seasonal variation due to daylight hours, yet supply must be assured whenever illumination is required. In addition to energy efficiency benefits, integrating street lighting with existing electricity infrastructure, such as that managed by public transport operators, can reduce the marginal cost of infrastructure expansion, making it a technically compatible and operationally efficient application.

Coupling is typically on low-voltage AC feeders, but DC coupling is possible where a host DC microgrid exists, for example, a PTO traction power network. LED lighting operates on DC and supports adaptive dimming, part-night operation, and sensor-based control. With cabinet- or pole-level ESS and smart controllers, installations can smooth clustered loads and absorb short local renewable surpluses, or regenerative energy where available. Operationally, ownership and maintenance are usually municipal, often delivered via contractors, making street lighting a candidate for integration with traction grids or other electricity systems that are, directly or indirectly, municipally owned. Where third-party services are added, clearer contractual agreements are required for operational responsibility, metering, and public-space permits as well as more complex frameworks, such as closed distribution systems or cable pooling.

In a pilot, public-space objects around Willemsplein in Arnhem are being supplied from the trolleybus overhead line, providing an alternative connection that relieves stressed DSO segments. The pilot is a collaboration between the Municipality of Arnhem, Connexxion/Hermes, and Liander, and demonstrates the feasibility of using existing traction infrastructure to power public spaces and, for example, lighting and other roadside assets while reducing pressure on the public grid [73].

Zero emission equipment

(PTO) electricity systems can serve such equipment through a fixed worksite connection or a mobile charging unit (energy bank or ESS), by connecting to the DC side of a host electrical system, for example, a nearby tram or metro overhead line or via a traction substation. Most traction power networks deliver direct current, which aligns with the DC nature of battery-electric equipment and reduces conversion steps. The operational impact depends on the use mode. Charging the equipment's batteries creates a more predictable, schedulable load that can be shifted to off-peak periods, most likely evenings and nights, whereas direct use imposes higher, more variable power draw that must be coordinated so traction supply remains a priority. Finally, the equipment can be owned by an external contractor or by the PTO or asset owner.

Zero-emission equipment comprises (battery-)electric excavators, cranes, and other site machinery that replace diesel, eliminating direct $\mathrm{CO_2}$ and pollutant emissions and reducing noise. Several countries, including the Netherlands, target fully emission-free construction by 2030 [74]. A recent pilot in Hoek van Holland demonstrates practical feasibility: RET supplies an electric excavator from the metro overhead line via a dedicated charger, reportedly under the first Dutch permit allowing a public transport operator to supply others, using spare traction capacity to avoid a new, congested-grid connection and pointing to scalable use cases such as public charging hubs [75].

Ownership by the PTO can simplify the legal framework by keeping supply within "own use," whereas supplying third parties generally requires additional contractual arrangements. Nonetheless, supplying electricity to most vehicles or mobile energy banks is relatively straightforward, because such assets are not classified as immovable property. The link therefore does not constitute a formal connection. Compliance can typically be achieved through simple contractual instruments and an installation-based coupling. More complex frameworks, such as recognition as a closed distribution system or cable pooling, are required when vehicles are to be powered or charged through alternative configurations.

Industry

This application concerns supplying large industrial facilities, for example, (municipal) water treatment plants, manufacturing plants, processing sites, or data centres, by leveraging a large proximate host electricity system such as a public transport electricity infrastructure. Typical use cases are an interim bridge while a public grid connection is delayed, a permanent partial supply for a defined share of demand, or a back-up supply when on-site generation is insufficient.

Some industries may operate on on-site generation, for large solar power installations. In such cases, the host network can serve as back-up when own generation falls short. Two configurations are possible, a legally defined direct line between the production plant and the facility, or a coordinated coupling in which the production plant feeds via the facility into the host network, with metering and controls that, where permitted, can also route power onward to the public grid. The latter requires a bidirectional interface and explicit operational agreements.

Integration requires a high capacity coupling (AC), typically at medium or high voltage. Practical options include connecting on the AC side of a traction substation, the intake station, or connecting the applicants' AC system to a DC host through a DC/AC inverter, or using a DC/DC converter where both sides are DC. The interface must provide protection, metering, controllability, and, if relevant, bidirectional power flow.

Operationally and legally, more complex frameworks, such as closed distribution systems or cable pooling, are required to connect industry. The industrial load must not compromise the host's primary function. Agreements should define allowable load boundaries, curtailment rights, and real-time monitoring, with automatic load shedding if needed. Many industrial processes are relatively steady, which can align with off-peak periods on traction power networks, for example, at night, allowing idle capacity to be utilised without affecting transport operations. Because industrial production can become dependent on the host system, legal and organisational complexity increases. When supplying an unrelated third-party, clear contracts should cover priority of supply, reliability and redundancy, curtailment, liabilities, and settlement.

Business Parks and Commercial Facilities

This application extends the industrial use case to clusters of multiple businesses, for example, business parks, industrial estates, large retail centres, or office campuses. The concept is to supply the park, or selected facilities, from a large proximate host electricity system, such as a PTO's traction grid, a port, or an energy hub, creating a secondary distribution backbone that relieves the public grid. Within the park, synergies are possible, for example, sharing rooftop PV, waste heat to power, or common storage, coordinated over the host it's network.

Coupling is preferably on the AC side at low or medium voltage, since heterogeneous park loads are predominantly AC and DC distribution would require extensive conversion. The diversity of end uses means not all facilities peak simultaneously, so the coincident peak of the park is usually lower than the sum of individual peaks. A shared inter-tie can therefore be sized more efficiently and used more continuously, provided an Energy Management System (EMS) controls power flows, enforces load envelopes, guarantees availability and safety, and sheds load when needed. The park can operate as a microgrid, anchored to the host system for capacity or back up. Where both a DSO connection and a host inter-tie are present, two sources increase reliability, and the park can act as a flexible hub that modulates demand and frees grid capacity.

The feasibility and sizing depend strongly on the park's activities and load characteristics. Warehousing with EV fleets, cold storage, light manufacturing, data centres, and offices have very different demand profiles and peak patterns. Understanding coincidence factors, daily and seasonal profiles, and shiftability is essential for connection sizing, scheduling, and curtailment design.

Supplying multiple independent businesses introduces complex multi-party regulation. The arrangement approaches local grid operation and typically requires recognition as a closed system (CS) with appropriate metering, allocation points, settlement, curtailment priority, and safety responsibilities. A clear governance model, for example, a special purpose vehicle or an energy service company representing the park, and standardised connection and operating agreements are necessary to ensure non-discrimination, reliability, and compliance.

A pilot in the West Groningen business park, a Qbuzz depot with approximately 9.5 MW of installed bus charging, is being developed as an energy hub. The concept couples planned rooftop PV from a large garden centre to bus charging to relieve the public grid, adds storage using second-life bus batteries to reduce simultaneity, and explores how adjacent firms can obtain capacity they cannot secure from the DSO by drawing on smart charge management at the hub. Freed capacity can be allocated across the business park, improving reliability and utilisation [70].

PTO offices, depots, and workshop

These applications focus on the facilities owned and operated by the public transport operator itself, such as administrative office buildings, maintenance workshops, tram/bus depots, and storage yards. Traditionally, these facilities are fed by the regular distribution grid under normal commercial connections, separate from the traction power supply. The idea here is to integrate or switch these internal facilities to be powered via the PTO's own traction electricity infrastructure. The purposes are twofold: first of all, the operational efficiency, using one integrated power system can simplify infrastructure and potentially reduce energy costs if the PTO has spare capacity or favorable energy tariffs for its traction power; and secondly, the grid relief, by keeping the PTO's considerable energy usage "on its own network," it avoids drawing additional power from the public grid, and opens up grid contracts for others, which is especially helpful in congested grid regions.

Coupling is preferably on the AC side at low or medium voltage, because the systems will run mainly on AC, except when chargers will be connected in the depots, for them DC connections are preferable. Also here, on-site generation (solar PV) can be integrated and considered stationary storage to further support the load – making the depots a self-contained energy ecosystem as far as possible. For offices or workshops, which have more stable loads (lighting, machinery, climate control), connecting to PTO infrastructure might simply involve extending a cable from a traction substation to the building's switchboard, along with a transformer if needed to match voltage levels.

From a regulatory perspective, this is the least problematic scenario because no third-party is involved, the PTO is simply rearranging how it sources power for itself. The electricity the PTO uses for traction is already purchased (often at high-voltage or bulk rates) from a supplier, and as long as the usage stays within its contracted limits, using some of it for depot or office consumption is permissible.

In Utrecht, a tram depot whose substation is dimensioned for the morning traction peak makes off-peak capacity available for bus charging. The site operates 36 pantograph charging points and 15 cable points. No additional depot or public grid connection was needed, more electric buses can be charged by using the existing connection more efficiently, which eases pressure on the DSO connection queue. Another pilot integrates renewable generation, installing PV on charging stations, depots, parking areas, and other assets to charge vehicles during periods of high solar or wind production, thereby lowering peak demand on the public grid. When generation and consumption profiles are aligned, local generation reduces the depot's draw from the public network [70].

Building services systems (schools, hospitals, and other public facilities)

This application supplies or supports critical public-service buildings, schools, universities, hospitals, libraries, and government facilities, from the electricity infrastructure of PTO where locally the DSO capacity is constrained. The intent is to avoid waiting for a new or reinforced public-grid connection by, providing either an interim bridge while reinforcement is pending, or permanent partial supply for non-life-safety services (HVAC/ventilation, domestic hot water, lifts, lighting, EV fleets), and/or a resilient backup path. Typical cases include a hospital needing extra capacity for a large heat pump, or clusters of schools seeking air-conditioning and school-bus charging in congested urban areas. A further angle is emergency resilience: because public transport electricity infrastructures often have their own feeders and backup arrangements, they can provide an auxiliary supply to hospitals or shelters if the main grid fails. Even once congestion is resolved, such host networks remain well-suited as dependable backup for these facilities.

Coupling is preferably on the AC side at low or medium voltage. In normal operations, the host feed acts as a supplementary source for non-vital loads, partly offloading a constrained DSO connection; in emergencies, it can serve as an additional path until on-site generators take over. School loads are mainly daytime and typically in the hundreds of kilowatts, manageable for many traction substations with appropriate scheduling to avoid traction peaks. Where public facilities host PV or storage, controlled coupling can share surplus over the host system, and reduce a tram line's net draw, when legally permitted.

Legally this is third-party supply, implementations generally proceed via closed-system arrangements, and where applicable cable pooling, with contracts specifying service levels, curtailment priority, metering/allocation, and safety responsibilities.

Arnhem is preparing a pilot to supply schools from the trolleybus network to enable ventilation upgrades and energy savings measures that cannot proceed due to the lack of a heavier DSO connection. By providing an alternative feed via the trolley network, subject to making the arrangement legally and contractually possible within the concession, the pilot aims to relieve stressed grid segments and keep public projects on track [70].

Event and temporary installations

This application supplies short-lived sites, like festivals, concerts, fairs, temporary markets or pop-up facilities, from a proximate host electricity system instead of diesel generators or scarce DSO connections. The aim is clean, quiet power for a defined period, quick set-up/tear-down, and minimal burden on congested feeders.

Technically, two couplings are common. A DC connection, with a mobile converter (trailer) including an inverter with protection and metering, that provides standard 400/230 V AC distribution to stages, lighting, and vendors. Or secondly an AC host, with medium (or low-voltage), to a mobile transformer with switchgear that feeds a temporary low-voltage board. In both cases, interfaces are modular and reusable, enabling fast connection and disconnection and redeployment across events. Optional battery energy banks (ESS) buffer peaks, keep power supply stable, and can be recharged off-peak; if the energy bank is the sole temporary installation which is fed by the host system, and that energy bank only energizes the event's own distribution, regulatory complexity is reduced, since the energy bank will probably not be considered as a WOZ-object.

Operationally, event loads are peaky but predictable and often occur evenings/weekends when traction demand is lower. A simple EMS regulates draw, schedules charging of the energy bank off-peak, and curtails non-essential circuits if the host system needs priority. The result is lower noise and emissions on site and fewer ad-hoc DSO requests in congested centres.

Legally, supplying multiple, separately owned WOZ-objects constitutes third-party supply and typically requires recognition as a closed system. An important exception pathway is using a temporary energy bank that is connected to the event's own installation. In that setup, the host supplies the storage asset rather than each vendor directly, which can simplify legal compliance.

Local generation (wind or solar)

This application connects renewable generation, like PV-plants, wind farms, or PV-panels on depots, stations, or other (third-party) buildings, to a proximate host electricity system. The goal is to self-supply loads, reduce draw from the public grid, and provide an outlet for local renewables when DSO and/or TSO feed-in capacity is constrained. In effect, the host network operates on locally produced renewable electricity that might otherwise be curtailed, lowering net demand on congested grid segments.

Two integration paths are common. Depending on power level and topology, PV (DC) can be coupled on the DC side to feed the traction power network directly; wind (AC) can be rectified to DC if required. Alternatively, AC coupling connects generation on the AC side (low or medium voltage) at intake or traction substations via standard inverters/transformers, supplying depots, stations, or the wider host loop. In both cases, controls must manage variability and voltage. If production exceeds instantaneous traction or facility load, a bidirectional interface, storage, or curtailment is needed to prevent overvoltage or unwanted backfeed. Pairing renewables with stationary storage (or reversible substations) increases utilization and stabilizes host-system operation.

For congestion and sustainability, local generation directly reduces consumption congestion (less import from the public grid) and can mitigate feed-in congestion by consuming renewable output on the host side of the meter. Coordination is essential: uncoordinated surplus can simply relocate the bottleneck if it flows back into constrained feeders. Aligning production and demand (e.g., charging buses or running HVAC during solar peaks) and adding storage yields the clearest grid-relief effects.

Legally and organisationally, PTO-owned generation used on PTO assets is straightforward (own use behind the meter). Third-party generation (e.g., a nearby solar farm) typically requires a Closed (Distribution) System, cable pooling, and in some cases a direct line. If the owners want to export electricity to the public grid, the host connection agreement must cover bidirectional flow, export limits, metering, and curtailment. When energy is fed into the grids of the DSO or TSO, quantities and timing should be explicitly coordinated. Furthermore, a direct line can be used to supply a third-party energy application with the proximate host system acting as backup; see *Direct Line*.

The HTM, MRDH, and the Municipality of The Hague are piloting the Concentrated Solar Power (CSP) concept: PV arrays integrated along the tram right-of-way and aggregated to a nearby traction substation. The first pilot ($\sim 50\,\mathrm{kW}$ PV with local storage) is AC-coupled on the primary MV side; the battery buffers PV, supplies passing/accelerating trams, reduces net export, shaves traction peaks, and cuts $\mathrm{CO_2}$ emissions. A follow-on pilot will DC-couple the CSP directly to the traction DC bus via DC/DC conversion, with the expectation of lower cable and conversion losses and wider scalability, because the overhead line is much more distributed. In both cases, co-located storage both absorbs PV and serves traction demand, lowering simultaneity and avoiding feed-in on constrained feeders [70].

Bidirectional inverters (reversible substations)

Bidirectional inverters are enabling equipment at the AC/DC interface that allow power to flow both ways between a host DC (traction) network and the public AC grid. The inverters are not an application but can be seen as an additional tool: they have the ability to convert and export a surplus of DC energy, due to regenerative braking energy and DC-side renewables, when permitted, to the DSO and/or TSO grid. They typically do not relieve public grid congestion, therefore they are included here mainly for their other advantages, such as traction energy savings for PTOs.

Legally and operationally, export is only possible if the host's connection agreement with the DSO/TSO allows bidirectional flow and specifies export limits, metering, and settlement. If such rights or contracts are absent, the inverter has not the ability to operate.

Yet, for this tool also further research is required. At TU Delft, a doctoral project is addressing the missing building blocks for this functionality. The work aims to develop the next generation of controllable, modular, and ultimately bidirectional traction substations, transitioning from passive rectifiers to actively dispatchable interfaces, while benchmarking reversible designs against alternatives such as stationary storage and evaluating the associated business cases [76].

Furthermore, RET and MRDH installed bidirectional converters at two metro sites to feed braking energy to the public grid, cutting traction energy use (up to $\sim 30\%$ depending on operations) and associated $\mathrm{CO_2}$ emissions while lowering grid draw and freeing capacity and the GVB and the TU Delft are piloting a bidirectional AC/DC converter to optimise energy flows and return regenerative energy to the DSO grid, reducing simultaneity and peak imports. Just as the RET pilot, storage coupling alleviates potential export-side congestion [70].

4.2. Categorization of applications

To identify which evaluation themes matter most for different use cases, the applications are organised by a small set of operational and integration properties. The resulting categorization will guide the formulation of prioritisation themes, and will help the PTO, and other hosts of energy systems, to quickly assess which applications suit their network, and what each option entails. For example, where AC connections are required, (usually most) DC only options can be ruled out at an early stage, and where the host must be able to curtail or disconnect, applications that cannot be safely interrupted should not be connected.

A consolidated overview that maps application types to suitable legal frameworks is provided in *Connection methods by application*. Underneath the definitions of the properties are explained.

Properties

- **AC/DC**: Indicates whether the application connects to alternating current, direct current, or can use both. This matters because connecting an application on its native current avoids avoidable conversion losses, and can simplify control and protection. The most favourable current is shown; in some cases both are feasible.
    - *Both* means the application can be integrated on either side, the selection depends on availability of connection points, conversion losses, and control needs.
- **Size range**: Refers to the typical connection capacity, from kilowatts to multi-megawatts. Knowing this up front helps screen out application types early when the available capacity is already known.
- **Predictable consumption**: Describes how well the load profile can be anticipated or controlled. If the profile is predictable, multiple applications can be integrated more easily and with lower operational risk, which is ideal when capacity is tight and the host its (transport) operations must always have sufficient power.
    - *Schedulable*: the load profile can be scheduled beforehand and shifted in time without compromising the primary function.
    - *High*: the load profile is nearly constant or closely follows predictable drivers.
    - *Medium*: the load profile shows moderate variability, making precise forecasting difficult.
    - *No*: the load profile is not predictable.
- **Critical connection**: Identifies applications that must receive uninterrupted power at all pre-agreed times. For such cases, the host must be assessed thoroughly to confirm that this requirement can be met; otherwise, the application should not be connected.
- **Intake/Feed-in**: Indicates the permitted direction(s) of power flow at the point of connection. It is important to know whether the application imports, exports, or can do both, because export may be contractually disallowed under the host's DSO/TSO agreements, and in some situations the infrastructure cannot accommodate reverse power flow without jeopardising stability or accelerating wear.
    - *Intake*: import only, consumption behind the point of connection.
    - *Feed-in*: export only, the application only feeds power.
    - *Both*: import and export possible, for example with storage or reversible conversion.
- **Storage option**: Indicates if the application inherently includes, or can integrate, energy storage. This matters because storage can deliver positive system effects, for example by charging during low-load hours and supplying during peaks, which supports (PTO) operations, improves grid stability, flexibility and shifting.
    - *If Yes or Limited*, briefly state the mechanism, e.g., battery, supercapacitor, thermal storage, or hydrogen.
- **Relocatable**: Whether the application or its connection can be moved and reused at another site. Relocatability adds flexibility: if capacity is needed elsewhere, the application can be moved to a location with sufficient headroom.
    - *Limited*: relocatability depends on the application and connection design.

- **Temporary**: Defines whether the application is short-term, event-based, or otherwise non-permanent. Temporary connections are often easier to host, since they will be removed later and do not create a lasting impact on the network. Typical durations are weeks to months. Owners may also request a temporary connection because they expect to obtain a public-grid connection within months or years. In principle, third-party connections should always be disconnected once sufficient public-grid capacity becomes available.
    - *Possible*: feasibility depends on the application and required duration.
- **Regulate**: Indicates whether the application can support voltage or grid stability by mitigating disturbances. This is valuable where the host network benefits from additional stability services, for example through storage, reactive-power control, or controlled curtailment of renewables.
    - *Limited*: depends on the application whether it can support the grid.
    - *If Yes or Limited*, briefly state the mechanism, e.g., voltage-support via inverter control, fast-frequency response from storage, or harmonic filtering.

Note: A connection to any of these applications may in principle be configured as a back-up supply, for this reason, the property “Function as backup” is not listed as a separate category in the table. In addition, the table does not specify whether an application constitutes a WOZ-object, because this is case dependent and must be assessed under the Dutch Valuation of Immovable Property Act

Table 4.2: Application overview by key integration properties

Energy Storage Systems								
AC/ DC	Size range	Predictable	Critical	Intake/ Feed-in	Storage	Relocatable	Temporary	Regulate
AC & DC	kW–MW	Schedulable	No	Both	Yes	Limited	Possible	Yes
EV chargers								
AC/ DC	Size range	Predictable	Critical	Intake/ Feed-in	Storage	Relocatable	Temporary	Regulate
AC & DC	kW–MW	Schedulable	No	Intake, with V2G both	Limited (V2G)	Limited	Possible	Limited (V2G)
Street lighting & public space								
AC/ DC	Size range	Predictable	Critical	Intake/ Feed-in	Storage	Relocatable	Temporary	Regulate
AC & DC	kW	High	Yes	Intake, with battery both	Limited (battery)	No	No	Limited (battery)
Zero emission equipment								
AC/ DC	Size range	Predictable	Critical	Intake/ Feed-in	Storage	Relocatable	Temporary	Regulate
pref. DC	kW–MW	Schedulable	No	Intake, with battery both	Limited (battery)	Yes	Yes	Limited (battery)
Industry								
AC/ DC	Size range	Predictable	Critical	Intake/ Feed-in	Storage	Relocatable	Temporary	Regulate
AC	MW	Medium	Yes	Intake, with ESS/ Renewables both	Limited (ESS)	No	No	Limited (ESS)
Business parks & commercial								
AC/ DC	Size range	Predictable	Critical	Intake/ Feed-in	Storage	Relocatable	Temporary	Regulate
AC	MW	Medium	Yes	Intake, with ESS/ Renewables both	Limited (ESS)	No	No	Limited (ESS)
PTO depots, offices, workshops								
AC/ DC	Size range	Predictable	Critical	Intake/ Feed-in	Storage	Relocatable	Temporary	Regulate
AC & DC	kW–MW	Medium	No	Intake, with ESS/ Renewables both	Limited (ESS)	No	No	Limited (ESS)
Building services systems								
AC/ DC	Size range	Predictable	Critical	Intake/ Feed-in	Storage	Relocatable	Temporary	Regulate
AC	kW–MW	Medium	Yes	Intake, with ESS/ Renewables both	Limited (ESS)	No	No	Limited (ESS)
Event & temporary installations								
AC/ DC	Size range	Predictable	Critical	Intake/ Feed-in	Storage	Relocatable	Temporary	Regulate
AC & DC	kW–MW	Schedulable	No	Intake, with ESS both	Limited (ESS)	Yes	Yes	Limited (ESS)
Local generation (PV, wind)								
AC/ DC	Size range	Predictable	Critical	Intake/ Feed-in	Storage	Relocatable	Temporary	Regulate
AC & DC	kW–MW	No	No	Feed-in	No	Limited	Possible	Limited
Bidirectional inverters								
AC/ DC	Size range	Predictable	Critical	Intake/ Feed-in	Storage	Relocatable	Temporary	Regulate
DC	kW–MW	Not applicable	No	Both	No	No	No	Yes

4.3. Chapter Conclusion

This section includes the answer to the second research question of this research.

> *What types of (third-party) energy applications are currently being connected, or are viable candidates for connection, and what characterizes them?*

In this chapter a set of potential applications and their defining properties is presented. The list below distils these applications. The properties used to characterise them are enumerated afterwards, followed by a brief explanation of why providing an overview and a categorisation is useful. The applications that can potentially be connected include, among others:

- **Energy Storage Systems**, store electricity in PTO or third-party assets to balance supply and demand, stabilize voltage, and capture regenerative braking, with AC or DC coupling as appropriate. Uniquely, mobile “energy banks” can act as unplugged substations for quick reinforcement. Batteries are the most widely used electrical storage facilities due to their scalability and responsiveness. Different ESS types have distinct advantages and drawbacks, depending on the objectives, some may score higher against selected criteria. If prioritisation is intended, the objectives and criteria must be defined explicitly, and an analysis is required to justify the choice of specific ESS technologies.
- **EV-chargers**, integrate electric vehicle charging stations with traction power to use spare capacity and regenerative energy, located near hubs for short cable runs(, the chargers can also be connected on the AC side). Uniquely, chargers can couple on the DC side or via substations and the vehicles are not seen as immovable property, simplifying the legal route when the PTO owns the charger.
- **Street lighting (and public spaces)**, turn distributed light poles into grid-interactive nodes that can host micro-ESS, enable adaptive control, and smooth clustered loads. Uniquely, LED loads are inherently DC and municipal ownership aligns with PTO traction power networks, enabling practical pilots.
- **Zero-emission construction equipment**, supply or charge electric excavators, cranes, and site machinery from the traction DC network or via mobile ESS, shifting energy to off-peak periods. Uniquely, equipment and energy banks are movable assets, which can simplify legal compliance while advancing emission-free construction goals.
- **Industry**, provide interim, partial, or backup supply to large facilities from a proximate host or public transport electricity infrastructure via high-capacity AC coupling. Uniquely, industrial loads could be quite steady and can align with off-peak traction capacity, legal arrangements should go through closed-system or cable-pooling frameworks and curtailment rights are typically required.
- **Business parks and commercial facilities**, serve clusters of mixed users through a host-backbone and EMS that might share PV, storage, and capacity. Uniquely, diversity lowers coincident peaks so the inter tie can be smaller and better utilized, with governance via a closed system or cable-pooling and clear, non-discriminatory operating rules.
- **PTO offices, depots, and workshops**, power internal buildings of the PTO (or other host) and bus depots from the electricity infrastructure to streamline assets and relieve the public grid. Uniquely, same-owner own-use makes this the least complex legally, while integrating PV and storage can create a self-contained energy ecosystem for charging.
- **Building services systems**, support schools, hospitals, and other public facilities by providing a congestion bridge or a resilient backup supply from a nearby host system. Uniquely, HVAC systems, lifts, and similar loads are candidates for connection, with service levels and curtailment priorities defined under closed-system or cable-pooling agreements.
- **Event and temporary installations**, replace diesel or scarce DSO connections by feeding festivals and pop-ups via modular converters or mobile transformers. Uniquely, peaks are predictable in evenings and weekends and an energy bank can simplify compliance by being the sole fed asset for the site’s distribution.
- **Local generation (wind or solar)**, connect PV or wind to the host network to self-supply traction and facilities and absorb local surpluses. Uniquely, AC or DC coupling is possible, and pairing with storage or reversible interfaces reduces net grid draw and mitigates feed-in bottlenecks.
- **Bidirectional inverters (reversible substations)**, enable controlled two-way flow between the traction DC bus and the public AC grid when contracts allow. Uniquely, this turns substations into active assets that can export braking and renewable energy, with capability maturing through pilots and ongoing research. However, Bidirectional inverters are more a tool and not really an application.

The key characteristics by which these applications can be characterized include, among others:

- *AC or DC coupling*: Indicates whether the application connects on the host's AC, DC, or either both side, which determines conversion losses and controllability.
- *Size range*: Specifies the typical connection capacity, from kW to multi-MW, enabling early screening against available headroom and infrastructure limits.
- *Predictability of consumption*: Rates how foreseeable the load profile is, schedulable, high, medium, or not predictable, informing forecasting needs, buffering, and operational risk.
- *Criticality of supply*: States whether uninterrupted power is essential at agreed times, constraining curtailment rights and driving redundancy and backup design.
- *Power flow direction*: Defines the (permitted) direction of power, intake only, feed-in only, or both.
- *Storage options*: Notes whether storage is inherent or can be integrated, for example batteries, which can support (PTO) operations, improves grid stability, shifting and flexibility.
- *Relocatability*: Indicates whether the asset or its connection can be moved and redeployed, increasing flexibility and improving asset utilization across sites.
- *Temporariness*: Identifies whether the connection is short term or event based.
- *Ability to regulate*: Captures the capability to support voltage fluctuations or stability.

Why an overview of applications and categorization are useful

A structured overview of potential applications enables systematic comparison and clarifies where and why they differ. By synthesising shared and distinguishing properties, the overview supports a transparent categorization that highlights technical and operational implications, expected benefits, and likely risks when connecting each application. This insight informs the formulation of preconditions and the prioritization framework, ensures that essential aspects are covered, and reduces omissions across technical, operational, and legal dimensions. It also allows PTOs and other hosts to quickly exclude options that do not align with their legal approach, connection topology, available capacity, or controllability requirements, and to translate these filters into clear preconditions.

The same structure underpins consistent scoring. Describing applications along common properties, for example storage potential, relocatability, predictability of consumption, and ability to regulate, allows assessment with comparable metrics, which improves reliability and repeatability across projects and sites. A shared overview further supports quantification of grid relief and system benefits, and by placing PTO internal uses, third-party loads, and local generation within one framework, it improves portfolio comparability, reveals synergies, and will help to allocate scarce capacity to the highest value combinations.

This thesis does not further elaborate on how different ESS should be prioritised, if a PTO or another party wishes to do so, they must determine their own criteria based on the intended use of the ESS, their requirements, and their constraints.

5

Literature review

This chapter reviews the bodies of literature that underpin the prioritisation framework. It synthesises evidence on how DC traction power networks behave when external applications are connected, how recuperated braking energy and renewable generation (PV and wind) can be integrated, and which legal constructions enable third-party connections in the Netherlands. It also draws on the triple bottom line and ISO 26000 to structure the societal theme. The aim is to translate established knowledge into clear, evaluable components for the framework.

5.1. Technical

This section outlines the technical effects that must be considered when connecting applications to traction power networks. Some effects can be beneficial, for example stabilising voltages or increasing receptivity to regenerative braking, and these are highlighted to clarify when a connection is favourable. The section also identifies enabling options worth considering, such as recovering braking energy to improve operational energy efficiency, and the conditions under which solar PV or wind generation can be coupled to the public transport electricity infrastructure.

Technical behaviour of traction power systems

To develop a prioritization framework that meaningfully incorporates technical components, it is essential to summarize what the literature says about how traction power systems behave when external applications are connected. The focus here is on DC traction power networks, Together with *DC versus AC electrification*, which briefly explains the working principles of AC and DC supply, this section clarifies why certain technical components are critical for feasibility and what their expected effects are once (third-party) energy applications are connected. Without this overview, it is difficult to judge both technical feasibility and the attractiveness of candidate applications, and to operationalize the technical theme and its components.

Not all required information is available in academic literature, because traction power is a specific niche. Where the literature is insufficient, this research complements findings with expert consultations in the themes development stage. Even so, multiple studies consistently highlight three topics that recur across cases and should be considered when connecting external loads to traction power networks: maximal allowable voltage drop, maximal load current, and acceptable transmission losses.

5.1.0.1. Voltage drops

In research into supplying external devices from trolleybus traction power networks, Bartłomiejczyk, Jarzebowicz, and Hrbáč [71] show that when constant-power converters are connected directly to the overhead contact line or to the substation's DC distribution bus, the load of the power section increases and the depth of voltage drops depends on the electrical distance to the substation and the effective impedance of the section. They formalize verification criteria for any new connection, namely a *minimum instantaneous voltage* at the point of connection, an *allowed mean voltage drop* at the current collector, and *acceptable power losses* along the section. This is important to know because the same study explains that constant-power control makes a device draw more current as the shared DC backbone voltage falls, so if voltage is not actively managed, dips that occur during traction acceleration can deepen, external equipment may derate or trip on undervoltage, and protection margins shrink.

In short, voltage behaviour is a gatekeeping constraint for traction-side connections. Minimum voltage limits are binding, connections must be demonstrated to remain above these limits in representative worst-case operation, including cold-day peaks and coincident auxiliary loads. Hernandez and Sutil [77] propose and analyse a station-area DC microgrid concept with common-DC-link sensing and power management that prioritizes regenerative braking and PV, buffers short mismatches with an energy storage system, and uses the AC distribution as backup. Their aim is to mitigate the impact of charging stations on the traction power network and stabilize the DC voltage profile. In parallel, Paternost et al. [78] analyse adding a mid-line stationary energy storage system to a real trolleybus corridor, with the aim of reducing voltage drops under high-power demand, maintaining a higher voltage level, and reducing network energy losses; they conclude that the storage raises minimum voltages along the section and strengthens voltage support at the substations in their case study. Together, these findings indicate that, for any application connected to the traction power network, location, sizing, and controllability must be set so that section voltage minima are respected at all times, while well-designed control and modest storage can also allow the application to contribute positively by absorbing recuperated energy and smoothing voltage excursions.

5.1.0.2. Load current

In research into connecting external applications to trolleybus traction power networks, Bartłomiejczyk, Jarzebowicz, and Hrbáč [71] show that the *maximum long-term load current* of the overhead contact line, feeders, connectors, and substation equipment is a primary design and screening limit for any traction-side connection. It represents the thermal capability over sustained operation on an I^2R basis and must be respected by the sum of traction demand and any added continuous or quasi-continuous external demand. This is important to know because the same study explains that constant-power converters increase their current when the traction-section voltage sags, so precisely when the network is under stress, an external application tends to pull more current and push the section toward its long-term limit. If this limit is approached or exceeded, thermal ageing accelerates, hotspots can develop in contact lines and joints, operating losses rise, and protective devices sit closer to their settings, which reduces operational headroom for rolling stock and can force curtailment of external loads on long or end-of-line sections and during coincident peaks. Furthermore, the overhead transmission lines often experience high-temperature overloads due to load fluctuations or faults, increasing the line current that results in thermal expansion of the conductors that again leads to an increase in sag, thereby affecting the safety of the line and the operation of safe public transport [79].

Complementing traction-side constraints with control and storage, Paternost et al. [78] show that the same mid-line stationary storage can be operated to discharge during acceleration events, which helps keep section current within long-term limits when demand peaks. Likewise, Hernandez and Sutil [77] report that common-DC-link sensing scheduling in a station-area DC microgrid smooths application current and reduces stress on the traction section by prioritizing locally available regenerative energy and PV and buffering short mismatches with storage. In short, maximum long-term load current is a gatekeeping constraint for traction-side connections, and controllability should be configured so that long-term margins are preserved under representative worst-case operation.

5.1.0.3. Transmission losses

In research into power transfer on traction lines, Bartłomiejczyk, Jarzebowicz, and Hrbáč [71] also show that transport losses follow $P_{\text{loss}} = I^2R$; therefore, they increase with higher long-term section current, longer electrical distance and higher path resistance, and with operation at lower voltage that forces more current for the same power. The same study treats acceptable power losses along the line as a screening criterion alongside minimum voltage and maximum long-term load current. This is important to know because increased losses heat conductors, raise resistance, and deepen voltage drops, creating a feedback over a service day if not controlled. It is mentioned that it is commonly assumed that transmission losses in the overhead contact line should not exceed 10%.

5.1.0.4. Synthesis of insights and solutions for the three constraints

Taken together, insights from Horst et al. [80], that focussed on the integration of EV chargers into the DC catenary of electric transport grids, show that effectiveness against these topics depends on section length, traffic, nominal substation voltage, application location, and electrical distance. The methods they test can be read as targeted levers against the three constraints:

Against voltage drops, minimum line voltage

A bilateral connection between adjacent sections and a third parallel overhead line reduces section impedance and electrical distance, which measurably raises the minimum line voltage along long sections. Raising the no-load substation voltage can help where protection and rolling-stock limits allow, particularly near end-of-line, but must be assessed against upper voltage limits and braking resistor activation. Fleet-aware smart charging, which is similar to applications that regulates its power draw or feed-in based on real-time grid-state measurements or information from other vehicles connected on to the network, for example DC bus voltage, section current, and substation loading, keeps power within safe envelopes so that local voltage dips are not aggravated, it harvests existing hosting capacity but does not create new capacity.

Against high section current, maximum line current

A bilateral connection and a third parallel overhead line materially lower section current by shortening the resistive path and letting substations share traction demand. Fleet-aware smart charging reduces application power during coincident peaks, preventing current-limit violations in real time. Raising the substation power limit does not solve current-constrained sections, since the line-current bound remains binding on long runs.

Against transmission losses, acceptable I^2R transport losses

Methods that reduce electrical distance, namely a bilateral connection and a third parallel line, deliver the largest loss reductions, especially when applications sit far from feed-in points. Fleet-aware smart charging trims avoidable peaks that would otherwise inflate I^2R energy, but again does not create capacity. In the same spirit, Paternost et al. [78] show that a mid-line stationary energy storage system, controlled via a bidirectional DC/DC interface, supports local voltage during high-power demand and reduces traction-line energy losses, provided storage and converter efficiency are adequate.

Methods generally not recommended in the case study

Multi-port feeding of one charger from two substations, as tested, underperforms the bilateral connection because it inherits end-of-line disadvantages on both sides and does not strengthen the section as a whole.

Recuperation of energy

An aspect why it is interesting to connecting applications to traction grids, is that is enables that applications might use recuperated energy of braking traction vehicles and thereby improve the efficiency of the system and reduce the overal power consumption In DC-fed traction power networks, regeneration is only useful when the network is receptive, that is, when there is an immediate sink for the returned energy and the DC link voltage remains inside the allowable window. In diode-rectified (the process whereby AC is converted into DC using diodes, which only allow the current to flow in one direction) systems, natural sinks are other vehicles drawing power at that same moment and galvanically connected to the braking vehicle, typically within the same section or sections tied to the same substation. If no sink is available or the DC voltage rises above the upper limit, energy is dumped in braking resistors [81].

Where does the recuperated energy goes

Bartlomiejczyk and Mirchevski [81] made field measurements in Gdynia and show three to four concurrent sinks: onboard auxiliaries (can also be braking resistors), other vehicles, and stationary storage, or onboard energy storage devices. Onboard auxiliaries typically consume a small but non-negligible share of the recovered energy. When traffic density is high, the dominant sink is vehicle-to-vehicle exchange. When traffic is sparse, storage can be more dominant. In many cases, the potential for vehicle-to-vehicle recuperation can be increased by reconfiguring the supply system. Implementing bilateral feeding of the traction catenary enlarges the galvanically connected supply area, thereby increasing the number of vehicles that can exchange recuperated energy [81].

Quantitative evidence

At the vehicle level, the Gdynia fleet reported substantial traction-energy reduction for trolleybuses equipped with regenerative braking, with the sectional split between sinks depending strongly on traffic density [81]. According to Cornic [82], his system simulations and prototype testing of a reversible DC substation indicate that, once the AC interface is made bidirectional, essentially all surplus kinetic energy can be recovered at all times, while still giving priority to natural vehicle-to-vehicle exchange. A practical rule of thumb follows: for headways up to about five minutes, direct vehicle-to-vehicle exchange is typically most effective, for larger headways, feeding back to the AC system via a reversible substation is more effective.

Diab, Mouli, and Bauer [83] frame the limits of regeneration as two electrical concerns, *Concern 1: addressing the traction substation voltage* and *Concern 2: addressing the impedance between a braking vehicle and a receptive load*. To increase braking energy recuperation without storage, they evaluate three methods: *decreasing the traction substation voltage* to lower the voltage hurdle for sharing, *installing catenary or rail with lower material resistivity* to shorten electrical distance and cut transmission losses, and *adding a smart grid load on the DC-side of a substation*, for example an opportunity charger, that acts as a controlled sink. In a hostile instantaneous case, decreasing the substation voltage can make all braking energy shareable but at the cost of higher line losses, whereas lower resistivity improves both sharing and losses relative to baseline, and a DC-side smart grid load provides the largest loss reduction while delivering useful service. Across a hostile and instantaneous scenario, reducing the substation nominal voltage appears most promising, the opportunity charger next, and lower-resistivity rail least. However, the full-day study of the metro of Amsterdam, this ordering reverses: lowering the substation voltage is net negative because added transmission losses outweigh recuperation gains, reducing third-rail impedance becomes the most promising technical option, although the authors caution that the expected benefits may not offset the higher capital and replacement costs of the lower-resistivity rail, and adding an electric bus opportunity charger on the DC-side remains the preferred suggestion overall because it delivers a net grid benefit and useful load functionality that better utilizes reserve and relieves the main AC grid, with best performance when power-limited, dispatched by common DC-link measurements, and sited at the electrically central substation [83].

Feeding (regenerated) energy into the local grid
A practical way to raise the energy efficiency of DC-fed rail systems is to use reversible DC substations. By replacing diode rectifiers with controllable rectifiers and adding an inverter at the AC interface, surplus braking energy is fed back to the AC grid instead of being utilised within the network or dissipated in braking resistors. System simulations and field trials reported by Cornic [82] show that reversible substations can achieve substantial, system-level savings. Under typical regional conditions, around 7% traction-energy savings were observed, with higher savings, up to 18%, in tramway networks with frequent stops and variable headways. Line receptivity above 99% was demonstrated, confirming that virtually all dynamic braking energy can be recovered whenever the AC grid is available as a sink. In addition to enabling full regeneration when the DC network is not receptive, such substations provide dynamic DC-voltage control, active harmonic filtering, and power factor correction Cornic [82]. However, as already mentioned, reversible DC substations are treated as enabling equipment/tool rather than an external application. They typically do not relieve public grid congestion and are not directly usable by third parties, yet enabling AC feedback can still yield substantial energy savings for PTOs.

Implications for external applications
For PTOs, external applications can be configured as smart grid loads on the DC-side of a substation that increase receptivity instead of competing with traction. In practice, an opportunity charger that is power-limited and dispatched by common DC-link measurements can raise power when DC voltage rises during braking events and back off when traction demand peaks, thereby harvesting energy that would otherwise be rejected without creating new capacity. Where policy and connection agreements permit, a reversible DC substation extends the sink to the AC grid, so surplus braking energy is exported rather than dissipated. For short bursts, add wayside storage, and consider bilateral supply to enlarge the galvanic area so vehicle-to-vehicle exchange occurs more often. [81, 82, 83].

Connecting solar PV and wind systems

To reduce the grid congestion it might be usefull to connect renewable energy sources (RES) to traction grids of the PTO. Yet, it is therefore important to understand what is relevant to take into consideration when connecting applications. Diab et al. [84] show that, for traction grids, centrally aggregated renewable plants that combine solar PV and wind align production with traction demand better than dispersed units at substations. Aggregation reduces dependence on the public grid and lowers storage needs. In the Arnhem case, a centrally sited hybrid PV–wind plant achieved the highest direct load coverage, which increased further when storage was added. Wind complements PV across day and season, therefore a PV–wind mix outperforms PV-only or wind-only options.

Two indicators guide design choices: *PV utilization*, the share of PV directly used by traction loads, and *direct load coverage*, the share of total demand served directly by renewables. Both improve when generation is aggregated at system level and when right-sizing avoids oversizing at low-traffic sites. Decentralized siting remains viable if capacities follow local traffic patterns and controllability is included, otherwise curtailment and underutilization increase. In the decentralized assessments by Diab et al. [84], only PV was considered, not wind or hybrid mixes.

Most effective strategies

For developing the technical theme, the following elements should be incorporated, with their emphasis adapted to the context of each public transport electricity infrastructure. In general, the most effective strategy for sustainably powering a public transport electricity infrastructure is to aggregate generation for the whole grid rather than deploy decentralized renewable energy sources, together with a hybrid renewable system with PV and wind. Hybrid systems outperform full PV or full wind options, in line with the Arnhem findings.

Where decentralization is necessary due to siting or scale constraints, size PV at large substations conservatively toward $U_{\mathrm{PV}} \approx 50\%$ without storage, where U_{PV} is the percentage of PV power directly used by the trolleygrid without exchange with low-voltage AC. At small substations, sizing for energy neutrality and adding storage can be beneficial even at modest capacities [84]. Given that Arnhem weather conditions are representative for much of the Netherlands, comparable performance can be expected for other Dutch public transport electricity infrastructures.

So the suitability of PV, wind, or hybrid coupling is highly network dependent. For small traction grids with low annual energy use, a wind connection can be "too large" relative to demand and difficult to site due to local constraints; in such cases, modest PV (optionally with storage) is often the more practical first step. By contrast, larger networks with substantial, year-round electricity use can effectively integrate wind alongside PV and benefit from complementary seasonal and diurnal profiles. A prominent example is from the NS: Dutch electric trains have operated on 100% wind power since 2017, and under the new electricity contract from 2025 they are supplied by a mix of wind and solar. This underscores that, as system size and load factor increase, hybrid PV–wind procurement and connection strategies tend to perform well [85].

Relevant Information for Themes Development

The information that is useful and relevant to include in the theme development:

Technical behaviour of traction power systems

DC traction power networks are bounded by three gatekeeping constraints, minimum line voltage, maximum long-term line current, and acceptable I^2R transport losses. These constraints determine where external applications can be sited, how large they can be, and which control features are required. They also reveal where applications can contribute positively. Favor locations with short electrical distance, for example electrically central substations or sections with low impedance. Reward controllability, for example power limiting during peaks and voltage-responsive control that avoids deep dips.

Recuperation of energy

Regenerative braking is only useful when a receptive sink is available and the DC-link voltage remains within limits. Higher receptivity reduces energy dumped in braking resistors, improves the traction energy balance, and can increase hosting capacity for external loads. Applications that are controllable, well-sited electrically, and able to act as receptive sinks are technically more attractive. Reversible substations and modest storage (in applications) are enabling options, with the highest benefit when headways are long or traffic is sparse. Treat line receptivity and controllability as screening criteria. Prioritize DC-side controlled loads. Consider reversible substations as enabling equipment where legally possible.

Connecting solar PV and wind systems

Aggregated, hybrid PV–wind production aligns better with traction demand across day and season, which raises direct load coverage and reduces storage needs. Prefer centrally aggregated hybrid PV–wind sized to system demand. Include controllability to avoid curtailment, and size conservatively at large substations toward $U_{\mathrm{PV}} \approx 50\%$ without storage, while at small substations target energy-neutral sizing with modest storage. For small networks, favor modest PV, for larger year-round networks, favor hybrid PV–wind.

5.2. Legal Framework

The literature review on the legal aspects started with a Tilburg University report from September 2021 by Lavrijssen and Stolle [86], which set out to clarify the legal preconditions and feasible routes for realizing a public transport energy hub (Dutch: *E-OV-HUB*) that could use metro traction power to supply municipal bus charging and other third parties. The report analyses EU and Dutch energy law, railway law, and competition law, and assesses whether such a hub could lawfully be structured as a Closed (Distribution) System, a private installation, or a direct line, with corresponding implications for appointing a system operator, third-party access, unbundling rules, and possible exemptions, thereby providing the municipality and the PTO with a sound legal basis. The report also notes that, under the applicable legal framework, a public transport undertaking may be treated as a single customer even if it operates multiple points of connection, traction substations each have their own connection, yet the overall system can still be regarded as a single connection. Because the report dates from 2021, subsequent research needed to review developments after 2021, focusing on the new Energy Act, ACM code decisions, and Netcode revisions, to verify which legal constructions remain viable for connecting (third-party) energy applications to public transport electricity infrastructures and to refine the evaluation criteria that will be set up in this thesis. The traction power network can also be seen as one WOZ-object.

Currently, there are multiple legal mechanisms available in the Netherlands for connecting (third-party) energy applications to the electricity infrastructure of Public Transport Operators (PTOs). Several Dutch PTOs have already applied some of these legal frameworks in practice, as discussed in *Legal Precedents: HTM and RET*. This section provides an overview of the different legal options, along with their associated characteristics, advantages, and disadvantages.

In practice, there are three principal constructions by which applications are connected to a public transport electricity infrastructure, first, obtaining a recognition to operate a Closed System, second, connecting third parties via cable pooling, and third, connecting an application directly to the PTO's private installation. A potential fourth construction is the use of a direct line. These constructions are not described in academic literature, they arise from legislation and regulatory instruments, therefore all four connection options are elaborated further in *Legal Constructs*.

5.3. Triple Bottom Line (TBL)

The Triple Bottom Line (TBL) is a sustainability framework that helps businesses to evaluate their success in three key areas: social (people), environmental (planet), and economic (profit) dimensions. Whereas traditional evaluations prioritize financial returns, the TBL enables decision-makers to foreground broader outcomes, such as social equity and ecological resilience, and to identify projects likely to deliver lasting, multi-stakeholder value [87].

Systematic reviews of the TBL emphasize its utility for integrating sustainability into strategic decision-making, revealing that applications framed within TBL are more likely to consider long-term environmental and social consequences alongside economic viability. Moreover, empirical evidence confirms that organizations incorporating TBL dimensions tend to demonstrate improved business performance, indicating that sustainability and competitiveness need not be mutually exclusive. This prevents companies from choosing the cheapest or easiest solution in the short term which can cause social or environmental problems in the long term. On the contrary, integrating TBL components promotes long-term success, innovation, and resilience of organizations and projects, according to Nogueira, Gomes, and Lopes [88].

ISO 26000, an international guidance standard on social responsibility, provides a comprehensive guideline for corporate social responsibility. Established in 2010, ISO 26000 outlines seven core subjects (Management of the Organisation, Human Rights, Labour Practices, The Environment, Fair Business Practices, Consumer issues, Community Involvement and Development), deliberately designed to steer organizations toward socially responsible and environmentally conscious behaviour [89]. According to Sulaiman and Anwar [90] the primary advantage of ISO 26000 is that it provides clear guidelines for practical implementation. Companies familiar with these guidelines find them useful in improving their reputation externally by transparently demonstrating their focus on sustainability within their operations and priorities. To effectively operationalize the people and planet pillars, the ISO 26000 can be useful to use as guideline.

The ISO 26000 guidelines can serve as the basis for formulating practical and sector-specific components relevant to public transport operators. These components can subsequently be utilized to prioritize applications effectively within the People and Planet dimensions. The following section contains some descriptions of social (People) and environmental (Planet) themes from the ISO 26000 [89]. The Profit dimension of the triple bottom line is not explicitly addressed here, as economic considerations are inherently embedded within all the themes discussed in this research.

People

For the People pillar, ISO 26000 structures its guidance around three core dimensions: the organization's own employees, its customers, and the broader community. This division enables organizations to address social responsibility in a comprehensive manner by targeting internal workforce practices, external service provision, and societal engagement. Each of these dimensions is supported by specific guidelines that help translate ethical intentions into actionable strategies within the context of sustainable and socially responsible operations.

Consideration for Employees

Companies should foster responsible labour practices that include ensuring fair employment terms, providing equitable remuneration, and maintaining rigorous health and safety standards. Organizations are encouraged to engage proactively in social dialogue with their employees, promote diversity and inclusivity, and facilitate ongoing personal and professional development opportunities. Moreover, businesses must continually seek to improve working conditions, actively uphold human rights, prevent discrimination in all forms, and establish clear, accessible grievance mechanisms to effectively address employee concerns and promote transparent ethical practices.

Consideration for Customers

Businesses should prioritize consumer protection through the delivery of safe, reliable, and high-quality products or services. Adhering to ethical and transparent marketing practices, safeguarding consumer privacy and data protection, and implementing efficient mechanisms for addressing and resolving customer complaints and disputes are essential. Companies should actively encourage sustainable consumption patterns, provide accurate, transparent, and unbiased information about their products and services, and engage in proactive consumer education to promote informed purchasing decisions.

Consideration for the Community

Companies should meaningfully engage with local communities to positively influence their social, economic, and cultural development. This can involve creating employment opportunities, initiating skill-development programs, supporting educational and health-related projects, and enhancing access to technology and resources. Businesses should develop and sustain partnerships with community stakeholders, respect cultural diversity, actively support community-building initiatives, and contribute to the improvement of local economies through responsible investment and strategic community investments.

Planet

For the Planet pillar, ISO 26000 advise organizations that they should commit to mitigating environmental impacts by prioritizing sustainable resource use, proactively preventing pollution, and engaging actively in climate change mitigation and adaptation measures. Companies are advised to implement specific actions such as reducing greenhouse gas emissions, promoting energy efficiency, conserving biodiversity, restoring ecosystems, minimizing waste production, and optimizing the use of natural resources. Businesses should embed environmental considerations within their strategic planning and operational processes, set measurable environmental goals, regularly monitor and report on environmental performance, and foster environmental awareness and sustainability practices among all stakeholders, ensuring alignment with global sustainable development objectives.

6

Legal Constructs

This chapter gives an overview of which legal constructs are possible to connect applications and summarises the national legislation and regulatory framework that governs how PTOs can connect third-party and internal applications to their electricity infrastructure, and it highlights related provisions that are useful for a comprehensive understanding. Integrating external applications is not straightforward, since each legal construct comes with distinct conditions, obligations, and suitability that may differ by application that needs to be connected. It also gives an overview of another measure, which a PTO can use to relief the grid congestion. It concludes by answering Research Question 3.

Figure 6.1 illustrates the reference situation in which any actor, such as a PTO, is connected to the public grid via a single main grid connection. In this baseline configuration, a public transport electricity infrastructure would only be used exclusively for core traction activities by the PTO himself. The legal constructs discussed in this chapter build on this situation by creating additional options to connect (third-party) energy applications to the PTO network.

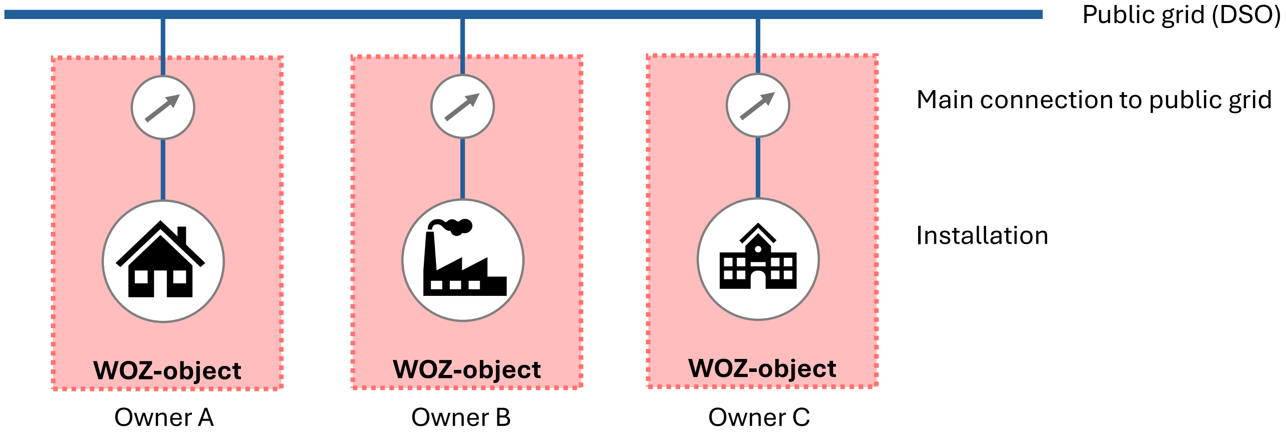


Figure 6.1: Reference situation in which multiple parties have a single connection to the public grid

6.1. Legislation

The New Energy Act

The newly adopted Energy Act aims to modernize and replace the outdated Electricity and Gas Acts. It also implements European directives into national legislation, such as Directive (EU) 2019/944, offering better consumer protection, increased flexibility in utilizing grid capacity, and clear regulations on data exchange between grid operators, energy suppliers, and customers [91]. Even prior to its formal enactment, the Authority for Consumers and Markets (ACM) has allowed specific legal mechanisms like cable pooling [5]. The new Energy Act introduces several crucial opportunities for shared electricity connections [91]:

The new Energy Act introduces several crucial improvements relevant to integrating (third-party) energy applications into Public Transport Operator (PTO) electricity infrastructure [91] [92]:

- *Cable Pooling (Shared Connections)*: Enables multiple installations, such as charging stations, energy storage, and PTO systems (electricity infrastructure), to legally share one grid connection, optimizing network capacity and mitigating congestion.
- *Energy Sharing Facilitation*: Obliges energy suppliers to support energy sharing among customers, also for cross-supplier energy sharing. ACM will secure safe and reliable data management which is crucial for

energy-sharing.

- *Clarified Responsibilities and Transparency*: Provides clearer delineation of responsibilities for measurement, reliability, and consumption data, thereby simplifying operational and legal constructs for shared infrastructure.

These improvements collectively enhance the viability of innovative energy-sharing models and third-party integration into PTO infrastructure.

Public Transport Act 2000 (Dutch: Wet Personenvervoer 2000)

Public transport concessions are granted under the Public Transport Act 2000. As noted by Lavrijssen and Stolle [86], the Act does not in itself prevent transport undertakings from engaging in ancillary activities. Article 63c, however, requires that PTO's that have obtained a concession through in-house awarding needs to maintain separate accounts for the activities performed under that concession, distinct from other activities conducted within the group or organisation. The accounting and administration must be arranged so that:

1. The revenues and costs of the different activities are recorded separately,
2. All revenues and costs are correctly attributed on the basis of consistently applied and objectively justifiable cost-accounting principles,
3. The cost-accounting principles on which the administration is based are clearly documented.

The purpose of separate accounts is to prevent cross-subsidisation, that is, to avoid using income from subsidised public transport services to finance commercial activities in a way that would distort competition. This is relevant where a PTO connects third parties. Activities on adjacent markets that fall outside the concession may not be subsidised with revenues or subsidies for services within the concession. By keeping transparent and separated accounts for distinct activities, and by applying objective cost-accounting principles in line with the Public Transport Act 2000, a PTO can demonstrate that prices for different services comply with competition law.

6.2. Legal Connection Pathways

The following section elaborates, based on national legislations and authoritative reports, the four legal pathways for connecting applications. In developing this framework, the new Energy Act as published on 23 January 2025 has been consulted [54]. The subsequent subsections set out the applicable conditions, obligations, advantages, and limitations for each pathway, and indicate how these factors inform prioritisation.

6.2.1. Closed System (CS)

A Closed System, in Dutch energy regulation, is a privately owned electricity network that can connect (third-party) energy applications (WOZ-objects) behind a single connection to the public grid. Recognized and regulated by the ACM, such systems enable third parties to obtain electricity via the private infrastructure, which can be an alternative where public networks face congestion. If a Public Transport Operator (PTO) acts as system operator, it assumes responsibilities toward third parties requesting connections. This arrangement entails legal and operational risks, since energy network management typically falls outside the core mandate of public transport entities [2]. All legal information on Closed Systems is derived from the Energy Act and is set out in full in *Regulatory and Legal Requirements for Closed Systems (CS)*, with an accompanying explanation of the applicable laws and regulations. To get the recognition of the ACM to operate a Closed System, you have to fulfil to all the requirements described down below.

Understanding the legal construct

In the Netherlands, electricity and gas are exchanged via public networks operated by national or regional system operators. These operators are publicly owned and supervised by the ACM. But exchange can also take place via a private network, which arises when multiple WOZ-objects are interconnected behind a single public-grid connection. The private network is owned by, for example, a company or municipality, and is managed by the owner or a designated operator. To connect third-party WOZ-objects, the owner must obtain a recognition from the ACM to operate a Closed System.

Under the current Electricity Act 1998 this construct is termed a Closed Distribution System (Dutch: *Gesloten Distributie Systeem*) (GDS). In the new Energy Act (Dutch: *Energiewet*), the concept is replaced by the broader term *Closed System*, since systems up to 150 kV may qualify as transmission systems and can still be recognized as Closed Systems. The former term *Closed Distribution System* no longer suffices [93].

Closed Systems are therefore private networks to which WOZ-objects of third parties can be connected. These parties then draw from, or feed into, the Closed System instead of the regional or national public networks. In the context of grid congestion on public networks, traction power networks can provide a solution by offering connections to third parties. The electrical infrastructure of Dutch PTOs can thus be recognized by the ACM as a Closed System, with a designated operator appointed by the ACM upon the owner's request.

The operator of a Closed System is primarily responsible for system management. The owner proposes the operator, and the ACM designates it. A PTO can act as operator itself, or outsource tasks to an external company, including a facilitating network operator that supports the ACM-designated operator with administrative obligations. Compared to transmission and distribution system operators, Closed System operators face a lighter set of obligations.

If a PTO is recognized as a Closed System operator, it also becomes responsible for handling connection requests. This can be risky for PT entities, because operating an electricity network is not a core activity [2]. In addition, a PTO that operates a Closed System can hold multiple connections to the public grid, in line with Article 1.3 of the new Energy Act, see *Connection, end-user and active customer*.

Most Important Regulatory and Legal Requirements

The new Energy Act (Dutch: *Energiewet*) defines conditions for recognition and operation of Closed Systems. The most important definitions are briefly explained beneath:

Closed System Conditions (Art. 3.7 Energy Act)

- The system is located within a clearly defined geographic site with shared services.
- The system has at most 1,000 connections.
- The system does not supply household end-users, except for incidental exceptions.
- Safety and reliability are sufficiently ensured, subject to ACM assessment.
- The voltage level is a maximum of 220 kV.

Recognition Grounds (Art. 3.7.1c Energy Act)
To get the recognition, at least one of the following grounds must apply:

- The recognition is required for technical or safety integration with the business processes of connected parties.
- The system primarily supplies the owner or related enterprises, with at least 50% of supply.

Applicant Conditions (Art. 3.7 Energy Act)

- No system operator has yet been designated for the network.
- The applicant is not part of an infrastructure group.

Designation of the Operator (Art. 3.6 Energy Act)

- Upon recognition of the Closed System, the ACM designates an operator.
- The legal owner of the system typically proposes the economic owner, for example a PTO, due to expertise and responsibilities.

Operator Obligations
Once a Closed System recognition has been granted for the system, the operator has the following obligations under the Energy Act:

- Act reasonably, transparently, and in a non-discriminatory manner.
- Cooperate with other system operators.
- Ensure technical and digital safety, reliability, and efficiency of the system.
- Establish and register transfer points and allocation points.
- Protect confidential information and provide necessary information to market parties.

- Put in place procedures for incidents and outages, handle complaints, and facilitate supplier switching.
- Install, operate, and validate metering equipment and associated data processes.
- Apply transparent, cost-based tariffs under ACM oversight.
- Maintain mandatory registers of technical and contractual data.

In addition, the PTO must conclude contracts and make arrangements with its network operator, its electricity supplier, the electricity suppliers of the parties connected to its network, and with the connected parties themselves. For a compact overview of the administrative and system-development tasks, see Table 6.1 at the end of this section, Detailed explanations of these tasks can be found in the *Appendix - Legal Precedents: HTM and RET*.

Supply within Closed Systems (Art. 2.1 and 2.17 Energy Act)

- End-users within a Closed System have full freedom to choose their supplier.
- Suppliers to small connections within Closed Systems do not require a license, which limits administrative burdens.

Obtaining a Closed System recognition makes several provisions of the new Energy Act applicable to the owner or operator, including a connection obligation. This obligation is not absolute. It does not apply when a request falls outside the geographic scope of the Closed System, when more than 1,000 end-users are already connected, or when the requested connection does not fit the nature of the Closed System, then there is no obligation to connect [94].

By clearly including these conditions and grounds for refusal in the exemption application to the ACM, the PTO creates legal room to refuse a connection request from a third-party at a later stage with a reasoned decision. The operator can then legitimately state that the request falls outside the conditions of the ACM's granted recognition, and that the connection cannot be permitted because doing so would risk withdrawal of that recognition. A request may therefore also be refused on one of the two recognized grounds included and substantiated in the original recognition:

1. Technical or safety integration that precludes or does not justify connecting third parties, which means that system specific technical adjustments or integration needs would be required to connect the third-party, and these are regarded as disproportionate modifications.
2. Group relationship, where the requesting party does not belong to the same group as the owner or operator within the meaning of Article 24a of Book 2 of the Dutch Civil Code (Dutch: *Burgerlijk Wetboek*), and where more than 50% of consumption would be used by third parties.

In addition, a request can be refused if transport capacity is reasonably insufficient and expansion is not technically or economically feasible or proportionate.

Applicants can optionally request an exploratory meeting with the ACM recognitions team before submitting, to discuss the case and clarify questions. The ACM does not provide bespoke legal advice or draft applications, and will assess completeness and quality, giving applicants the opportunity to supplement or correct documents during the procedure.

Table 6.1: Overview of responsibilities of a Closed System operator [95]

Administrative obligations	**System operation and development**
Transparent and non-discriminatory conduct	Operate, maintain, and develop the system
Cooperation and data exchange with other operators	Install smart meters (on request)
Maintain a technical and administrative register	Collect, validate, and determine metering data
Use and provision of data to market parties	Define transfer points
Protection of confidential information	Assign allocation points at connections
Complaints handling and facilitating supplier switching	Provide connections and transport (subject to capacity)
Reporting of incidents and irregularities	Manage data exchange via central systems
Transparent, cost-based tariff setting	Prepare maintenance, outage, and contingency plans
Accountability to the ACM regarding complaints	Prepare investment and replacement plans
Facilitate free supplier choice for all connected users	Keep an asset register
Notify the ACM of network changes (ownership changes, number of users, etc.)	Ensure safe and reliable operation of the system
Facilitate supplier switches within statutory timelines (max. 3 months for first switch)	
No charges for supplier switching	

Advantages of the Legal Construct

The biggest advantage of a Closed System is that it enables multiple connections on a public transport electricity infrastructure, including WOZ-objects with different owners, and allows active end-users to feed electricity back into the Closed System. A Closed System provides practical ways to relieve grid congestion, and facilitates compliance with expected requirements from concession grantors to use public transport networks in parallel.

Within a geographically bounded site, a Closed System can distribute multiple sustainable energy sources efficiently, which reduces load on the main grid, improves reliability, and supports cost-effective, sustainable use of the energy infrastructure [96]. Owing to bi-directional flows, appropriately connected third parties may also use braking energy, improving energy efficiency because less energy is dissipated in braking resistors. The framework moreover allows, in limited cases, a direct line which connects renewable energy sources (RES) to an application so that sustainably generated electricity can be used by the application and the the extra connection to the Closed System can act as a back-up.

Cost-based and transparent tariffs under ACM supervision permit recovery of operational and administrative costs. Potential revenue streams are context dependent and should not be a goal in themselves. In practice, remuneration can arise from regulated network charges per connected user, which consist of connection costs, transport costs, a fixed administrative fee, and meter rental [97]. A legally permitted margin above cost may apply, with ACM annually setting maximums to ensure cost coverage and competitiveness. Price parity requirements limit arbitrage on energy supply. Where the end-user has the same energy supplier as the PTO, use of braking energy can yield revenue to the operator, whereas if the end-user is supplied by a different supplier, the value of braking energy may accrue to that supplier rather than to the PTO.

Challenges and Limitations

Obtaining a Closed System recognition is complex. (PTO) ownership structures are often fragmented, the use of the network is concession based, and PT infrastructure may be located on land owned by one or more municipalities, which all have to consent to the application of a Closed System recognition. This makes the process time-consuming and administratively demanding [2]. Municipalities may nevertheless be willing to cooperate because Closed Systems can help meet societal objectives, including reducing congestion on public grids.

Operating a Closed System brings extensive responsibilities, both administrative and technical. The operator must maintain transparent, non-discriminatory processes, keep detailed technical and contractual registers, protect and exchange data with market parties, handle complaints and outages, manage metering and data validation, and ensure safe, reliable, and future-proof operation, see 6.1. The value for a PTO depends on the technical characteristics of the PT network, for example the available connection capacity, and networks with higher voltage connections have the most potential [2]. Connecting external parties can also reduce future flexibility. For instance, a charging hub for third parties could later constrain capacity needed for a newly required depot in the same area [2], and since the connected application may be owned by a third-party, the PTO has less direct control over it.

Furthermore, due to the congestion management obligations for Closed Systems, new contract forms, such as time bound arrangements, may add legal and organizational complexity [2]. In addition, the PTO must conclude contracts and make arrangements with its network operator, its electricity supplier, the electricity suppliers of parties connected to its network, and with the connected parties themselves.

On top of that, Closed Systems are also expensive. Costs arise in four components, namely applying for the recognition, fulfilling administrative obligations, realizing connections and enabling infrastructure, and ongoing operations to ensure safety and reliability, including maintenance, fault response, and cyber security. Tariffs must be published in advance and applied objectively, transparently, and non-discriminatorily. Costs incurred to perform the operator's tasks may be reflected in tariffs, which can differ by connection capacity, provided that they are the same for comparable users [94]. In practice, developing the application and establishing compliance can be expensive and time-consuming, potentially requiring external consultancy support, as seen in practice, see 3.1.0.6.

Useful Cases and Applicable Applications

In principle, all potential applications are possible under this framework. Household end-users cannot be connected, except in cases of incidental use by a small number of household end-users who work for, or have comparable ties with, the owner of the Closed System. Sufficient capacity on the PT network must remain available, the number of connected end-users may not exceed 1,000, and all connections must lie within the geographic scope of the recognition.

Laws and Regulations Regarding Closed Systems

As mentioned, the information given over Closed Systems in this section originates from the relevant national legislations, including detailed conditions, obligations, refusal grounds for Closed Systems, that are provided in the appendix: *Regulatory and Legal Requirements for Closed Systems (CS)*, including explanation.

Figure 6.2 illustrates how a traction power network can be recognised as a Closed System, with multiple third-party WOZ-objects connected within a geographically bounded site. This figure illustrates the option where the traction grid operated by the PTO or municipality has multiple connections to the main grid, but that it allowed, as it is in line with Article 1.3 of the new Energy Act. The PTO or municipality that operates the Closed System and supplies these end-users will have additional administrative and operational duties.

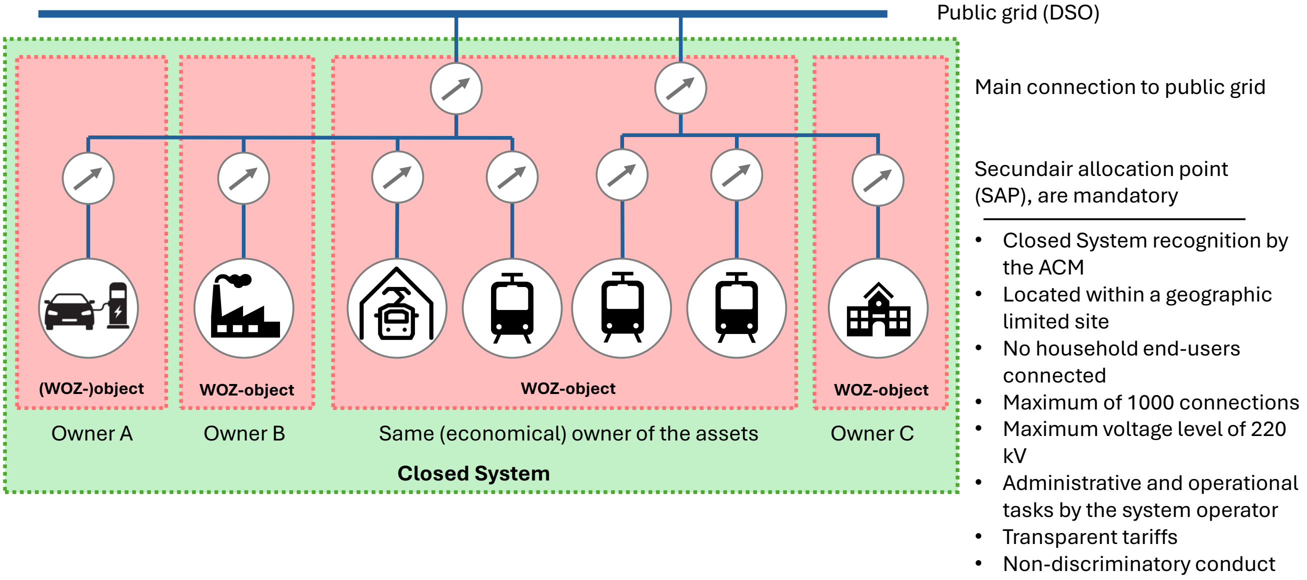


Figure 6.2: Example of a traction power network recognised by the ACM as a Closed System that connects multiple third-party WOZ-objects

6.2.2. Cable Pooling

Cable pooling is the shared use of a single electricity grid connection by multiple parties, and it is a fairly new concept. For PTOs that do not wish to obtain, or cannot obtain, a Closed System recognition, cable pooling offers a way to share the existing connection with the public grid (DSO or TSO) with third parties at the intake substation. The approach is behind the meter, the PTO remains owner of the main connection to the public grid and may set participation requirements for parties that share the connection [5]. All legal information on Cable Pooling is derived from the Energy Act and Energy Decree which is set out in full in *Regulatory and Legal Requirements for Cable Pooling*, with an accompanying explanation of the applicable laws and regulations. The shared connection to the DSO is in practice an AC connection at the connection point, so the pooled connection itself is an AC connection.

Understanding the Legal Framework

Under the new Energy Act, cable pooling allows a PTO to share its main connection (with a minimum capacity of 100 kVA) with a maximum of 4 other WOZ-objects, while the connection remains in the PTO's ownership. Cable pooling is available for all types of users, namely production, storage, and consumption [5]. The participating WOZ-objects will be treated as a single WOZ-object, enabling MLOEA, see 3.1.0.5, this connection structure allows that each participant receives its own allocation point with an EAN code, its own metering installation, and can choose its own supplier.

Technically, the additional participants are connected at available fields in the PTO's intake substation, that is, behind the PTO's existing connection to the regional or national grid (DSO or TSO). All participants must behave as one connected customer in aggregate, which supports more efficient use of the contracted capacity and helps avoid building new connections.

To implement cable pooling, five steps are required: consult the relevant system operator on feasibility, conclude a joint connection and transport agreement (ATO) with the system operator, conclude a Cable Pooling Agreement (CPO) among the participating parties, notify the ACM, and physically realize the connection. The ACM notification includes the joint ATO, cadastral information for the installations, and the inter-party contractual arrangements set out in the CPO [98].

Most Important Regulatory and Legal Requirements

From the Energy Act and Energy Decree, the following key conditions apply:

- Between two and at most four different installations may participate, for production, storage, conversion, or consumption.

  - The shared connection must have a minimum capacity of 100 kVA.
  - The installations must be in each other's immediate proximity.
  - The participants jointly conclude a connection and transport agreement (ATO) with the TSO or DSO for electricity.
  - The PTO acts as operator with the Primary Allocation Point (PAP) and remains responsible for the connection as a whole, including the Secondary Allocation Points (SAPs), which form part of the ATO.

Cable Pooling Agreement (CPO)
Because only an agreed amount of power may flow through the main connection under the ATO, the CPO sets the operational and legal framework for shared use, including control measures to prevent exceeding the contracted capacity and time-based allocations of power per participant. The CPO also assigns responsibilities and costs for maintenance, metering, administration, curtailment handling, infrastructure modifications, expansion conditions, and necessary real rights over physical assets. For a compact overview of key CPO components, see Table 6.2 [99]. In the Appendix B.2 the aspects of the CPO are extra emphasized.

Advantages of the Legal Construct

Cable pooling is less complex than obtaining a Closed System recognition and is therefore a relatively fast and straightforward way to connect third parties to an existing PTO connection. Contractual arrangements give the PTO practical control over when and how much power each participant may consume or generate, and costs of the connection and network losses can be shared among the parties. Where a SAP is added in series with the PAP, the main connection does not need to be taken out of service temporarily, which is a comparatively simple and low-cost way to add an extra metering point.

Challenges and Limitations

Operation depends on the coordinated behaviour of all users on the shared connection. If one party's demand or generation profile changes, the aggregate balance can be disturbed, leading to curtailment or temporary shutdown of certain applications and, if recurring, additional costs to keep the connection workable for all. Growth opportunities can be constrained if expansion conditions are not well documented.

Furthermore, sufficient free fields must be available in the intake substation, the minimum connection capacity should be 100 kVA, at most four WOZ-objects per intake substation may participate, and the connection is mainly used for AC applications. Each new use change or added participant requires renewed contractual arrangements, consultation with the system operator, and notification to the ACM. If a SAP is connected in parallel to the PAP, the main connection must be temporarily taken out of service and additional technical adaptation costs apply.

Consequently, in cases where no free field is available in the intake substation, the minimum connection capacity of 100 kVA is not met, or four WOZ-objects are already participating, this method cannot be applied.

Useful Cases and Applicable Applications

Cable pooling is particularly effective where participants do not consume or feed in simultaneously. Asynchronous profiles reduce the risk of exceeding the shared capacity. If two applications peak at the same time and the maximum capacity is exceeded, one may need to curtail or shut down. Where the connection capacity is sufficiently large, simultaneity becomes less critical and a wider set of applications can be combined. Cable pooling is especially suitable for high-capacity applications, which in a congested grid context often face long lead times for new connections, see *Grid congestion*. Smaller applications with a low load profile are not eligible for Cable Pooling.

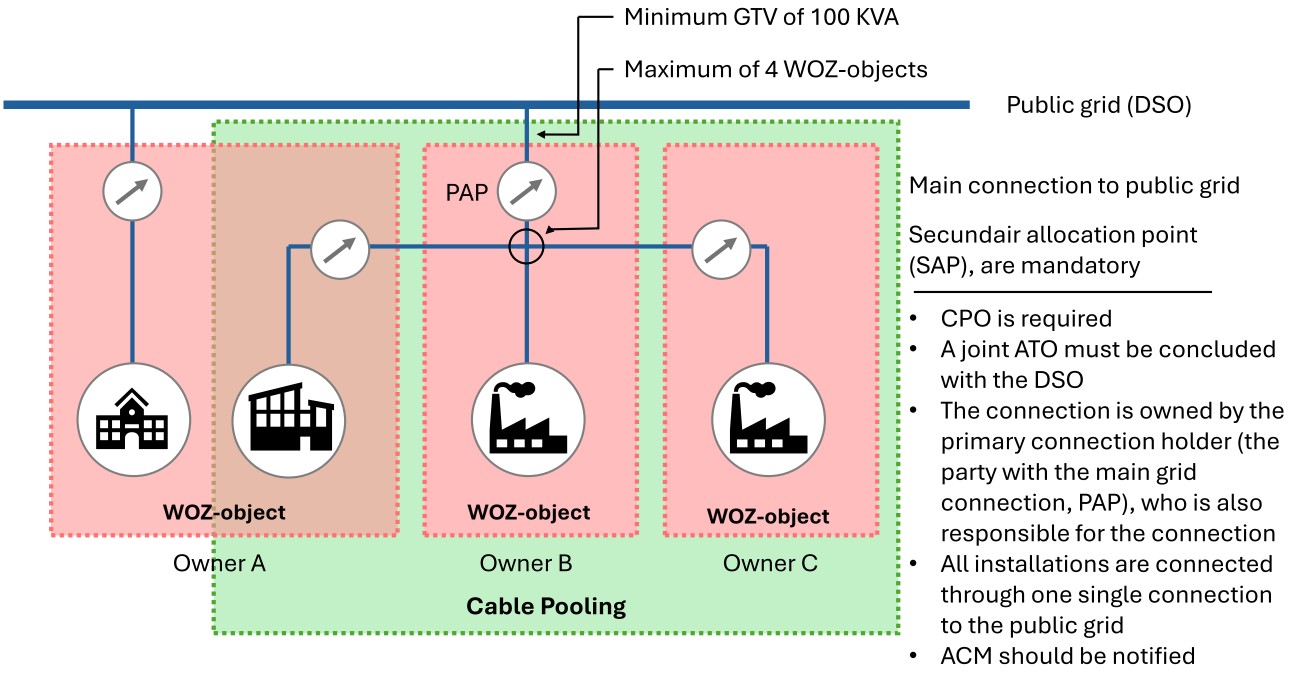
Laws and Regulations Regarding Cable Pooling

As mentioned, the information given over Cable Pooling in this section originates from the relevant national legislations, including detailed conditions, obligations, refusal grounds for Cable Pooling, that are provided in the appendix: *Regulatory and Legal Requirements for Cable Pooling*, including explanation.

Table 6.2: Key components of a Cable Pooling Agreement (CPO) [99]

Component	**Description**
Operation and use of the connection	Agreements on how the connection is shared, within which power limits and time windows
Cost allocation	Allocation of operational, maintenance, metering, and administrative costs
Control arrangements	Measures to prevent exceeding the contracted capacity (GTV)
Production loss or consumption restrictions	Settlement and compensation of curtailment or restrictions
Capacity expansion	Conditions and financial implications for expanding installations
Legal rights	Rights of superficies, easements, and rights of way for shared assets
Infrastructure modifications	Responsibilities and costs for changes to the intake substation or network components
Decommissioning or insolvency	Arrangements for transfer or termination of use of the connection

Figure 6.3 schematically depicts a cable pooling arrangement in which the PTO shares its main connection with several other WOZ-objects. The PTO retains the primary allocation point, while the additional participants receive secondary allocation points behind the same public-grid connection. Through the Cable Pooling Agreement (CPO), the parties jointly determine how the contracted capacity is used and how curtailment is handled.



- CPO is required
- A joint ATO must be concluded with the DSO
- The connection is owned by the primary connection holder (the party with the main grid connection, PAP), who is also responsible for the connection
- All installations are connected through one single connection to the public grid
- ACM should be notified

Figure 6.3: Schematic representation of cable pooling at a PTO intake substation with a shared connection and multiple allocation points

6.2.3. Installation

An Installation can be considered as a privately operated electrical infrastructure that enables the connection of applications without appointing a system operator (as with a Closed System), provided there is only one legal end-user. In PT contexts, PTO networks (electricity infrastructures) frequently qualify as installations, allowing the connection of non WOZ-objects or WOZ-objects under common ownership, as long as no third-party owned WOZ-objects are involved. This classification can apply even if the PTO is not the owner of the infrastructure, so long as it is the sole user, as clarified by the ACM's advisory opinion in *HTM*.

Understanding the Legal Framework

Qualification as an installation simplifies the connection of applications to the PTO's electrical network because no system operator needs to be designated. As set out in *Connection, end-user and active customer*, the decisive test is whether there is a WOZ determination for an immovable property of a third-party. If there is such a third-party, that party qualifies as an end-user, and the network cannot be considered as an installation. If there is not, the PTO's, or municipality's, electrical infrastructure can be classified as an installation. Consequently, only non WOZ-objects may be connected, or WOZ-objects under the same ownership, thereby maintaining a single end-user of the network. In the ACM's 2018 advisory on the HTM case, it was considered permissible that the end-user is not the owner of the infrastructure, provided the concession holder is the only party using it, thus preserving the single end-user condition, furthermore HTM keeps in control of the chargers and therefore it will be seen as one party that utilize the network, see *HTM*. Finally, a supply license is not required when electricity is supplied to a non WOZ-object, since it is not considered an end-user, or when the connection capacity is more than 3*80A, see *Small connection*.

Most important regulatory and Legal Requirements

- All conductors and permanently affixed electrical equipment located behind the electricity meter at the transfer point from the TSO or DSO to the customer's electrical infrastructure, with a single owner and a single end-user, may be regarded as an installation.
- No independently owned WOZ registered third-party properties may be connected. Only non WOZ-objects, or WOZ-objects under the same ownership, may be connected so that a single end-user remains in place.
- No supply license is required for non WOZ-objects.

Advantages of the Legal Construct

With only one end-user, the PTO retains full control over connected applications, including how much power they consume or feed in, at which times they operate, and whether they can be curtailed or disconnected when traction operations require capacity. The PTO can focus on its own operations, without incurring the statutory obligations that arise when making the network available to third parties. Costs are relatively low because no special exemptions are required and there is no need for multi-party contractual frameworks as in cable pooling, nor the administrative load associated with a Closed System. Revenue can be generated by operating non-WOZ applications on the installation, for example EV charging infrastructure run by the PTO, and renewable generation can be coupled to the public transport electricity infrastructure to reduce electricity costs, subject to project-specific feasibility.

Challenges and Limitations

Only non WOZ-objects, or WOZ-objects under the same ownership, can be connected. Where concession grantors or legal owners of the PTO electrical infrastructure expect third-party connections, for example as discussed in the *Bestuursakkoord Netcongestie & OV*, the installation construct will not meet those expectations and is therefore not a realistic working framework for enabling third-party access.

Useful Cases and Applicable Applications

Applications that are not WOZ-objects can be connected to the PTO's installation, provided the electrotechnical equipment required to convert and deliver electricity to the application, such as chargers or inverters, is owned by the PTO. The connected object itself must also not be a WOZ-object, for example a car, a bus, or a movable energy bank. Alternatively, the PTO can connect WOZ-objects that it owns, such as depots, workshops, passenger stations, or offices. In an interview with the ACM, it could not be confirmed whether mobile energy banks can be connected under this regime. Further research is required to check whether mobile energy banks do not qualify as WOZ-objects, see *the interview with a Regulatory Expert (1)*.

Laws and Regulations Regarding Installation

As mentioned, the information given over Installation in this section originates from the relevant national legislation, including detailed conditions, obligations, refusal grounds for Installation, that are provided in the appendix: *Regulatory and Legal Requirements for an Installation*, including explanation.

Figure 6.4 and 6.5 illustrate how an installation is defined as all conductors and permanent electrical equipment behind the meter when there is only one legal end-user. In the generic case in Figure 6.4, this is a single industrial user. In Figure 6.5, the same concept is applied to a public transport electricity infrastructure, where the PTO is the sole end-user and can connect non WOZ-objects or WOZ-objects under the same ownership without appointing a system operator. A traction power network can be considered as one WOZ-object, eventhough it has multiple connections to the public grid.

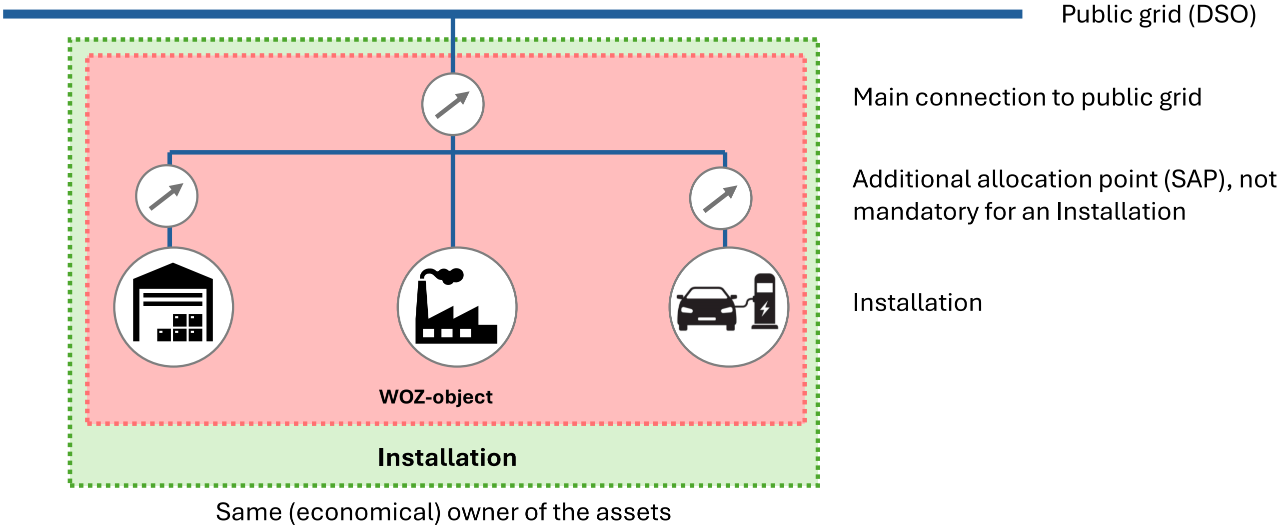


Figure 6.4: Installation in a generic situation with one legal end-user behind a public-grid connection

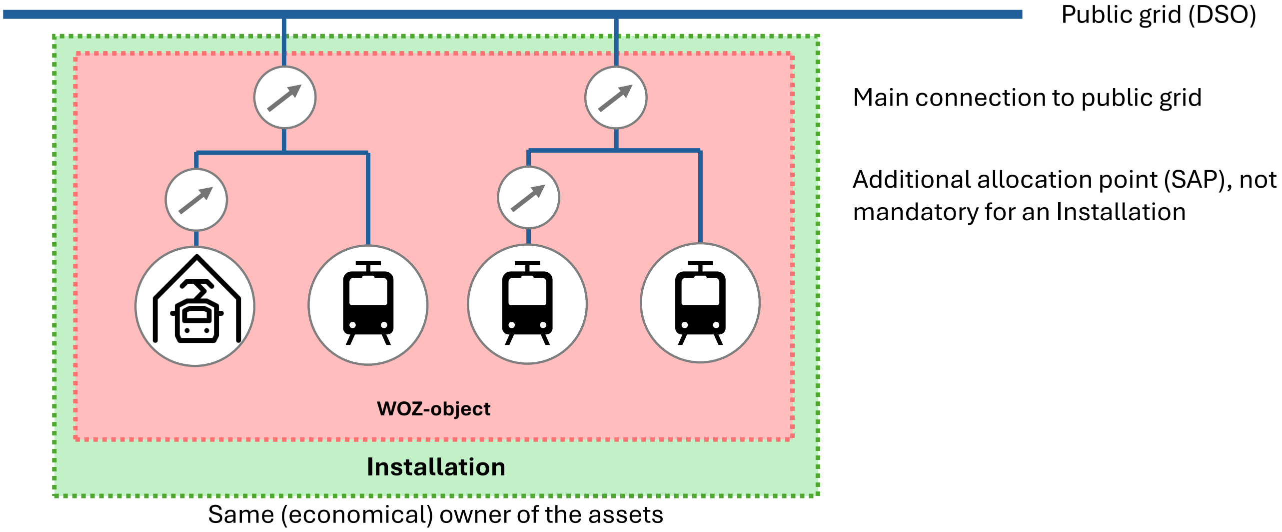


Figure 6.5: Installation formed by public transport electricity infrastructure with the PTO as single end-user, which might have multiple grid connections

6.2.4. Direct Line

A Direct line is a physical connection between a producer of renewable energy and one or more end-users that bypasses traditional public or closed grids. Two variants exist: a fully off–grid line that links an isolated production installation to an isolated consumer, and a line with a single connection to the public grid via either the producer or a business user. If multiple public–grid connections exist, or if the link between producer and consumer is itself directly connected to a grid, the arrangement is no longer a direct line but is legally considered a network [44].

Note:
This method is included because there are scenarios in which the public transport electricity infrastructure can serve as a backup for an application that is primarily supplied via a direct line, drawing on the public transport electricity infrastructure when the direct line cannot deliver sufficient power. The method also allows a PTO to use electricity for its own consumption via a direct line, on the condition that the PTO is the sole user of that electricity, and that no electricity is fed back into the public grid. Other applications connected to the public transport electricity infrastructure could in principle also be supplied in this way, but this must be described in the ACM registration of the direct line. As this concept has not yet been implemented in practice, and definitive legal guidance is not yet available, it is presented as a recommendation, and further research is required to assess feasibility and legal permissibility.

Understanding the Legal Framework

A direct line is a dedicated cable between a production installation, for example a wind or solar plant, and one or more business consumers (end-users). Dutch law distinguishes two forms:

1. *Without any connection to the public electricity grid*:
   The direct line links an isolated production installation directly to an isolated consumer, there is no connection to the public grid or to a Closed System at either end. Energy flows only over the private cable between producer and consumer.
2. *With exactly one connection to the public electricity grid*:
   The direct line links one production installation to one or more business users (end-users), via a single connection to the public grid. Commercial contracts are concluded via a supplier who handles metering, settlement, and other administrative tasks, but this supplier does not deliver energy, because that is produced by the production installation [44].

Direct lines are intended for large users, and the producer's generation profile is aligned with the large user's consumption [100]. A direct line does not carry the obligations of a network, there is no requirement to appoint a system operator, no unbundling, no third–party access, no connection obligation, and no regulated tariffs.

Most important regulatory and Legal Requirements

The new Energy Act defines conditions for a Direct Line. The most important definitions are briefly explained beneath:

Definition (Energy Act, Art. 3.9)

- A direct line is a pipe or cable, possibly including relevant equipment, directly connecting a producer to one or more end-users, either fully independent of the grid (Art. 3.9.1(a)) or connected to the grid only via the installation of one connected party (Art. 3.9.1(b)). Delivery to household end-users is only permitted under strict conditions.

Furthermore:

- More than one public–grid connection, or a direct link between the producer–consumer line and a grid, disqualifies the arrangement as a direct line and makes it a network [44].
- The owner must notify the ACM immediately upon commissioning of the direct line, and must also report significant changes, for example capacity or routing changes. Further requirements for form and content of notifications may be set by ministerial regulation.
- A surplus may not be delivered to parties other than those with whom the direct–line contract is concluded.

The ACM notification must use the official form and include supporting documents: evidence that the notifier is a producer within the meaning of the Energy Act and operates a production installation connected to the direct line, proof that any supplier involved is a recognized supplier, a cadastral map showing the direct line, public–grid connection(s), and end–user connection points, and a technical single–line diagram.

Advantages of the Legal Construct

A direct line reduces dependence on the public grid, therefore the impact on the public grid is smaller. This can make it easier to realize additional public–grid connections elsewhere, because the direct line supplies part of the demand directly from the producer. A battery may also help by temporarily storing excess power.

Challenges and Limitations

If an application is primarily supplied via a direct line, it might still need to be connected to the PTO's electrical infrastructure, as a back-up, to receive power when the producer cannot supply. When that application is not owned by the PTO, a Closed System recognition is required for connection to the PTO infrastructure, otherwise this is not legally possible. With renewable generation, production may be variable and difficult to predict, which complicates forecasting the application's demand at specific times and can make it harder to connect multiple applications, since the direct–line application also needs allocation during periods without sufficient generation. If the production site is not near the application, or the application is not near the PTO's infrastructure, construction of the necessary cable route may be difficult, for example where roads, waterways, or residential areas must be crossed. Finally it is important that the consumption profile of the large user should match the producer's generation profile, that is, comparable and simultaneous use. Any surplus may only be delivered to the contracted parties in the Direct Line agreement.

Useful Cases and Applicable Applications

Direct lines are suited to large business users whose consumption closely matches the producer's output. They are particularly relevant where a producer wishes to supply a PTO directly and the PTO can use practically all of the power. Proximity between the production installation and the application, or proximity to the PTO infrastructure for back–up supply, facilitates implementation.

Laws and Regulations Regarding Direct Lines

As mentioned, the information given over a Direct line in this section originates from the relevant national legislations, including detailed conditions and obligations for a Direct line, that are provided in the appendix: *Regulatory and Legal Requirements for a Direct line*, including explanation.

Figure 6.6 summarises two variants of a Direct Line. A fully off-grid variant, the producer and large user are connected only by a private cable and are not linked to a public grid. In the other variant, there is exactly one public-grid connection at either the producer or the business user, which allows settlement and metering while the energy itself is supplied directly over the private cable. In both cases, no system operator has to be appointed and there is no third-party access obligation.

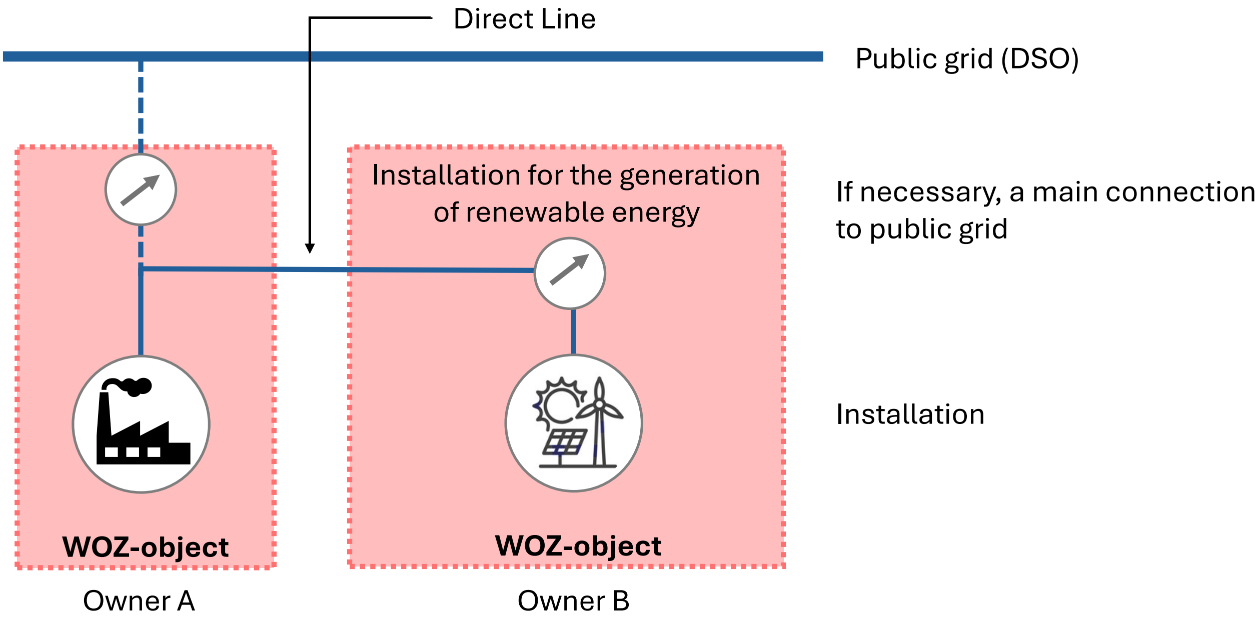


Figure 6.6: Overview of a Direct Line between a producer of renewable energy and one or more business end-users

Prioritise Applications

For the different legal constructs, the extent to be able to prioritize applications changes.

- **Installation**
  Because an installation presupposes a single end-user, the PTO can decide which non-WOZ objects (and WOZ objects under the same ownership) to connect to its own infrastructure. There is no duty to open the installation to third parties, so the PTO has effective discretion over which internal applications to realise.
- **Cable Pooling**
  The PTO remains owner of the main connection and can decide who to participate with. He can also set the participation requirements in the Cable Pooling Agreement (CPO) himself. Once the agreement is set, the PTO has less control over the connection.
- **Closed System**
  As formulated in *the interview with a Regulatory Expert (2)*, a PTO must open its Closed System to third parties, and therefore the approach to prioritisation remains uncertain. There are no known cases in which a Closed System operator had to choose between applicants who all meet the conditions in the recognition and the requirements of the new Energy Act. Further legal research is required to determine whether refusals are permitted in such circumstances and whether an operator must follow the ACM's prioritisation framework. What only can be stated is that a Closed System operator must act in a non-discriminatory manner towards connection requests that fall within both the functional and geographical scope of the recognition, that the Closed System operator does not need to follow the ACM's prioritisation framework for DSOs, and that perhaps the formulation in the request for recognition can make it possible to get some control over the connection requests.
- **Direct Line**
  Prioritisation under a direct line depends on the PTO's role and on the legal status of the public transport electricity infrastructure:
  - *PTO as end-user only*
    If the direct line supplies the PTO's own demand, the PTO simply decides whether to contract with the producer, third-party prioritisation does not arise.
  - *Application needs back-up via the public transport electricity infrastructure*
    Prioritisation then follows the regime that applies to the public transport electricity infrastructure: if the network is an *installation*, third-party connection is not permitted, so no prioritisation is required and other wise the application is in ownership of the PTO; if the network is a *Closed System*, the PTO must handle eligible requests within the recognised functional and geographic scope and on a non-discriminatory basis. In all cases, deliveries over the direct line are limited to the contracted parties.

6.3. Alternative Approach to Reduce Grid Congestion

Beyond connecting applications to the public transport electricity infrastructure, a PTO can also contribute effectively to relieving grid congestion by applying congestion management. Because this topic does not directly address the core research question, namely how applications should be prioritised, it is not discussed in detail here. It is nevertheless noted, since for PTOs and other organisations it may be a relevant, and potentially more effective and economically advantageous, way to reduce grid congestion in their area.

Congestion Management

When the objective is to alleviate grid congestion, the PTO or host can apply congestion management within its own connection and installations before connection third parties. Examples of congestion management could be shifting controllable demand, unlocking flexibility, or dispatching local storage and on-site generation, thereby reducing peaks and contributing directly to congestion relief by creating free available capacity on the public grid.

On top of that, ACM's code decision of 8 February 2024 to revise the Netcode Electricity (Dutch: *Netcode Elektriciteit*) makes participation in congestion management mandatory for Closed Systems. The Closed System operator must enable flexibility from connected users to relieve congestion on the public grid, and DSOs or the TSO may require the operator to make such flexibility available [101]. Participation can be organised by appointing a CSP, a Congestion Service Provider, or a BSP, a Balancing Service Provider, or by allowing individual Closed System users, and their CSP or BSP, to make their flexibility available via the Closed System operator to the grid operator or to the operator of any overlying grid. Flexibility sourced within a Closed System may be used to resolve congestion on the directly connected grid and on overlying grids. Safety and reliability remain the operator's responsibility, with limits on participation permitted only where genuinely necessary for safe operation.

In declared congestion areas, participation is required for connected parties, with a contracted transport capacity for offtake or injection above 1 MW. Outside congestion areas, a standing obligation applies to connected parties with a contracted transport capacity for offtake or injection above 60 MW to contribute under the same procedures and specifications. Within a CS, the Closed System operator must facilitate compliance with these obligations [102].

Congestion-management measures

In declared congestion areas, congestion management measures establish clear agreements between grid operators and connected parties, both producers and end-users, enabling more efficient use of the network and alleviating congestion. The ACM groups these measures into four categories, flexible contracts, tariff incentives, rules for dealing with scarcity, and operational congestion management. The list below consolidates the options that a PTO or Closed System operator can deploy or facilitate to relieve grid constraints while safeguarding safe operations [103].

- **Flexible contracts (capacity-limiting contracts)**
  Grid users can opt for alternative transport rights that make better use of scarce capacity. The ACM distinguishes three variants, a fully variable right on both transmission and distribution grids, a time-duration bound right on the transmission grid, and a time-block bound right on regional grids. In addition, capacity can be shared via group transport agreements, **cable pooling**, and, where applicable, group agreements with **closed systems**. These instruments help connect parties sooner by shifting or sharing rights in time and across users.

  On regional distribution grids, a customer can agree with the DSO that contracted capacity may be reduced at specified moments in return for compensation. Core clauses typically specify:

  - The maximum contracted capacity,
  - When capacity may be reduced, either at all times or within defined time windows,
  - The compensation rate in € per megawatt (MW) for curtailment,
  - The EAN code of the connection,
  - The contract term.
- **Tariff incentives**
  Time-of-use structures on the transmission and distribution grids, together with infeed tariff options and small-user network tariff design, provide price signals that discourage peak use and encourage off-peak behaviour. These tariff signals complement contractual instruments by steering when capacity is used.
- **Dealing with scarcity**
  A set of norm-setting rules addresses how scarcity is handled. Key elements are use-it-on-time-or-lose-it rules to curb hoarding, enforcement around contracted transport capacity, a societal prioritisation framework for allocation in congestion areas, defined connection lead times for large users, and a real-time interface that lets grid operators cap infeed from generation and storage in precise increments. The ACM notes the CBb ruling on priority rules in March 2025, with interim application until at most 1 January 2026, and states the real-time interface entered into force on 26 April 2025.
- **Congestion management**
  When physical overload must be averted, grid operators deploy market-based redispatch and capacity-limitation contracts (CBC). Before refusing transport requests, they must run and publish a congestion study. Where voluntary supply is insufficient, a participation duty can oblige connected parties to offer redispatch or a CBC, including for GDS operators above a 1 MW threshold in congestion areas, with standardised contracts available to speed up agreements.
- *Experimentation*. In addition, grid operators may pilot alternative approaches to unlock additional transport capacity. Such pilots are not explicitly regulated and therefore fall outside the formal congestion management regime, however, where legislation or code provisions would otherwise prevent a well-founded pilot, the ACM may, in specific cases, grant a temporary recognition from the energy codes.

Implementation note
In practice, selecting a bundle of measures, for example a CBC plus time-of-use incentives and coordinated

charging on PTO sites, tends to yield the most effect with manageable operational risk. All measures must be embedded in agreements that define load envelopes, curtailment priority, monitoring, and settlement, and they must respect the Closed System operator's duty to maintain safe and reliable operations.

6.4. Chapter Conclusion

This section includes the answer to the third research question of this research.

> *Which legal constructions are available for connecting (third-party) energy applications to public transport electricity infrastructure, what requirements do they entail, and what are their main advantages and disadvantages?*

In this chapter, we outlined the legal constructs that enable connections to PTO infrastructure, together with their core conditions, obligations, and practical implications. Each construct serves a different purpose and entails distinct trade-offs for types of applications, controllability, contractual effort, and congestion impact. Below is a concise synthesis per construct, followed by a comparative table.

Overview per construct

Closed System
A Closed System is a privately operated network recognised by the ACM that permits connecting third-party WOZ-objects within a defined site, with lighter duties than public DSOs yet clear operator obligations. Closed System operators have to connect all (third-party) energy applications that request a connection when they fall within the recognition criteria. It can materially relieve grid congestion and supports bi-directional flows, but recognition is complex, administratively demanding, and time-intensive. Tariffs must be cost-based and non-discriminatory, and extensive compliance and contracting are required.

Installation
Where the PTO is the single end-user, its infrastructure can qualify as an installation, allowing only non-WOZ applications or WOZ-objects under the same ownership to connect. No system operator is required, costs and lead times are relatively low, and the PTO retains full operational control. Third-party access is not possible under this construct.

Cable Pooling
Cable pooling lets two to four installations in close proximity share one main connection behind the meter via a joint ATO and a Cable Pooling Agreement (CPO) with a shared connection that must have a minimum capacity of 100 kVA. It is faster to implement than a Closed System, gives the PTO contractual control through the CPO, and can help use contracted capacity more efficiently. Participation criteria must be applied consistently and coordination among participants is essential to avoid curtailment. It is only possible for AC applications, in case there is no inverter used.

Direct Line
A Direct Line is a dedicated cable from a producer to one or more business end-users, either fully off-grid or with exactly one public-grid connection. It reduces reliance on the public grid. A Direct Line can be used in two ways. It may couple on-site renewable generation directly to the public transport electricity infrastructure to cover the PTO's own consumption, or secondly, an application that has a direct line to a generation plant requires a back-up connection to the public transport electricity infrastructure in case the plant cannot meet the demand of the application temporally. If the backup serves a non-PTO property, a Closed System recognition is required

Advantages and disadvantages by construct

Table 6.3 compares the four legal constructs: Closed System, Installation, Cable Pooling, and Direct Line, plus the measure Congestion Management. It summarises whether third parties can be connected, the compatibility of each construct with either AC and/or DC applications, the typical implementation speed of that construct or measure, the indicative effect on congestion (which is an estimate, and is case dependent), the applicability of connecting WOZ-objects, the possibility of bi-directional use, the expected contract effort, and a high-level view of internal feasibility for a PTO (which is again an estimate, and is case dependent). Values are indicative rather than prescriptive and reflect typical cases.

Legend:

🟩 Can be connected
🟧 Only if same owner as host network
🟥 Cannot be connected
⬜ Not applicable

Table 6.3: Comparison of legal constructs (including Congestion Management)

Criterion	**Closed System**	**Installation**	**Cable Pooling**	**Direct Line**	**Congestion Management**
Third parties can connect	**Yes**	**No**	**Yes**	**Yes**	**No**
AC/DC connection compatibility	AC and DC	AC and DC	AC	AC and DC	**Not applicable**
Speed of applying	Slow	Fast	Moderate	Case Dependent	Fast to moderate
Impact on grid congestion [×]	High	Low to moderate	Moderate	Moderate	High
WOZ-objects	**Yes**	**Owner only**	**Yes**	**Yes**	**Not applicable**
Bi-directional use possible	**Yes**	**Yes**	**Yes**	**No**	**Not applicable**
Contractual complexity	High	Low	Medium to high (ATO, CPO)	Medium to high (supplier, ACM notice)	Medium
Internal feasibility (PTO) [××]	Challenging	High	Moderate	Case dependent	Moderate to high

Notes.
[×] The congestion impact is highly context-dependent (site, load profiles, capacity), figures are indicative only and not universally representative.
[××] Internal feasibility likewise depends on PTO capabilities, governance, and site specifics.

Control and administrative burden per legal construct

The choice of legal construct not only determines which applications can be connected, it also shapes how much operational control the PTO or municipality retains and how heavy the contractual and administrative workload will be. Table 6.4 summarises these trade-offs by distinguishing control over application consumption, control over use of the network, and the associated contractual and administrative burden.

For the **Installation** construct, control is highest and the burden is lowest. Because the operator will be the single end-user and most energy applications will probably be self-owned, it can determine the load profile of those energy applications. If an application is not a WOZ-object, it can also be connected to the network, and such applications are often easier to control, for example mobile energy banks or EV chargers, although this remains case specific. No special exemption procedure is required, since most public transport electricity infrastructures can qualify as an installation, and there is no obligation to admit third parties. Installation is therefore attractive where a PTO or municipality wants to retain a high degree of control while avoiding extensive administrative and contractual burdens.

Because the main connection is shared, **cable pooling** reduces the direct control of the PTO or municipality. Clear participation conditions and operating rules in the Cable Pooling Agreement (CPO), for example power limits, time windows, and curtailment arrangements, can provide meaningful control over the applications, but they must be agreed in advance. Once the CPO and joint ATO have been concluded, later changes to capacity, new participants, or network modifications require cooperation from the other parties and the system operator. The contractual and administrative burden is medium: a significant one off effort is needed to negotiate and draft the agreements and to organise metering and settlement, but the recurring workload is more limited.

In a **Closed System**, control over individual applications is lowest while administrative and contractual obligations are highest. Within the recognised functional and geographic scope, the operator must treat eligible third parties in a non-discriminatory way and cannot freely select or manage connected users beyond objectively justified technical and safety grounds and agreed congestion management arrangements. At the same time, the operator becomes responsible for a wide range of statutory tasks, including metering, data exchange, tariff setting, incident handling, and reporting to the ACM. The construct therefore increases organisational effort and reduces discretion over the day-to-day use of the network.

A **Direct line** gives high control over both application consumption and network use, but requires careful contractual and technical preparation at the outset. Because the line is dedicated to one producer and one or a limited group of business users, producer and users can align generation and demand contractually and decide how the private cable is used, without third-party access obligations. During operation, the PTO or municipality can decide how much power it wants to receive and can reduce this when technically desirable. The burden lies mainly in designing the technical solution, obtaining permits, notifying the ACM, and drafting the contracts between producer and user. Once these are in place, recurring administrative work is moderate. Direct lines are therefore suitable where a PTO, municipality, or another large user can match its demand closely to a specific producer and where a dedicated connection is feasible.

Taken together, the table illustrates that higher control over external parties generally comes with lower ability to host third-party demand at scale, while constructs that open the network to many users, such as Closed Systems, significantly increase contractual and administrative responsibilities. These trade-offs should be considered when selecting an implementation route for the applications that emerge from the prioritisation framework.

Legal construct	**Control over application consumption**	**Control over use of the network**	**Contractual and administrative burden**
Installation	**High**	**High**	**Low**
Explanation	The PTO or municipality is, in most cases, the single end-user and most applications are self-owned. The PTO can decide when applications run, how much they consume or inject, and can curtail or disconnect them when traction operations require capacity.		No special recognition is required, there is no duty to open the installation to third parties, and only standard accounting rules apply. Administrative effort and legal risk remain limited.
Cable pooling	**Medium**	**Medium**	**Medium**
Explanation	In the CPO the PTO or municipality can agree power limits, time windows, and curtailment rules for each participant. Once signed, these rights are shared and future changes, expansions, or reallocation of capacity must be agreed with the other participants and the DSO.		A one off effort is needed to negotiate and draft the joint ATO and CPO, set up metering, liability, curtailment, and expansion clauses, and coordinate with the DSO or TSO. Afterwards, recurring administrative work is modest but not negligible.
Closed System	**Low**	**Low**	**High**
Explanation	Within the recognised functional and geographic scope, eligible third parties must be treated in a non-discriminatory manner. Once connected, the operator has limited influence over when and how much they consume or inject, apart from congestion management arrangements and contractually agreed flexibility.		The recognition procedure is complex and time consuming. Afterwards the operator must comply with extensive statutory obligations on metering, data exchange, tariffs, registers, incident and outage handling, and reporting under ACM supervision, in addition to contracts with all connected parties and their suppliers.
Direct line	**High to medium**	**High to medium**	**Low to medium**
Explanation	The line is dedicated to one producer and one or a small number of business users. Producer and users can align generation and demand contractually, and the PTO or municipality can decide how much to take to, to ensure safe and technically efficient operations.		No system operator has to be appointed and there are no regulated network tariffs or unbundling requirements, but technical design, permits, ACM notification, and the contracts between producer and user still require careful preparation and legal review.

Table 6.4: Control and contractual burden per legal construct

Figure 6.7 provides a qualitative overview of how the main legal constructs compare on two dimensions: (i) the degree of operational control the PTO or municipality retains over the traction power network, and (ii) the contractual and administrative burden associated with enabling third-party applications. Moving upward indicates more control over how and when capacity is used, while moving to the right indicates a lighter burden in terms of contracting, procedures, metering, and ongoing compliance. The figure illustrates table 6.4.

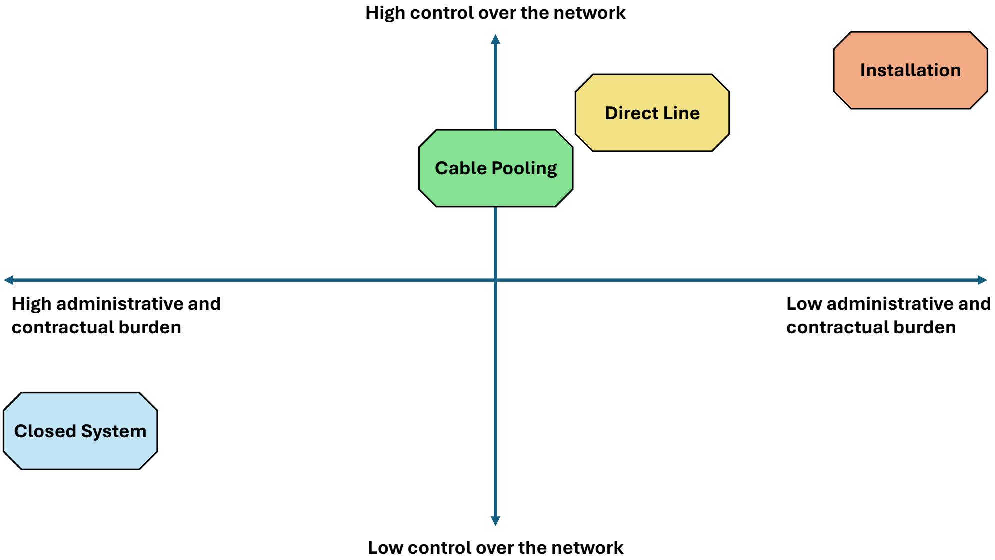


Figure 6.7: Qualitative overview of how the main legal constructs compare on control over the network and administrative and contractual burden

Connection methods by application

Table 6.5 indicates which connection constructions are, in principle, possible for each type of application. Green means “the application can be connected via this approach”, orange means “the application can only be connected if the application is owned by the same entity that owns the host electrical network”, red means “the application cannot be connected via this approach”, grey means “technically possible but unrealistic under normal constraints, for example cost, time inefficient, contractual difficulties, control complexity, unpredictability, or concession limits”. Furthermore, it should be noted that bi-directional inverters are considered as enabling interface equipment, not an application, and are therefore excluded from the table.

Note for a Direct Line: A Direct Line can be configured as the application’s primary supply, while the PTO, or another host network, provides a back-up connection when renewable generation is insufficient. Alternatively, the Direct Line can be set up to supply the PTO, or another host network, as the primary source of energy.

Legend:
🟩 Can be connected
🟧 Only if same owner as host network
🟥 Cannot be connected
⬜ Unrealistic in practice

Table 6.5: Indicative feasibility of the type of application for each legal construct

Application	Closed system	Installation	Cable pooling	Direct line
Energy Storage Systems	**Yes**	**Owner only**	**Unrealistic**	**Unrealistic**
EV-chargers	**Yes**	**Yes**	**Yes**	**Unrealistic**
Street lighting & public space	**Yes**	**No**	**Yes**	**Unrealistic**
Zero emission equipment	**Yes**	**Yes**	**Yes**	**Unrealistic**
Industry	**Yes**	**No**	**Yes**	**Yes**
Business parks & commercial	**Yes**	**No**	**Yes**	**Yes**
PTO depots, offices, workshops	**Yes**	**Yes**	**Yes**	**Yes**
Building services systems	**Yes**	**No**	**Yes**	**Unrealistic**
Event & temporary installations	**Yes**	**No**	**Unrealistic**	**Unrealistic**
Local generation (PV, wind)	**Yes**	**Owner only**	**Yes**	**Owner only**

Conclusion

There are five practical approaches, namely four legal constructs plus another separate measure: applying congestion management. The legal constructs are a Closed System, Cable Pooling, the Installation method, and a Direct Line. Some options provide more discretion and long-term flexibility, others are faster to implement with fewer obligations. The sixth option is doing nothing. This can be a defensible choice where the regulatory burden would be disproportionate or where available capacity is already fully required for the core operations of the PTO, leaving no headroom for congestion-management measures or (third-party) energy application connections.

In principle, the legal constructs can be ordered by ease of implementation for a PTO, considering contractual and operational burden, and the effort of to get permission or approval by the ACM. Direct lines are excluded from this ordering, since they are a special case mainly used to couple RES directly to a PTO for own consumption, and are relatively straightforward to arrange. If a direct line supplies an application that also requires a back-up via the public transport electricity infrastructure, that back-up must be arranged through the Installation method, Cable Pooling, or Closed System recognition.

Order of ease:

1. **Installation method** — Most simplest in practice
2. **Cable Pooling** — Moderate complexity
3. **Closed System** — Most complex

The choice of legal construct will not be assessed within the prioritisation framework; it is treated as an implementation instrument to be able to connect an application. Once applications have been prioritised, the PTO or any other organisation can determine which construct enables that or those connection(s). Selecting the route that is lawful, proportionate, and presumably the one that entails the least regulatory, operational and contractual burden. If the highest ranked application cannot be connected under the legal construct that the PTO or organisation is willing to use or can use, the organisation should proceed to the next highest ranked application, until the legal construction makes the required connection possible and feasible. Therefore, if the construct is predetermined, applications that are incompatible with that construct should be removed from scope and not be scored anyway. Table 6.5 can be used as a practical preselection filter by indicating which applications are, in principle, feasible. It should be noted that the table may not be accurate and should be used as a guide only; additional research should be conducted for each type of application.

Where third parties are connected, the PTO must ensure separated accounts in line with the Public Transport Act 2000, so that subsidies for public transport are not used to finance activities on adjacent markets and to avoid unfair competition. Transparent cost-accounting principles and clear tariff setting are essential to demonstrate compliance with competition law, the ACM determine the rates for the network tariffs.

To conclude, in all cases, PTOs should discuss with the DSO and TSO in joint consultations to determine how to contribute most effectively to relieving local grid congestion and which path is realistic for their ambitions, network characteristics and location. Much depends on the PTO and neighbouring stakeholders, governance structure, distribution of ownerships, their needs, their willingness to cooperate, and their operational and legal capacity.

7

Focused Expert Consultations

After completing the research, including a targeted literature review, a scan of non-academic sources, and a researching relevant legislation and regulatory guidance, three in-depth expert consultations were conducted to get the last valuable knowledge required to develop the first themes and components. Two of them are presented in the report. The aim was to resolve legal ambiguities around connection routes, to probe technical feasibility and operational constraints, and to ensure that the prioritisation logic remains usable for Dutch PTOs.

7.1. Legal Consultation

Regulatory Expert 1

Profile

The interviewee is a senior lawyer and senior inspector at the energy supervision directorate of Netherlands Authority for Consumers and Markets (ACM) [104]. The answers are **not official responses from the authority**, but are formulated based on the interviewee's interpretation of current law and regulations.

A detailed overview of this consultation have been omitted from the appendices in this public version. These are available from the author upon request.

Important take-aways

- Closed system operators must act in a non-discriminatory way toward connection requests that fall within both the functional and geographical scope of the recognition.
- Clearly defining recognition grounds and geographical scope during the CS application process simplifies compliance and helps avoid future disputes.
- Non-discrimination is mandated in Electricity Act and will remain under the new Energy Act, but the law leaves at some points flexibility in how to operationalise it.

7.2. Technical Consultations

Technical Expert in DC Traction Systems

The discussion focused on technical preconditions for connecting (third-party) energy applications to DC traction systems, realistic application types, connection topology choices, and measures to safeguard power quality and reliability, with an expert in electric traction systems who has practical experience across DC networks in public transportation. In this interview, the expert explained several aspects that are critical to consider when connecting applications to the electrical networks of public transport operators.

Profile

The interviewee is a researcher and professor in the field of electrical and control engineering at a European technical university [105].

A detailed overview of this consultation have been omitted from the appendices in this public version. These are available from the author upon request.

Important take-aways

- DC traction environments are volatile, with low average demand but high peaks; voltage may vary widely due to simultaneous acceleration and regenerative braking.
- Point of connection matters, connections near substations experience fewer voltage excursions and lower effective impedance than connections at section ends.
- For AC loads, substation AC-side connection via auxiliary transformers is typically simplest and most reliable; DC-side catenary taps suit DC loads but require careful voltage stability management.

- Local storage, whether vehicle-based or stationary, enables voltage stabilization, buffers regenerative bursts, and improves power quality for sensitive consumers.
- PV on the DC side can achieve high self-use without storage in suitable locations, yet performance is strongly site specific and demand dependent.
- Distance and conductor sizing are critical, long runs significantly increase voltage drop and losses, especially at higher powers.
- Controllability is essential, applications must modulate demand to avoid amplifying traction voltage swings and to respect operational priorities.
- Feasibility assessments should be local and data driven, reflecting city-specific topology, rolling stock, recuperation settings, and traffic patterns.

8

Themes Development

Based on the synthesised outputs of Research Questions 1 to 3, the expert consultations, and the literature review, the themes for prioritising applications are formulated and will be presented in interviews with the municipalities, provinces/PTA , and PTOs to test their relevance and importance. Prioritisation will be focused on the *Technical* and *Societal* themes, since *Legal* is treated as an enabling instrument for connection rather than a primary criterion.

Some themes naturally overlap across disciplines, because certain technical properties are also socially desirable, and socially desirable objectives can only be realised if technical requirements are met. For example, if stakeholders value an application that is flexible, widely deployable across the city, and relocatable, this desirability must be verified against technical feasibility. Relocatability, therefore, is assessed within the Technical theme to determine whether it is realistic and feasible, whether it is desirable from a technical standpoint to have relocatable applications, and which design aspects determine feasibility. In this chapter, each theme is introduced with concise, evidence-based components, so that interviews can probe which components stakeholders prioritise and why.

The prioritisation framework is applied to score applications against the *components* they influence. Stakeholders identify which (sub-)themes and components are most important for them, based on their context and situation. The societal theme is additionally organised into sub-themes. Those (sub-)themes are grouped into related components. Each component is then operationalised through a concise set of assessable aspects, which together provide a consistent basis for scoring and comparison, see Figure 8.1.

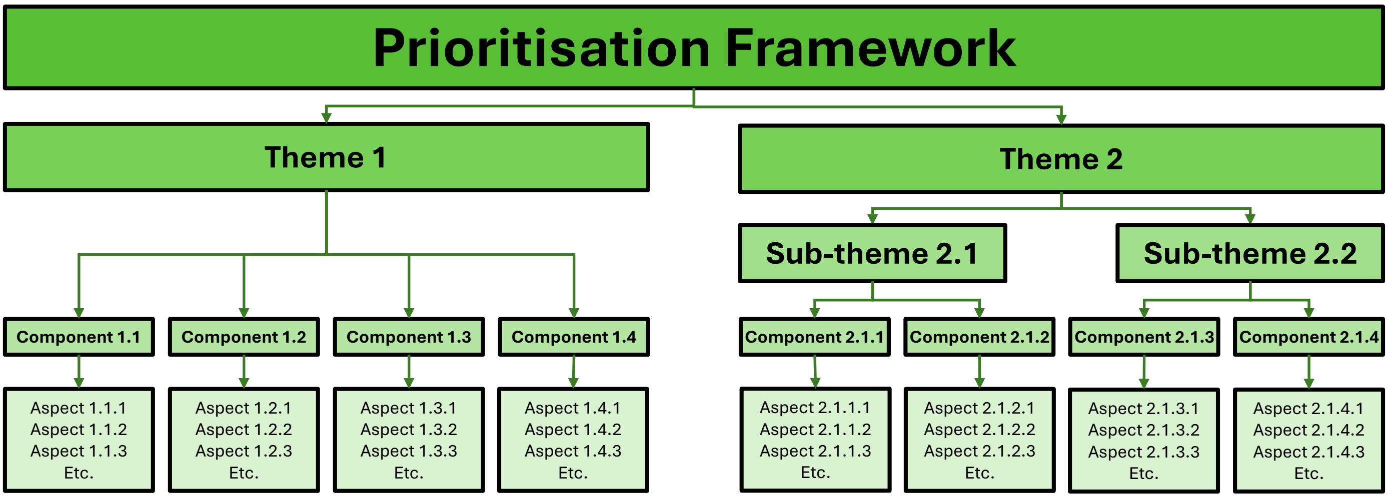


Figure 8.1: Structure of the prioritisation framework, showing themes, optional sub-themes, components, and assessable aspects

8.1. Technical

This section defines the components that are technically relevant for prioritising applications. First, salient findings from the literature review, expert consultations, and synthesised insights are summarised, then the components of the Technical theme are defined.

The sub-themes of the Technical theme might also occasionally overlap, however the interviews will clarify where the stakeholders from the technical departments want to place specific prioritisation.

Outcomes of previous research

Literature review

Technical behaviour
Prioritisation should include components that count for for minimum DC line voltage, maximum section current, and acceptable I^2R losses, and electrical distance which can be covered in a section that determines the controllability of an application, its efficiency and the quality of service .

Recuperation of energy
The assessment should also cover the capability of an application that might act as a managed DC-side sink, or stationary storage, which has smart-grid behaviour, and the siting of the application.

Connecting solar PV and wind systems
The theme should distinguish aggregation level at system scale versus substation scale, the resource mix with hybrid PV–wind versus single-source options, based on the sizing and demand of the network, including controllability and storage features to limit curtailment.

Technical expert

The expert input indicates that DC traction environments are volatile, with low average demand, high peaks, and wide voltage variation. The point of connection is decisive, connections near substations face fewer excursions and lower effective impedance than end-of-section connections. It should also include that the type of current of the application is taken into consideration, as AC consumers preferably require a substation AC-side connection via an auxiliary transformer, which is for them the simplest and most reliable option, while DC-side taps suit DC loads but require careful voltage-stability management. Controllability is essential, applications must modulate demand to avoid amplifying traction-voltage swings and to respect operational priorities. Feasibility is local and data-driven, outcomes depend on network topology, rolling stock, recuperation settings, and traffic patterns. PV on the DC side can achieve high self-use in suitable locations, although performance remains site-specific and demand-dependent.

Synthesised insights

Across the research, it became apparent that applications can also contribute positively when they are controllable, sited at an electrically favourable location. The theme should therefore include aspects that incorporate the point of connection on the public transport electricity infrastructure, electrical distance and controllability. In the exploratory interview with a Transition Expert [63], it was mentioned that scalability is an interesting topic, namely the ability of the application to be easily scaled up or replicated without disproportionate additional works. It also emerged that relocatability should be assessed, including its implications. Finally, it is also important to consider that some applications must be supplied continuously, while others can be curtailed, and it should be tested whether such always-on priority is feasible and acceptable and if that should be part of the evaluation.

Technical components

The technical components are developed to test the technical theme as broadly as possible and are discussed below. The technical theme defines the conditions under which an application can be connected and operated safely, reliably, and efficiently on the host network. These components have been compiled based on the knowledge gained from the literature review, expert consultations, and the synthesised insights from the previous research, of which a brief overview is given above.

Grid Impact

This component addresses the potential technical effects of connecting a new energy application, and the type of connection, on the public transport electricity infrastructure. It strongly interacts with *Controllability*, since grid impact can be mitigated by controllability. The component should surface which electrical characteristics matter most to generate negative (or positive) impact, which can endagnger the operations of the PTO , so that they can be weighted appropriately in the decision, including voltage fluctuations, current fluctuations, reduced power factor, network losses, and the point of connection. These effects influence the stability, reliability, and efficiency of the PTO internal network, and can propagate to upstream DSO or TSO networks. The assessment should also capture whether the application can have a positive effect on the network. Finally, the implications of always-on priority for a given application should be made explicit, including any risks for network stability or reliable public transport operations.

Efficiency

This component concerns the energy efficiency of connecting applications to the public transport electricity infrastructure. It includes reducing losses through appropriate siting and connection design, for example avoiding long cable runs that increase voltage drop and current, and improving the use of locally generated energy, such as recuperated braking energy or renewable production, as well as optimising consumption profiles. It may be relevant to compare multiple smaller applications against a single large one. The theme efficiency can therefore have both technical and financial advantages or disadvantages. The theme maps efficiency-related benefits and drawbacks, the stakeholder interviews will determine whether this component warrants significant weight in prioritisation.

Scalability

Scalability concerns the extent to which an application or connection can be scaled up or replicated at multiple locations. Expert input indicates this is desirable, provided that it fits the network. Scalability includes replication across different networks or sites, and phased expansion within one network. Potential benefits include reusable knowledge, standardised practices, cost and operational scale effects, and support in addressing grid congestion. An explicit design choice concerns whether the network should host many instances of the same application or connection type, or a more varied set of applications. A homogeneous portfolio can reduce engineering and operational complexity, enable standardised procedures, shorten delivery times, and ease maintenance, yet it may synchronise demand and limit the ability to shape a flatter and more resilient load profile. A diverse portfolio can create complementary operating patterns across time and location, support peak reduction and resilience, and limit correlated failure modes, yet it may increase integration effort, and unit costs. The framework will, together with stakeholders, determine whether more scalable or less scalable applications should score higher, and whether a homogeneous or a diverse load mix is preferable in the specific network context. The evaluation will also assess whether prioritising scalable applications is preferable to prioritising individual, standalone solutions.

Controllability

This component addresses the extent to which the load of an application should be controllable (by the PTO). Multiple sources emphasise that controllability is critical to keep the *Grid Impact* low. Relevant capabilities include limiting consumption during peaks, temporarily switching off the application (during network issues), and regulating any export. Interviews should clarify when control is desired, and on which technical dimensions, for example power, timing, and direction of flow. The role of storage in reducing impact or increasing controllability should be assessed, including whether storage is a desirable attribute for scoring.

Installation and Maintenance

This component concerns the practical feasibility, required adaptations, installation effort, and periodic maintenance that a specific application and its connection requires. It includes necessary technical modifications, installation cost, periodic maintenance, and fault response. It should identify whether PTOs can perform the work in-house or require external support, and whether this should influence prioritisation. It shoudl also therefore cover preferred connection types (AC or DC) and connection points, and makes explicit which components, such as converters, transformers and metering equipment, introduce additional implications, since these factors can materially affect cost, reliability and recurring operational effort.

Relocatability

Relocatability refers to the extent to which an application can be moved to another location within the network. Relocatable applications can be valuable because they can be sited where capacity is available, and thereby supporting different locations over time. Whether this is desirable and practically feasible should be tested with stakeholders. Applications that can be relocated may need to be moved in the event of changes in spatial planning, altered operational requirements, or to respond strategically to network congestion in other areas. The degree of relocatability depends on the type of connection, physical installation, necessary permits, and the flexibility of the infrastructure. This component influences both initial design choices and the long-term value of the investment. Because some applications are intended to be relocatable, such as *Zero emission equipment* or *Event and temporary installations*, stakeholder preferences and any technical hurdles warrant explicit discussion.

8.2. Societal

This section defines two sub-themes divided in multiple components and related aspects that capture societal value. The societal theme is split into *Social* and *Sustainability*. Financial aspects are not scored separately, they are partly internal to the *Technical* theme, since applications that are only technically achievable at disproportionate cost will be scored technically unfeasible, as is discussed in *Chapter Conclusion*. The societal theme is used to investigate what stakeholders value most and what they would like the application to contribute to.

Outcomes of previous research

Literature review

Triple Bottom Line (TBL)
The literature review revealed that the Triple Bottom Line framework can contribute to an organisation being more likely to have a positive impact on the world while still improving financial performance, see *Triple Bottom Line (TBL)*. Since the theme *Cost* is not incorporated in this research, the societal value will be captured through the people and planet dimensions, and these are operationalised within the Societal as the *Social* and *Sustainability* sub-theme. Informed by interviews with the relevant stakeholders, the complete set of sub-themes and components will be finalised. Incorporating these components in the prioritisation process aligns PTO practice with corporate social responsibility, and is expected to support sustainability outcomes in public transport and contribute to the broader energy transition.

ISO 26000
ISO 26000 is used because it provides internationally recognised guidance on social responsibility that is practical, principle based, and adaptable to sector context, see *Triple Bottom Line (TBL)*. It offers categories and indicative actions that can be translated into clear scoring components and measurable indicators. For the PTO context and (third-party) energy applications connected to public transport electricity infrastructures, these subjects are adapted to a concise set of assessable components. Table 8.1 maps the core subjects to the sub-themes used in this thesis and clarifies the boundary of what might be scored. The aim is to prioritise applications with higher societal value, without turning the framework into a generic corporate responsibility checklist.

For PTOs, this research it helps to convert broad social and environmental objectives into concrete criteria for prioritising applications. Using ISO 26000, makes it general applicable to all PTOs, but also other organisations, it is consistent and transparent, it covers all relevant social and sustainability components, and it supports comparability between applications and other projects. Because ISO 26000 integrates social and environmental subjects, it also justifies combining these components within one theme during interviews and in the framework design.

ISO 26000 core subject	Scope to the context of connecting applications	Implementation
Organisational governance	Transparent decision-making and stakeholder engagement in prioritizing applications	Not scored within the framework, but stakeholder engagement is ensured through the interviews
Human rights	Safe, non discriminatory access and use, accessibility for vulnerable groups	Implemented in the Social theme - *Passenger and customer impact* & *Community and society impact*
Labour practices	Health, safety, and working conditions for staff who operate and maintain applications and PTO operations	Implemented in the Social theme - *Impact within the organisation*
Environment	Pollution prevention, resource efficiency, climate mitigation, local environmental quality	Implemented within Sustainability theme
Fair operating practices	Compliance, fair competition, anti corruption	Not scored within the framework, but baseline compliance is assumed with a fair transparent framework
Consumer issues	Passenger safety, service quality, information and accessibility	Implemented in the Social theme - *Passenger and customer impact*
Community involvement and development	Participation, local economic effects, education and knowledge sharing	Implemented in the Social theme - *Community and society impact*

Table 8.1: Adapting ISO 26000 to the context of connecting applications

Synthesised insights

Stakeholders emphasised learning effects and knowledge sharing [63]. Therefore, components are included that indicate whether an application supports knowledge development and sharing that benefits other PTOs or other organisations.

8.2.1. Social Sub-Theme

The *Social* sub-theme considers three domains of impact that an application can have; impact on the PTO's own workforce, impact on passengers or customers of the application, and impact on surrounding communities and/or society in general.

Impact within the organisation (PTO)

This component measures the extent to which an application has a positive impact on its own staff and the people who work directly with the application and can be divided into the following aspects, see Table 8.2.

Aspect	Contribution description
Working conditions	The application improves safety, occupational health, and noise exposure for staff who operate, maintain, or work near the application.
Worker participation	The application is adopted through meaningful dialogue with employees, including training and operational feedback loops.

Table 8.2: Social component: Impact within the organisation

Passenger and customer impact

This component measures the extent to which the application has a positive impact on travellers and the direct customers of the application and can be divided into the following aspects, see Table 8.3.

Aspect	Contribution description
Public transport service	The application improves public transport performance or accessibility, and benefits a substantial number of passengers.
Application users	The application has a wide range of users and/or improves safety, occupational health, noise exposure or reduces harmful emissions for the persons who work or interact with the application.

Table 8.3: Social component: Passenger and customer impact

Community and society impact

This component measures the extent to which the application helps to improve matters that are beneficial for society in general and for surrounding communities. There are mainly two areas that can be prioritised: quantitatively measurable components (which can be more easily expressed in figures) and qualitatively measurable components (which are more about perception, process or context and are more difficult to express in figures). Some components are hybrid in nature, and these have been added as a separate category at the bottom. An overview of the different aspects is given in Table 8.4.

Aspect	Contribution description
Quantitatively measurable components	
Air and water quality	The application reduces local emissions of CO_2, NO_x, particulate matter, prevents or purifies water (pollution), or reduces any other harmful emissions
Noise environment	The application reduces ambient noise levels in sensitive areas.
Physical footprint	The application fits available space efficiently, minimises land use, and limits surface disruption.
Local employment and economy	The application supports jobs or generates local economic value during delivery and operation.
Grid congestion	The application is sited to relieve severe grid congestion or to align with areas where capacity becomes available earlier.
Direct renewable coupling	The application connects to new renewable generation (via a direct line), reducing demand on the public grid.
Reusability of connection	The connection can be disconnected and repurposed efficiently for other users when needed.
Qualitatively measurable components	
Participation and governance	The selection of applications involves local communities in planning and decision-making.
Innovation and policy learning	The application stimulates innovation and knowledge sharing that benefits other PTOs or organisations.
Hybrid measurable components	
Connection duration and flexibility	The application's connection is temporarily and supports network flexibility and will make room for new applications in the future.

Table 8.4: Social component: Community and society impact

Table 8.5 gives a full overview of all the components within the *Social* sub-theme.

Category	Contribution description
Impact within the organisation (PTO)	The application improves working conditions for PTO staff, for example by increasing safety, reducing occupational health risks and noise exposure, and by involving employees meaningfully in the selection, design, training and operational feedback around the application.
Passenger and customer impact	The application benefits travellers and direct users by improving public transport performance or accessibility, and by enhancing safety, health, and comfort for people who use or interact with the application in practice.
Community and society impact	The application delivers wider societal benefits for surrounding communities, for example through improvements in local air and water quality, noise environment and spatial fit, support for local employment and the economy, targeted relief of grid congestion, direct coupling to renewable generation, opportunities for community participation and policy learning, and flexible or temporary use of connections.

Table 8.5: Social components adapted to the PTO application context.

8.2.2. Sustainability Sub-Theme

The subtheme *Sustainability* considers various ways in which an application contributes to sustainability and environmental improvements, following ISO 26000 categories as well. The components includes the prevention of pollution, sustainable resource use, climate change mitigation, protection of the local environment, and the alignment with development goals.

Prevention of pollution

This component measures the extent to which the application prevents harmful emissions to air and water, including metals and local air pollutants. An overview of the component is given in Table 8.6.

Aspect	Contribution description
Heavy metals prevention	The application prevents the emission or release of heavy metals during installation and operation.
Local air pollution reduction	The application prevents local air pollution, for example NO_x and particulate matter.
Water pollution prevention	The application prevents water pollution, for example through containment, treatment, or avoidance measures.

Table 8.6: Sustainability component: Prevention of pollution

Sustainable resource use

This component measures the extent to which the application improves material circularity and energy efficiency, including enabling sustainable generation. An overview of the component is given in Table 8.7.

Aspect	Contribution description
Material circularity	The application or connection uses recycled materials or is readily recyclable at end of life.
Energy efficiency and direct renewables	The application improves energy efficiency or enables sustainable generation, for example regenerative braking or direct coupling to on site renewables.

Table 8.7: Sustainability component: Sustainable resource use

Climate change mitigation

This component measures the extent to which the application reduces greenhouse gas emissions. An overview of the component is given in Table 8.8.

Aspect	Contribution description
Greenhouse gas reduction	The application delivers a comparatively large reduction in greenhouse gases, CO_2, CH_4, and N_2O, in line with sectoral goals.

Table 8.8: Sustainability component: Climate change mitigation

Protection of the local environment

This component measures the extent to which the application protects or enhances local environmental quality and spatial fit. An overview of the component is given in Table 8.9.

Aspect	Contribution description
Biodiversity and ecosystem health	The application improves local biodiversity and supports ecosystem health.
Minimal land use	The application minimises space use and physical footprint.
Sustainable area development	The application contributes to sustainable area development in the surrounding context.

Table 8.9: Sustainability component: Protection of the local environment

Alignment with development goals

This component measures the extent to which the application aligns with internal and external sustainability objectives. An overview of the component is given in Table 8.10.

Aspect	Contribution description
Alignment with municipal/provincial goals	The application aligns with municipal or provincial social and environmental objectives.
Contribution to SDGs	The application contributes to relevant UN Sustainable Development Goals.

Table 8.10: Sustainability component: Alignment with development goals

Table 8.11 gives a full overview of all the components within the *Sustainability* sub-theme.

Category	**Contribution description**
Prevention of pollution locally	The application aims for local impact and reduces harmful emissions (for example VOCs, SO_x, dioxins) and locally relevant NO_x and particulate matter, and prevents water pollution.
Sustainable resource use	The materials used in the application or connection are made from recycled sources or can be easily recycled and/or the applications increases the use of renewable or recycled materials, and raises energy efficiency, for example through regenerative braking or direct use of on site renewables.
Climate change mitigation	The application reduces greenhouse gases, CO_2, CH_4, and N_2O, and contributes to sectoral goals.
Protection of the local environment	The application protects biodiversity, preserves or restores ecosystems, and reduces land use while supporting sustainable urban or rural development.
Development goals	The application aligns with internal sustainability targets or concession requirements, and contributes to relevant UN Sustainable Development Goals.

Table 8.11: Sustainability components adapted to the PTO application context.

8.3. Chapter Conclusion

This section includes the answer to the fourth research question of this research.

> *Which decision-making themes and corresponding components are relevant for understanding and assessing the feasibility of connecting (third-party) energy applications?*

This chapter synthesises academic literature, expert input, and synthesised insights from the preceding research to propose a coherent set of themes and components that can be used to prioritise applications. The set is designed to cover the decision space that matters for a robust assessment, so that applications can be compared consistently and transparently and based on topics that are considered important and relevant.

The themes and components were selected because they meet requirements that stakeholders and experts consider essential. Within the *Technical* theme, several components focus on safeguarding the *own operation* of the PTO, since uninterrupted service is the primary constraint given which emerges from multiple sources. In addition, components recommended by experts are included because they can alleviate grid congestion or enable faster rollout at scale, see *synthesised insights*. Advice from a *technical expert* was to include in framework components to account for grid impact and the requirement controllability, so that grid impact can be limited in practice.

The *Societal* theme was constructed from the literature review, expert input, and synthesised insights, and is operationalised using *ISO 26000*. The additional synthesised insights are embedded within the ISO-derived components so that the set remains concise and applicable. ISO 26000 provides internationally recognised, principle-based guidance that can be translated into clear scoring components and measurable indicators. Using this guidance keeps the framework practical for PTOs, consistent across cases, and comparable across projects, while avoiding a generic checklist approach.

Some themes and components naturally overlap, therefore there is a limited degree of correspondence between the components and aspects. The ultimate prioritisation framework will sort those out or warn for double counting.

Cost is not scored as a separate theme. First, precise cost and benefit estimates are difficult to establish in advance for diverse applications. Second, cost is already internalised in the *Technical* theme, since options that are only achievable at disproportionate cost will be judged technically infeasible in practice. In other words, very complex and expensive connection options tend to be screened out through technical feasibility, so a separate cost score would add limited decision value. A section on benefits could ultimately be added, but this section has not been included in this thesis, partly because of the difficulty of making any meaningful predictions about the benefits it will yield. Furthermore, to do so, you would need to have a good overview of the costs of an application and the connection, which are not included in this study either.

The proposed themes and components will be discussed with the stakeholders. Their views and perspectives will be used to confirm which components are relevant, testable, and important for inclusion in the ultimate prioritisation framework. For a complete overview of all components per theme, see Table 8.12.

Theme	**Technical**	**Societal**	
Sub-theme		*Social*	*Sustainability*
Components	Grid Impact	Impact within the organisation (PTO)	Prevention of pollution
	Efficiency	Passenger and customer impact	Sustainable resource use
	Scalability	Community and society impact	Climate change mitigation
	Controllability		Protection of the local environment
	Installation and Maintenance		Alignment with development goals
	Relocatability		

Table 8.12: Overview of themes and components used in the provisional prioritisation framework.

9

Stakeholder Perspectives

The interviews and surveys explore which themes and components are most relevant for prioritising applications connected to public transport electricity infrastructure. Building on the preliminary research, they integrate the expertise, perspectives, and objectives of PTOs, municipalities, and provinces/PTAs/PTAs, with the aim of identifying the most salient components for a practical evaluation framework. In addition to the cross-sectoral findings, two stand-alone interviews, with the Municipality of Rotterdam and the Municipality of Arnhem, are presented in greater depth to illuminate recurring challenges faced by municipalities.

Beyond establishing which components are considered important, the interviews and surveys surface where views diverge across departments and stakeholder groups. Such differences are informative, since they reveal areas where consensus is limited and further alignment, or mutual understanding of issues, is required. During the conversations, attention is paid to the reasoning behind stated priorities, drawing on internal knowledge. This enables a comprehensive analysis of which components are regarded as essential within each theme.

9.1. Design and Approach

The interviews are (semi-)structured and partly administered through surveys. Some stakeholders preferred a telephone conversation and explained their preferences verbally. In principle, each interview touches on all three themes, yet two interview categories are distinguished. A *technical interview* targets technical teams within PTOs, and a *societal interview* targets municipalities and provinces/PTAs/PTAs to deepen societal considerations. In both interview types, legal questions are included to probe knowledge and opinions on the legal feasibility of connection approaches and to evaluate understanding of legal complexity. In addition, each interview contains several questions from the other theme to cross-check views and ensure a holistic picture. Within each organisation, the department most closely specialised in the relevant theme is interviewed.

Each interview therefore addresses all three themes, in order to identify similarities and differences both between departments within the same organisation and across organisations. More detailed questions are asked in the interviewee's area of expertise, while the remaining themes are covered in a more general way.

Participants

The technical survey was held with representatives from the technical departments of the Municipality of Arnhem, the Province of Utrecht, and two representatives of GVB. The societal survey was held with representatives from the Municipality of Arnhem and the provinces/PTAs of Gelderland, Utrecht, and South Holland, some of which also operate as PTAs. Participants in both surveys were also asked questions beyond their primary domain, including several questions about legal topics.

In a joint consultation which was focussed on the role of the GVB within Amsterdam, the GVB, Liander (DSO), VRA (PTA) and the Municipality of Amsterdam were present.

The Dutch national regulator, ACM, is not part of the stakeholder interviews. ACM was consulted separately during the *Focused Expert Consultations* to provide elaboration and confirmation on closed systems, non-discrimination, and access.

Objectives

Through interviews and surveys, this study identifies which components stakeholders consider important within the technical and societal themes, assesses their beliefs and knowledge about legal options and feasibility, and maps areas of convergence and divergence among stakeholder groups to pinpoint practical opportunities and highlight where further alignment is needed.

9.2. Themes

9.2.1. Technical

This section reports what stakeholders consider important within the technical theme, how items compare, and why certain aspects matter in practice. Again it should be noted that the results are network dependent, since a priority for one traction power network may be less critical for another. The survey therefore identifies aspects that are widely considered important in general. When a PTO applies the prioritisation framework, it should still verify which themes and components are most relevant for its own network and operational context.

Participants included a policy advisor, a system lead responsible for the electrical traction power supply, an installation responsible tram operations, and a metro project manager.

These stakeholders were deliberately selected because they have the technical knowledge on traction power networks and combine system-level expertise in public transport electricity systems with intimate knowledge of PTO organisational capabilities and current operational challenges, enabling them to assess which components are technically salient and to explain why they matter.

A comprehensive overview of the interview results for the *Technical* theme is provided in the appendix, see *Overview of Survey Results on the Technical Theme*. It sets out which components and aspects stakeholders regarded as most important, and includes concise overviews related to connecting applications to the public transport electricity infrastructure.

Conclusion stakeholders perspective on technical components

Figure 9.1 shows which components stakeholders consider most important to include in the technical theme. *Controllability* is rated most important, followed by *Grid Impact* and *Installation and Maintenance*. *Efficiency*, *Scalability*, and *Relocatability* receive the lowest importance.

This pattern is consistent with earlier findings. Within each specific component section, respondents identified relevant aspects, yet most concerns concentrated on *Controllability*, *Grid Impact*, and *Installation and Maintenance*. Respondents also emphasised that, for *Installation and Maintenance*, external support can effectively provide with installation, operation, and maintenance capacity, which can ease the urgency of that component.

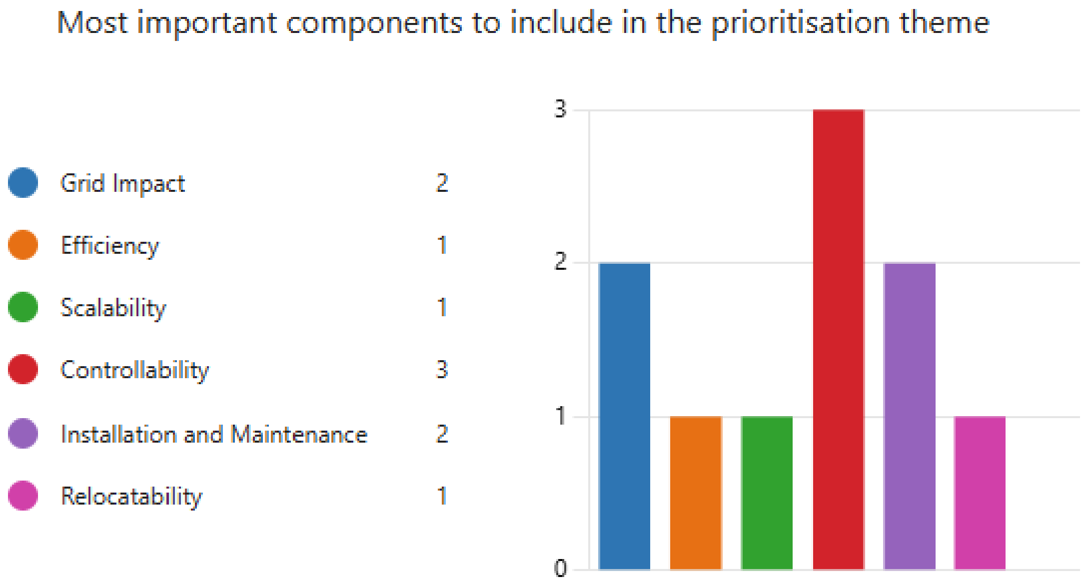


Figure 9.1: Most important technical components to include in the prioritisation theme.

Therefore, the technical prioritisation framework should focus on:

- Components that address *Controllability*, *Grid Impact*, and *Installation and Maintenance*,
- Possibly treating *Efficiency*, *Scalability*, and *Relocatability* as context dependent criteria that should be assessed per network, rather than imposed as general requirements,

- Taking *Controllability* as a primary component, because effective control can shape Grid Impact directly and enable applications to contribute to a more stable, efficient, and robust electricity infrastructure of the PTO (or any other organisation).

9.2.2. Societal

This section reports what stakeholders consider important within the societal theme, how items compare, and why certain aspects matter in practice. As with the technical theme, results are context dependent, municipal priorities and local policy conditions shape what is most salient at each location. The survey therefore identifies societal aspects that are widely considered important in general, with the understanding that for every network it should be verified which components are most relevant in that organisational context, and concession setting.

Participants included a spatial planning advisor, a cluster manager responsible for public transport assets and sustainability, an external consultant on sustainable mobility, and the client and project lead for public transport.

These stakeholders were purposefully drawn from municipalities and the province/PTA because they carry the public mandate for social and environmental outcomes, and therefore are accountable for defining and steering societal objectives. They oversee spatial planning, permitting, public health, equity and environmental standards, and they can align applications with local and regional policy priorities. In many cases they are also shareholders or owners of the PTO, and the electricity infrastructure on which these PTO operates. This gives them both the legitimacy and the instruments to influence concession requirements, funding choices, and long term governance. This combination of societal responsibility, policy authority, and ownership insight makes them the most suitable group to judge which components of the Societal theme matter, how they should be prioritised, and why.

In line with the Societal theme structure developed earlier, societal components are grouped *Social* and *Sustainability* themes and drawed on ISO 26000 guidance and the triple bottom line perspective.

A comprehensive overview of the interview results for the *Societal* theme is provided in the appendix, see *Overview of Survey Results on the Societal Theme*. It sets out which components and aspects stakeholders regarded as most important, and includes concise overviews related to connecting applications to the public transport electricity infrastructure.

Conclusion stakeholders perspective on societal components

Respondents were asked to distribute 10 points between *Social* and *Sustainability* to indicate which they would weight more heavily. Two valid responses were recorded, one response did not sum to 10 and was proportionally rescaled to 10 for analysis. Table 9.1 reports all entries, shows the adjusted values for R3, and includes the averages based on R1, R2 and R3 (adjusted).

Respondent	Social	Sustainability	Sum
R1	3.0	7.0	10
R2	3.0	7.0	10
R3[×]	7.0	8.0	15
R3 (adjusted)[××]	4.7	5.3	10
Average (incl. R3 adjusted)	**3.6**	**6.4**	**10**

Table 9.1: Allocation of importance between Social and Sustainability.
[×]Response does not sum to 10. [××]Proportional rescaling to a total of 10.

Including the adjusted value for R3, the average allocation is *Social* 3.6 and *Sustainability* 6.4. This indicates a consistent preference to weight *Sustainability* more heavily, approximately two-thirds of the total and is therefore considered almost twice as important as the *Social* sub-theme.

Finally, stakeholders were asked to rank the components of the *Social* sub-theme and the *Sustainability* sub-theme from most to least important to incorporate those visions in the framework. Figure 9.2 reports the ranking for the Social components, and Figure 9.3 reports the ranking for the Sustainability components.

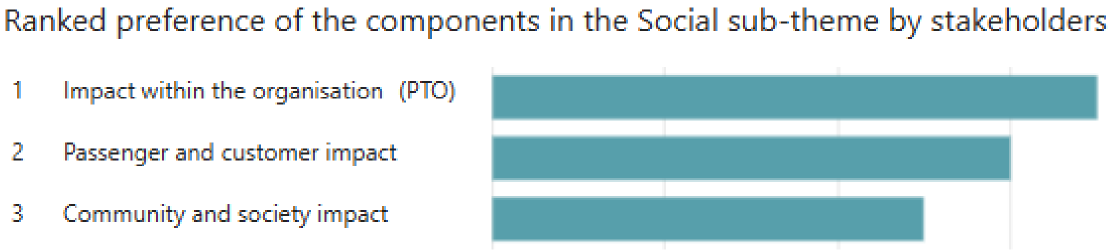


Figure 9.2: Stakeholder ranking of Social sub-theme components, from most to least important.

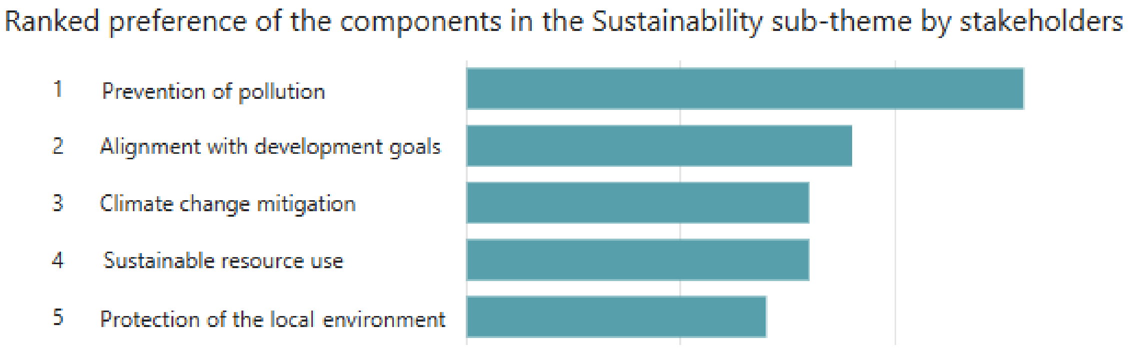


Figure 9.3: Stakeholder ranking of Sustainability sub-theme components, from most to least important.

From the Social ranking it follows that *Impact within the organisation (PTO)* is most important, followed by *Passenger and customer impact*, with *Community and society impact* ranked third. From the Sustainability ranking it follows that *Prevention of pollution* is most important, followed by *Alignment with development goals*, with *Climate change mitigation* and *Sustainable resource use* grouped in the middle, and *Protection of the local environment* ranked lowest.

In general, it should be noted that all components are actually assigned with a certain degree of importance, which is also visible in the specific scores that are given for each aspect in each component, because all of these aspects has been given some importance at least.

Within *Impact within the organisation (PTO)*, respondents highlighted the importance of improving employee safety, reducing occupational exposure to harmful emissions, reducing noise exposure, and employee involvement in decision-making. Involving operational teams is viewed as beneficial because they understand the network, know where needs exist, and can identify what is feasible.

Within *Prevention of pollution*, respondents placed particular emphasis on reducing local air pollution, which will therefore be explicitly incorporated. For *Alignment with development goals*, respondents stressed that applications should contribute to municipal or provincial social and environmental objectives(, these points must, of course, be provided by the municipality or province themselves). Moreover, this is also a very democratic point, these objectives are democratically mandated, set by elected councils or parliament, and should be reflected transparently in the prioritisation process.

Given that stakeholders assign roughly twice as much weight to *Sustainability* as to *Social* in aggregate terms, the framework will reflect this balance while keeping all components in scope, in practice this means emphasizing *Prevention of pollution* within the Sustainability sub-theme and *Impact within the organisation (PTO)* within the Social sub-theme, while incorporating the remaining components with lower default so that they can be adjusted to local context.

Survey responses indicate that, although some components were not ranked among the highest priorities, many stakeholders assigned high importance to specific aspects within those lower-scoring components. To ensure a broadly supported framework, a small set of standalone aspects should therefore be added to the sub-themes. In the *Social* sub-theme, the high-scoring aspects focussed on improving local air or water quality, and prioritising sites where grid congestion is most severe. In the *Sustainability* sub-theme, the high-scoring aspects focussed on improving energy efficiency or enabling additional renewable generation, for example regenerative braking and direct coupling to on-site generation, achieving comparatively large reductions in greenhouse gases CO_2, CH_4, and N_2O, and contributing to sustainable area development.

Therefore, the societal prioritisation framework should focus on:

- Placing greater emphasis on *Sustainability* components than on *Social* components.
- Emphasising the components *Prevention of pollution*, *Alignment with development goals*, and *Impact within the organisation (PTO)*,
- Aspects from these components:
  - *Social*: Improving employee safety, reducing occupational exposure to harmful emissions, reducing noise exposure, and involving employees in decision-making.
  - *Sustainability*: Preventing against the emission of heavy metals, local air and water pollution and contributing to municipal or provincial social and environmental objectives, which are democratically mandated and the contribution to United Nations Sustainable Development Goals (SDGs)
- However, all other components are considered to be important to a certain extent, and so ultimately every PTO or organisation will have to decide whether they consider a specific component important to include them in their framework.
- To broaden support, a few standalone aspects should be added, namely: for the *Social* sub-theme, improving local air or water quality and siting where grid congestion is most severe, and for the *Sustainability* sub-theme, improving energy efficiency or enabling additional renewable generation, achieving comparatively large reductions in greenhouse gases (CO_2, CH_4, N_2O), and contributing to sustainable area development.

9.2.3. Legal

Respondents in both the technical and the societal surveys were asked a set of questions on legal aspects related to connecting applications to the electricity infrastructure of PTOs. These covered awareness of legal possibilities and constraints, expected implications and additional burdens for PTOs or any other organisation, preferred connection methods for applications, and, in case of applying for a Closed System, indicative timelines for getting the recognition. A comprehensive overview of the interview answers to these legal questions is provided in the appendix, see *Overview of Survey Results on the Legal questions*.

Conclusion, stakeholders' perspective on the legal topic

- Technical respondents generally consider a Closed System the most effective route, timelines are viewed as variable, and Cable Pooling is not a primary focus.
- Societal respondents show mixed awareness of legal implications and additional burdens for PTOs, several are following the new Energy Act, and some expect additional workload depending on legal choices.
- In the Societal respondents ranking of preferred applications types, the top six preferred application types that are all feasible via the installation construction.

9.3. Individual Interviews and Joint Consultation

In addition to the cross-sector interviews, two stand-alone interviews and one joint consultation are presented separately. These cases provide a clear view of how stakeholders reason about third-party connections, which principles guide their judgements, where perspectives align or diverge, and what they expect from one another regarding roles, information, and collaboration.

Joint Consultation Amsterdam

In a joint consultation between the Municipality of Amsterdam, GVB, the Vervoerregio Amsterdam (VRA (PTA)), and Liander (DSO), stakeholders discussed perspectives, knowledge, and expectations regarding third-party connections to GVB's electricity infrastructure and the role of the PTO in mitigating grid congestion in and around Amsterdam. The main insights are summarized below.

Profile

Participants included representatives from GVB, the Vervoerregio Amsterdam (VRA), the Municipality of Amsterdam, and Liander (DSO) [106].

A detailed account of this joint consultation, is provided in the appendix, see *Joint Consultation Amsterdam*.

Highlights of the Joint Consultation

- GVB must first secure its own operations through cross-modal optimisation and, where feasible, on-site RES integration; third-party facilitation requires a credible business case.
- Mutual system knowledge is limited; targeted collaboration with Liander is necessary to identify where GVB's network can deliver the highest congestion relief.
- Within the Municipality, expectations differ: some prioritise core PTO operations, others favour a proactive role in enabling additional urban connections and flexible, capacity-limiting contracts.
- Liander discourages filling GVB's consumption troughs with external loads, prefers cooperation on peak shaving, and requests early visibility of GVB's long-term expansion and demand plans.
- VRA expects GVB to prepare its network for potential third-party connections and to support regional operators, for example through shared charging infrastructure.
- Metro infrastructure is the primary candidate for facilitation, given predictability, higher voltages, and prospective 20 kV ring; tram networks are technically and legally less favourable.
- Storing regenerative braking energy in ESS currently lacks a convincing business case; direct feed-in via bidirectional substations is technically feasible.
- Regenerative braking energy can be fed to applications when they are located at the right place in the network, thereby helping to reduce grid congestion and making the PTO system more energy efficient.
- Congestion is a temporary challenge, asset lifetimes are long; prioritisation should balance short-term relief with long-term system robustness.

Municipality of Rotterdam

At the time of the interview, Rotterdam had not yet defined a concrete method for assessing societal benefit, as the Municipality intends to let the city council determine priorities through a democratic process. Nevertheless, the discussion surfaced several noteworthy considerations that inform the broader prioritisation debate, the most important of which are summarised below.

Profile

Interview with a coordinator of the Municipality of Rotterdam working at municipal programme addressing grid congestion [107].

A detailed overview of this consultation have been omitted from the appendices in this public version. These are available from the author upon request.

Highlights of the interview

- Prioritisation of societal benefits is a political choice, to be set through a council-led process with the result of an apolitical and transparent framework.
- The Municipality will not instruct RET on connection decisions; municipal steering is primarily via spatial planning.
- Residual capacity in RET's closed distribution system (GDS) has historically been linked to mobility because of load flexibility and institutional ties, but this is being reconsidered under current congestion.
- Technical feasibility and flexibility are binding constraints; boundary conditions must be defined first, then societal priorities calibrated to what is realistically achievable.
- A coordinating function across actors is missing; the Municipality is temporarily facilitating collaboration with RET, the DSO, and other stakeholders.
- Decisions require visibility on available capacity, which is not yet fully present; RET is the key technical knowledge holder, while the Municipality is building in-house technical and legal capability.

Municipality of Arnhem

Arnhem is a special case: the Municipality is not a shareholder of the locally operating PTO, yet it owns the public transport electricity infrastructure. This separation of ownership and operations, combined with an already awarded concession and a complex stakeholder setting, makes Arnhem a critical case for understanding how governance and coordination shape the prioritisation of third-party connections. For this reason, a longer interview was conducted, and the principal insights, relevant to a practical prioritisation methodology, are summarised below.

Profile

The interview was conducted with a policy advisor from the municipality of Arnhem that is actively involved in energy and mobility policy [108].

A detailed overview of this consultation have been omitted from the appendices in this public version. These are available from the author upon request.

Highlights of the interview

- The stakeholder landscape is complex, the Municipality owns the traction infrastructure but is not a shareholder in the PTO, cooperation of the PTO is voluntary rather than mandatory.
- The primary priority is to safeguard a reliable public transport operation, applications will only be considered once this baseline is secured.
- There is no overview of available room existing energy contracts and therefore not yet clear whether additional applications can be accommodated.
- A clear vision on which applications to connect and where is not yet defined, choices will be developed in consultation with stakeholders.
- Internal capacity is limited at present, in house electrical engineering and legal expertise is being built, the Municipality aims to gain more operational control through metering, monitoring, and EMS.
- Cable pooling has not been taken into consideration, it is viewed as challenging.
- Legal routes considered to date focus on the installation option, a Closed System is judged difficult and likely not realistic at this stage.

9.4. Chapter Conclusion

This section includes the answer to the fifth research question of this research.

> *How do internal, external stakeholders and experts perceive and assess these components, and where do perspectives align or diverge?*

Mutual uncertainties and ambiguities

Across stakeholders there are still substantial uncertainties and ambiguities. Many report to limited or information over available grid capacity, and a general lack of understanding of how one another's systems operate. This results in confusion and missed opportunities. Visions also differ on how the PTO should help and with what, which underscores the need to learn more about each other's systems, to investigate concrete needs, and to develop joint plans. At present, there is no actor that consistently initiates and coordinates this process. The Municipality of Rotterdam is willing to take on such a role, yet it acknowledges that its own knowledge and capacity are not yet sufficient, even though it sees a clear coordinating function for itself.

At present, familiarity is largely limited to Closed Systems and the installation method, because these are the options known from practice. There is insufficient knowledge sharing, which is consistent with the generally low understanding of one another's systems, perspectives, and needs.

Mutual agreements

On the other hand, there is broad agreement on several principles. All agree that PTO operations always have priority. The selection of societal objectives against which applications are assessed should be determined democratically. Stakeholders agree that a technical assessment should be conducted first, after which societal considerations are applied.

Practical recommendation

A practical recommendation follows from these observations. One stakeholder should take a coordinating role and bring the relevant actors to the table, in order to build mutual understanding of each system characteristics, clarify where each system can contribute, research where there is need among stakeholders, and verify capacity availability in advance. This should involve the DSO, and where relevant the TSO, the PTO, the municipality, the province(, and the PTA). The first step is to draft a plan that sets out how the network can contribute, and, if applications are to be connected, to agree on the societal components against which those applications will be scored. Before doing so, it should be clearly explained how the PTO can contribute to alleviating grid congestion, including for example through congestion management, including peak reduction, lower consumption, and flexible contracts, and through the connection of external applications, connecting renewable energy sources. In addition, parties need clearer information about what is possible with PTO systems, in terms of utilising regenerative braking energy and, and which legal routes exist for connecting applications. While this technical scoping proceeds on what to do, where to do it and how to do it, stakeholders should already begin to consider societal prioritisation, so that both tracks align.

Since a metro network is considered more suitable for connecting applications, cable pooling may be of interest for a number of large tram connections to the intake substation, because obtaining closed system recognition is more complex for a tram network.

How do internal and external stakeholders perceive and prioritize these components

The survey results provide concrete guidance for the prioritisation framework. On the technical side, controllability should be included to limit grid impact. Installation and Maintenance is also valued highly. Since external support can reduce pressure on installation, operation, and maintenance capacity, this is treated as case dependent and should be incorporated accordingly.

On the societal side, stakeholders allocate more weight to Sustainability than to Social. Sustainability is regarded as almost twice as important and should be reflected in the theme. Within the Social sub-theme, Impact within the organisation (PTO) ranked highest. This includes improving employee safety, reducing occupational exposure to harmful emissions, reducing noise exposure, and involving employees in decision-making. Within the Sustainability sub-theme, Prevention of pollution ranked highest, followed by Alignment with development goals. This includes preventing against the emission of heavy metals, local air and water pollution and contributing to municipal or provincial social and environmental objectives, which are democratically mandated and the contribution to United Nations Sustainable Development Goals (SDGs).

To ensure a broadly supported framework, a small number of standalone aspects should be added to the sub-themes. Survey responses show that, although the overarching components were not ranked among the highest priorities, many stakeholders assigned high importance to specific aspects. In the *Social* sub-theme, these are the aspects that focus on improving local air or water quality, and prioritising sites where grid congestion is most severe. In the *Sustainability* sub-theme, these are the aspects that focus on improving energy efficiency or enabling additional renewable generation, achieving comparatively large reductions in greenhouse gases CO_2, CH_4, and N_2O, and contributing to sustainable area development.

Stakeholders from municipalities and provinces/PTAs currently prefer applications that can be connected through the installation method. Most stakeholders are aware that a Closed System entails implications and additional burdens for the PTO, yet many still consider it the best route and some believe recognition can be obtained relatively quickly, which is more difficult in practice. This indicates a gap between expectations and implementation experience, and again points to limited knowledge sharing on the complexity of obtaining Closed System recognition.

What to conclude

For now, many parties are not yet in a position to act on third-party connections. Other hurdles must be cleared first, after which the prioritisation of applications can receive more attention. In sum, discussing prioritisation is premature in several cases because shared knowledge of systems is limited, there is no clear overview of where parties can reinforce each other, and there is not yet municipal consensus on how the public transport electricity infrastructure should be used or on which societal components applications should deliver a positive contribution.

Based on the survey outcomes and the synthesised results of all the preceding research, the themes for technical assessment can be formulated and applied in general terms. The societal theme can likewise be formulated from the survey outputs, however it should be regarded as less prescriptive and deliberately open to local, democratic deliberation, since many stakeholders prefer to discuss and define these choices within the municipality. Also, the number of survey responses that informed the societal theme was relatively small, which means the evidence base is not strong enough to support firm, general conclusions. By contrast, the technical theme can be grounded more robustly in expert judgement and academic literature, which allows clearer statements about which components are important to include.

10

Qualitative Analysis

This chapter synthesises gathered knowledge and data from stakeholder interviews, expert consultations, literature, and other sources during the study. Its aim is to analyse these materials to characterise the current system, highlight key problems and clarify ambiguities, and develop the insights needed to answer the updated main research question and the newly formulated research objectives. In addition, the analysis derives an outline for a future prioritisation framework, in the form of a generic set of themes and components that can serve as practical guidance for PTOs and municipalities that wish to connect (third-party) energy applications. These components are formulated at a sufficiently general level so that they can be interpreted and adapted across different public transport electricity infrastructure contexts.

10.1. Analysis of the System

The qualitative analysis is organised around a set of cross-cutting items that emerged from the interviews, expert consultations, and document review. Rather than discussing each data source separately, the chapter brings together converging and diverging perspectives to highlight how the current system functions, where the main bottlenecks arise, and which conditions are most critical for enabling the use of public transport electricity infrastructures to host (third-party) energy applications.

The following subsections present the principal system level topics. First, *silo mentality* and *limited knowledge sharing* describe how fragmented ways of working and learning constrain progress at sector level. Next, *stakeholder involvement* and *case specific considerations* examine how roles, governance settings, and local network characteristics shape what is feasible in practice. Finally, *legal considerations* summarise the main regulatory and contractual issues that influence which options are available in different contexts. Together, these topics provide the basis for the synthesis in the discussion chapter and for the recommendations developed later in the thesis.

Silo mentality

A recurring pattern in both the interviews and practice is that many actors primarily focus on their own problems and seek solutions within their own organisational boundaries, which is described as silo mentality. Knowledge of how other systems work, what potential resides in the assets of other stakeholders, and how parties can support each other is often limited. This results in narrow, actor-specific focus and insufficient collaboration on shared objectives. Therefore, stakeholders should collectively take broader view of the challenges in order to contribute effectively to shared objectives, such as reducing grid congestion through connecting applications to PTO electricity systems.

Silo mentality refers to ways of thinking and working in which departments, disciplines, or organisations reason from their own goals and internal logic, share little information or interests, and consequently make suboptimal choices, progress slowly, and miss system-level benefits. Remedies include integral system architecture, shared objectives, and coordination across boundaries, enabling genuinely system-oriented solutions [109]. This study revealed that, PTOs, DSOs, municipalities, provinces, and PTAs often hold differing views on how to contribute and on what is technically and organisationally possible. Within the Municipality of Rotterdam, for example, coordination has historically clustered within mobility-related departments, while links to other municipal domains and perspectives have been limited. Individual organisations and departments pursue their own priorities and preferred options, even when the core challenges transcend organisational boundaries. By examining the challenges together with the other departments, other solutions with better results might have emerged.

Moreover, substantial analysis is still undertaken by each PTO individually, which limits the emergence of solutions that are sector-wide and scalable, as is recommended by *Interview with a Transition Expert on Public Transport Networks and Grid Congestion* [63]. Although this is gradually changing through initiatives such as *Energy in the PT* (Dutch: *Energie in het OV*) that are committed to making smart use of the public transport electricity infrastructure in order to resolve grid congestion [110] and the *Grid congestion & PT* which is a knowledge programme (Dutch: *Netcongestie & OV*) under TKI Urban Energy [111], a broader and more actively and integrated perspective remains necessary.

Toering, De Bruijne, and Veeneman [112] observes a pattern in the energy–mobility domain, where historically rooted divisions of domains and mandates lead to siloed decision-making and slower realisation of synergies. The study describes how the initiative to use a metro network of RET for public charging challenged existing role divisions, how persistent silo mentalities resurfaced in discussions, and how progress requires shared goals, informal networks, and new forms of coordination.

Even though this silo mentality was addressed by Toering in the RET case, it still remains present as can be demonstrated in the joint consultation with stakeholders in the Amsterdam case, it was shown that the interests and knowledge differ. DSOs emphasise early clarity on expected load profiles and collaboration on peak shaving, whereas PTOs are interested, for example, in using their available capacity to connect applications and in supplying braking energy to third parties. As Farhangi [109] argues, actors tend to redefine problems within their silos in ways that favour their own technologies, which obscures integral choices. Despite being pointed out by Toering, no lessons have yet been learned in the sector, meaning that a great deal of potential is being lost and parties are again not obtaining the highest potential.

To make a meaningful contribution to relieving grid congestion, silo mentality needs to be overcome. Farhangi [109] argues that optimisation per layer should be avoided, system goals should be central, and governance should be organised across sectoral boundaries, with shared objectives and joint decision-making. Toering, De Bruijne, and Veeneman [112] similarly explains that harnessing synergies requires integrated thinking and sufficient space for joint goal-setting across sectors, supported by sustained collaborative processes, informal cooperation, and clear role agreements.

Limited knowledge sharing

Limited knowledge sharing reinforces siloed practices. Organisations observe what others do, yet frequently adopt isolated elements without maintaining an overview of alternatives or investigating broader possibilities. Current attention has concentrated on two legal–technical constructs, Closed Systems and the Installation Method, largely because RET and HTM offer concrete examples. This has unintentionally narrowed the search space. While case learning is valuable and re-inventing the wheel should be avoided, solutions should not be steered by a small set of high-profile cases.

Sector-wide learning should combine practical experience from earlier pilots with new, relevant knowledge and options, and should consider what is optimal for the specific system at hand. Joint knowledge teams that span organisations, departments, and disciplines can help develop generic, sector-wide solutions that remain sensitive to local case specifics. The aforementioned initiatives, *Energie in het OV* and *Netcongestie & OV*, can support this function.

Stakeholder involvement

Interviews and the stakeholder surveys indicate that stakeholders are not yet consistently aligned on how to use a PTO's network, which parties should be involved at which stage, and what each party can or cannot contribute. To develop sector wide solutions, and avoid siloed decision-making, both the timing and the scope of stakeholder involvement require recalibration. A clear overview of stakeholders, their roles, their points of influence, and their expected contributions is needed to prioritise applications effectively and to identify how a PTO can most usefully help relieve grid congestion. Figure 10.1 presents this overview.

DSOs should be engaged early to examine how the public transport electricity infrastructure could contribute, to identify where the public network, distribution grid and transmission grid, has sufficient capacity, and, where relevant, to express for the TSO. Early coordination with the ACM is also advisable, focused on specific legal questions about how different application types might be connected. The ACM can clarify interpretations and, where justified, assess and grant exemptions, however it should not be embedded throughout the entire process as a participant. Day to day involvement of the national government is neither required and limited as well, since legal changes and exemptions follow formal procedures and are rather discussed with the ACM.

This study identifies a material difference between privately operated PTOs (private PTOs) and PTOs in which the municipality holds shares (public PTOs). In both cases, the municipality typically owns the traction power infrastructure, but under private PTO arrangements the PTO usually holds the energy contracts and controls access to operational data. This significantly limits municipal insight into consumption profiles and available connection capacity. Public PTOs, by contrast, are more directly aligned with municipal objectives, tend to adopt a broader societal perspective, and are more willing to cooperate in using their networks to help relieve grid congestion, especially where they hold a long term, directly awarded concession. Private PTOs, however, bear greater commercial risk because they operate entirely on their own account: although they may be willing in principle to cooperate, they are less inclined to take on additional risk or jeopardise their core business.

At the same time, municipalities cannot simply instruct even a public PTO to cooperate. In practice, steering takes place primarily through the concession contract rather than through ownership, and if cooperation on connecting (third-party) energy applications or sharing data is not explicitly embedded in the concession, both public and private PTOs retain the right to refuse. In tendered concessions with private PTOs this is particularly strict: if collaboration on grid congestion is not specified, it is unlikely to occur. This has two implications. First, future concession contracts need to explicitly require collaboration on data sharing and on facilitating (third-party) connections if the PTO network is expected to contribute to reducing grid congestion. Alternatively, the concession can stipulate that the municipality, rather than the PTO, holds the energy contracts and the associated rights to data access and metering. Second, if the municipality is neither the network operator nor the holder of the energy contracts, both public and private PTOs can still treat it as an external party with respect to the network: the actor that holds the energy contracts decides who can connect, and municipal projects should pass through the same prioritisation framework as other applicants, even where the municipality is also the infrastructure owner or a PTO shareholder.

PTAs must be involved in both settings, since they set concession requirements and should be included in decision-making. Once concession conditions are clarified, more implementation steps become feasible. PTAs may naturally prioritise regional public transport objectives and coordination across operators, which can introduce preferences that need to be balanced against network and societal objectives.

Effective collaboration, therefore centres on structured consultation between the DSO, the PTO, private or public, the PTA, and the municipality, public or operating alongside a private PTO. Additional actors contribute in line with their roles. PTAs can refine concession requirements. Provinces/PTAs and municipalities can support business case development and funding. Owners of prospective applications can pre-assess compliance with preconditions. The ACM and the national government can adjust rules or grant exemptions where justified. DSOs and the TSO can provide new contractual instruments or technical support where feasible.

Early in the process, the central role of DSOs was not always recognised at its full importance, and the ACM clarified that, while it can address specific questions, PTOs and other organisations must conduct their own legal analysis and submit their own applications. Figure 10.1 summarises each stakeholder's expected impact and the appropriate level of involvement across the process, and, where applicable, contrasts currently experienced positions with the positions required to achieve the best outcomes for using the electricity system to reduce grid congestion.

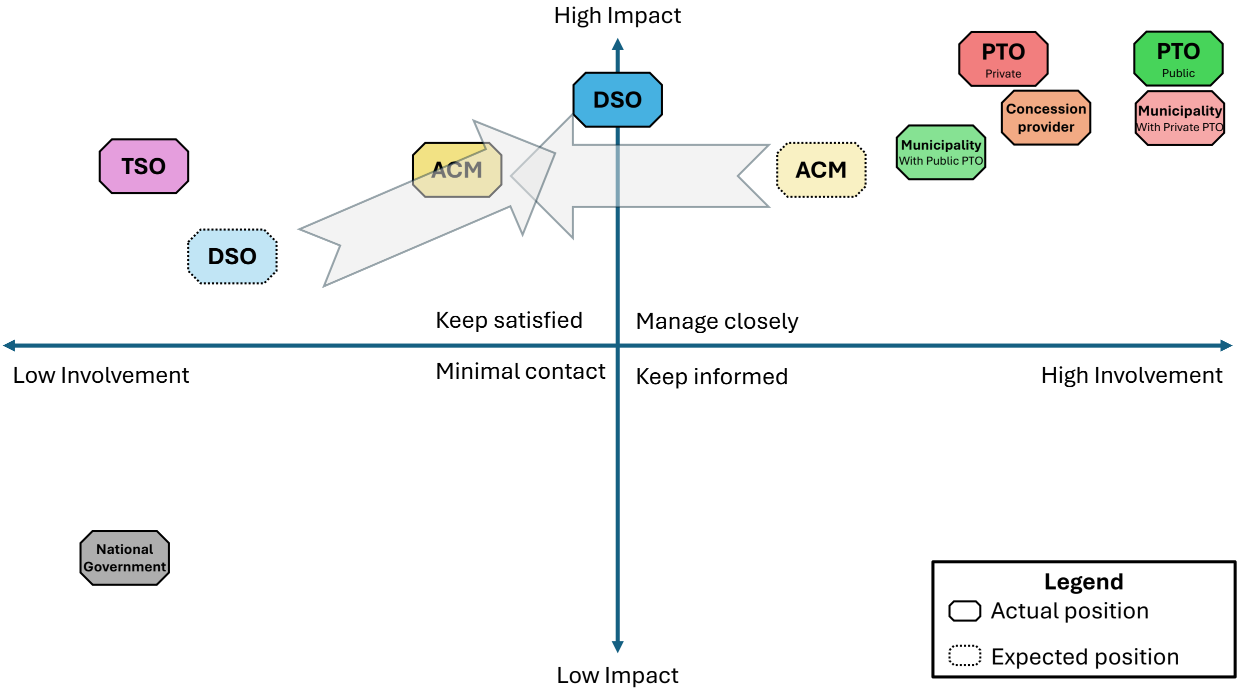


Figure 10.1: A schematic overview of the impact and involvement of the stakeholders
This schematic positions key stakeholders along two axes, impact on decisions to allocate, prioritise, and select applications for connection to the electricity infrastructure, and the degree of involvement appropriate in those decisions. The figure also contrasts for some stakeholders the current experienced position with the position required to obtain the best outcomes for using the electricity system to reduce grid congestion.

Case-specific considerations

Despite the need for sector-wide coordination, prioritisation energy application require also a case-specific assessment. Relevant factors include the technical characteristics of the network and rolling stock, service frequency. The governance structure of the stakeholders and local objectives. And to conclude, location-specific conditions, as well as what is desired from the DSOs and TSO perspective of what is needed at the prospective connection location/area.

The stakeholders can assign importance to the various components themselves in order to develop a framework that is tailored to their values, objectives, network and situation.

Legal considerations

To emphasise it once again, it was highlighted in the surveys that the current practice places disproportionate emphasis on connecting energy applications via Closed Systems or the Installation Method. Other options may also be feasible, sometimes with fewer complexities, and organisations could also contribute with relieving grid congestion with connecting applications.

The different legal issues remain complex. Options differ, each with their own challenges, and each network requires specific assessment to determine what is permitted by the ACM. Network-specific characteristics complicate both decision-making and applications, and lessons from the RET and HTM cases are not yet widely transferable. The dissemination of lessons learned remains limited, although *Energie in het OV* and *Netcongestie & OV* can support broader sharing. Some stakeholders are still encountering first-of-a-kind issues. The new Energy Act is expected to simplify options (Cable Pooling) to connect (third-party) energy applications, however, transitions to a new legal framework can temporarily increase complexity for stakeholders.

Finally, it appears advantageous for municipalities and provinces, as infrastructure owners, to hold the electricity supply and grid contracts with the DSO or TSO themselves. This can widen the set of options for using the network to relieve congestion, improve visibility of possibilities, and reduce dependency on private PTOs that might otherwise control those contracts. Because the municipality of Arnhem, without having the energy contracts themselves, is now demonstrating that they have little influence to connect applications and that they do not have an overview of the usage on the network.

Legal should not be included as a theme
Legal considerations should not be included as a separate theme in the prioritisation framework, because it is generally unwise to reject an application upfront on legal grounds alone. Ultimately, each organisation must assess what is legally feasible in its specific context, and avoid pursuing options that are unrealistic due to disproportionate time and cost, limited in-house legal capacity, or unacceptable risks to core public transport operations. In addition, the framework aims to prioritise applications with strong societal value and a positive (or minimally negative) technical contribution. If legal feasibility were treated as a scoring theme, it could unintentionally steer choices away from these core priorities, even though legal arrangements are often easier to adapt at the organisational level than technical system constraints.

There are also practical reasons to avoid detailed legal scoring. Legal feasibility is highly case-specific and can be qualitative in nature. For example, the difficulty of becoming (or acting as) an operator under a specific legal status, such as a closed distribution system, differs substantially per organisation. Moreover, the regulatory landscape is evolving, which means that legal criteria defined today may become outdated. For these reasons, it is more robust to develop a decision tree that helps organisations identify, at a high level, the simplest legal pathway for connecting third-party applications to their system.

Legal should therefore not be treated as a property of the application type that determines its priority, but as an enabling tool to make a connection legally possible. In practice, the highest-scoring application under the framework should be pursued first. If that application cannot be connected under the legal construct currently applicable to the system, it should be skipped and the next highest-scoring application should be considered. If multiple top-ranked applications prove legally infeasible, an organisation may then consider whether an alternative legal construct is justified to enable the intended connections.

That said, interviews suggest that provinces and municipalities often prefer applications that can be connected via the Installation Method, as this is typically the simplest route in terms of permitting, involves the least contractual burden, and provides the organisation with the highest degree of control.

In the following section, the collected data and information from the stakeholder interviews, expert consultations, literature are analysed to develop recommendations that will form the outline for a future prioritisation framework.

10.2. Analysis for the Outline of a Future Prioritisation Framework

This section develops the outline for the prioritisation framework, comprising a technical theme and a societal theme with social and sustainability sub-themes. Drawn on the literature, stakeholder and expert input, and other insights, gained throughout this research.

The outline for the framework is designed to be general and transparent. It does not prescribe specific scoring criteria or weights, instead it offers guidance on how topics could be scored. The aspects to assess, and the scales and weights to apply, should be determined by stakeholders, since these depend on their context and objectives. Further research should develop robust procedures for assigning scores to applications. The guidance here is intended to support that process.

When stakeholders define the scoring, they can align the outline with their design choices. For example, a stakeholder that values applications with a positive impact on network stability could specify that the controllability score is positive only if the application can support stability by feeding electricity back to the grid. If that capability is absent, the score becomes negative in proportion to other controllability characteristics. Other stakeholders may be less concerned with stability contributions, and may adopt a strictly non-negative scheme that only awards points for desired features without deducting points for features the application does not possess.

10.2.1. Technical Theme

A close reading of stakeholder perspectives, along with insights from expert consultations, reveals patterns that shape the outline. Experts and stakeholders emphasised that it is important to limit the grid impact, which can be achieved by controllable applications and the right siting of an application and its connection point.

Stakeholders also stressed installation and maintenance as a priority, while assigning comparatively less importance to efficiency, scalability, and relocatability.

The main prioritisation framework should comprise two core components within the technical theme. Grid impact is represented by two distinct components, *Controllability* and the *Effective Load Coefficient* (ELC), with the ELC also covering the efficiency component.

In addition, *Installation and maintenance* and *Scalability* are developed as supplementary components alongside the main framework. These are either case specific, and therefore not generally applicable to all PTOs, or were assigned lower importance by stakeholders. For that reason, they are formulated as additions rather than as elements of the general framework. *Relocatability* received little emphasis from both experts and stakeholders, therefore it is not further developed.

Within this theme, there are several aspects that have similarities, so when applying or establishing the prioritisation framework, care must be taken to ensure that certain aspects are not included twice.

Controllability

Controllability concerns the ability to operate without causing unacceptable voltage deviations or exceeding maximum long-term line currents, thereby preserving stable network conditions. It is thus a measure to prevent against adverse grid impact. It is also valuable because some applications can improve host-network stability and therefore ensure that PTO operations can be effectively executed, for example by providing storage or controlling the supply of RES. Both the literature and stakeholder input identify controllability and grid impact as a key component.

Analysis that accounts for the component

The literature (read: *Relevant Information for Themes Development*), underscores the importance of limiting grid impact and rewarding controllability in the outline. The component should focus on whether the application maintains voltage within acceptable bounds, avoids exceeding maximum long-term load current, and does not create excessive transmission losses due to high current, long electrical distances, or unsuitable connection points, since these conditions depress voltages and harm operations. Transmission losses follow $P_{\text{loss}} = I^2R$. These three constraints can have severe adverse operational effects and these constraints are generic across traction power networks and other networks, which makes this component widely applicable. The literature further suggests measures to mitigate these constraints via network design. Depending on network characteristics, some aspects may already be less critical. In general, bilateral connections, an additional parallel OHL, or local energy storage are often recommended, see *Synthesis of insights and solutions for the three constraints*. Because siting and connection-type losses are not governed by an application's controllability, they are addressed separately under the effective load coefficient (ELC). Finally, where renewable generation such as PV and wind is connected, controllability also helps to reduce curtailment.

Experts and stakeholders also highlighted controllability as a central component to minimising grid impact and noted that local storage can contribute to network stability. Stakeholders from municipalities and provinces stressed that PTO operations must never be compromised, which reinforces the need for controllable applications.

Explanation of the component

Controllability is the capability of an application to modulate its import from, or export to, the host network in real time so that voltage and line currents remain within acceptable limits. The objective is to keep the network stable, limit adverse grid impact, and to ensure that PTO operations are never compromised.

Control can be executed by the application itself or via an energy management system (EMS). For best performance, the EMS of the application should interface with the public transport electricity infrastructure EMS, so that setpoints account for accelerating, braking, or passing vehicles and other real-time operating conditions.

Table 10.1 summarises the aspects that determine controllability.

Aspect	Aspect description
Flexible power limits	Ability to operate across a wide setpoint range, including very low or zero power when needed, while still meeting functional requirements.
Load-shifting capability	Ability to shift energy use across time windows while meeting functional needs.
Rate of change of power	Ability to ramp up or ramp down quickly and stably in response to network conditions.
Feeding capability	Ability to export power to the host network in a controlled manner, including bi-directional operation where applicable.
Storage capacity	Presence of internal storage or pairing with storage to decouple power from energy and support stability; examples include stand-alone ESS, EVs with V2G capabilities, and applications with internal storage.
Interruptibility and curtailment tolerance	Ability to be reduced or switched off without prior notice and to resume normal operation safely, in contrast to non-interruptible loads with strict quality-of-service requirements.
Robustness to electrical disturbances	Tolerance to voltage deviations and other electrical events without damage or malfunction.

Table 10.1: Technical component: Aspects that might determine Controllability

Operational interpretation

High controllability enables tighter control of power flows, fewer voltage deviations, lower line currents, reduced thermal stress on feeders and substations, and lower losses. It increases the number of applications that can be connected within existing capacity and keeps any curtailment minimal and predictable. Low controllability and non-shiftable demand create fixed loads that are difficult to accommodate during traction peaks, increasing the likelihood of curtailment for transport operations. Non-interruptible applications reduce system flexibility and may force reinforcements or limit additional connections. Storage can be beneficial when well controlled, however poorly managed storage can create new peaks, so controllability and quality-of-service constraints remain decisive.

Example of a controllable application

A *fleet-aware smart charging* application receives real-time information from the supplying substation and from vehicles on the same section. As a smart application, it regulate its charging speed (off-take) or feed-in (V2G), so that it will not violate grid limits anywhere on the line. It can ramp up, hold, reduce, feed-in, or disconnect as needed, which makes it a highly controllable application, see Figure 10.2.

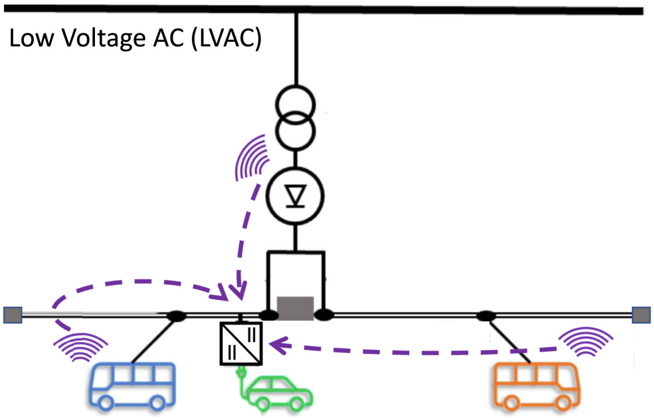


Figure 10.2: Illustration of Fleet Aware Smart Charging [80]

How can it be scored?

An application can be scored on multiple requirements, allowing its controllability to be measured. Bonus points may be awarded if the application contributes positively to grid stability, for example by using storage or by feeding electricity back to the grid, when that will stabilize the grid again. The specific scoring approach and weights should be determined by the relevant stakeholders. Table 10.2 summarises suggested scoring aspects.

Potential scoring aspect	Scoring guidance
Setpoint range	Wider controllable range, including operation at very low or zero power when needed, may score higher.
Ramp performance	Faster and stable ramping in both directions, may score higher.
Grid-aware control	EMS integration with real-time coordination with the host-network to manage loading and voltage, may score higher.
Feeding	Ability to feed electricity to the host-network in a controlled manner to stabilise the network, may score higher.
Bi-directional control	Capability to both import and export power to support stability, may score higher.
Shiftability	Ability to shift required energy use over time without missing functional needs, may score higher.
Interruptibility	Tolerance to unexpected curtailment with quick and safe recovery, may score higher.
Storage contribution	Effective use of storage to stabilise the host-network, or to maintain essential service when curtailed, may score higher.
Curtailability	Applications with the tolerance to unexpected curtail without damaging (and having the ability to resume nominal operation autonomously), may score higher.

Table 10.2: Technical component: Suggested scoring aspects for the Controllability

Nuances

Controllability must be interpreted in context. Low controllability should not automatically exclude an application if its operation is confined to periods when the traction power network is inactive or lightly loaded. For example, if the application only requires power at night, the network impact is negligible, since it will not endanger the operation of the PTO. In those cases a low controllability score may be acceptable and the application should not be rejected on controllability alone.

Effective Load Coefficient (ELC)

The Effective Load Coefficient (ELC) is a component that mainly concerns the losses and benefits of a particular type of application or connection. It captures efficiency and the influence of siting and the connection type. It assesses how energy-efficient the application and the overall system become when the application is connected. The intention is to minimise avoidable losses due to siting (electrical distance) and unfavourable connection points, and to prioritise cases where losses decrease or the system is made more efficient, for example by capturing otherwise dissipated braking energy.

Transmission losses are emphasised in the literature as an important component. Although stakeholders tend to rate efficiency as less critical than controllability, the weight of evidence supports inclusion of the ELC to reflect how efficiently the system can operate with the application connected.

Analysis that accounts for the component

The literature indicates that electrically well-sited applications that can act as receptive sinks are technically preferable, and that modest storage within applications can improve energy utilisation. Benefits are context dependent, with the highest gains when headways are long or traffic is sparse. Line receptivity matters, and DC-side controlled loads can be most efficient. Because storage presence is already recognised under controllability, it is not double-counted here.

The technical expert (read: *the interview*), emphasised the importance of siting (location) and connection type both influence grid impact and efficiency. Correct siting and connection can reduce voltage drops that would otherwise raise current and increase energy losses and would therefore have a negative grid impact. That is why the ELC also partly includes the component grid impact, as it can be exacerbated by connecting at unsuitable points, for example, on the overhead line (OHL) instead of the AC switchboard in a traction substation, or at unsuitable locations in the system, for example, where loads are already high or where the connection to the OHL is far from the substation. Therefore, it is desirable to include this component to minimise the grid impact and score applications that improve the energy efficiency of the system. Furthermore, efficient energy use can be linked to the overarching objective of relieving grid congestion, since avoiding losses and improving utilisation indirectly reduce strain on the public grid.

The interview (read: *the interview*) with the technical expert also corroborate the practical trade-offs between AC and DC connections. For AC applications, connecting on the substation AC-side, for example via an auxiliary transformer, is typically the simplest and most robust approach, reducing DC-side voltage fluctuations and simplifying protection and interfacing. Direct DC connections to the catenary are feasible and attractive when the application itself is DC and when easy access to the existing OHL avoids new cabling. DC-side connections must, however, account for larger voltage variations and traction induced disturbances. Any prospective benefit from harvesting regenerative energy needs to be weighed against added conversion complexity and control requirements, since practical gains may be modest for many AC loads.

Explanation of the component
The ELC is a dimensionless indicator that expresses how advantageous a specific connection option is by combining (recoverable) local DC energy (injections) and incremental losses into a single efficiency indicator. The objective is to prefer connections that make better use of locally available energy while keeping avoidable losses low, and also minimise the grid impact with unfavourable connections. Furthermore, when the application increases receptivity to regenerative braking, the network can be used more efficient and makes a connection more favourable.

Table 10.3 summarises the aspects included in the ELC.

Aspect	Aspect description
Connection point	The point where the application connects to the system, for example the OHL on the DC-side, a DC switchboard, or an auxiliary transformer on the AC-side at the substation. The need to convert to the application's native current type influences conversion losses and therefore the ELC.
Connection location and distance constraints	The electrical distance to substations, that is, the position on the traction power network, and the physical distance from the point of connection to the application. Together these determine voltage drop and resistive losses, which is mainly relevant for connections on the DC-side.

Table 10.3: Technical component: Aspects included in the Effective Load Coefficient (ELC)

Transmission losses are resistive and location dependent losses incurred along the chosen route from source to application. They arise on DC feeders and return conductors between substations and the connection point, and on any downstream service cables from the connection point to the application. They scale with current and electrical distance, and can be approximated from the load profile with associated voltage drop. For AC connections within the traction power network, incremental transmission losses to the application are usually small, although downstream service cable losses still apply. For DC-side connections, section resistance and position on the network are typically more influential, because additional voltage drop raises I^2R losses and can limit usable recuperation. Conversion losses are losses in power electronic and transformer interfaces required by the connection type. They include rectifier, inverter, and DC/DC stage inefficiencies, as well as auxiliary and standby consumption. They depend on direction of power flow and operating point. Unidirectional rectifiers on AC only interfaces preclude direct use of DC-side energy, whereas bidirectional converters enable it but incur efficiency penalties for both import and export.

Where converters feeding the DC traction power network from the AC switchboard are unidirectional, using DC-side energy locally can be beneficial, whereas exporting surplus back to AC may require additional bidirectional equipment. If bidirectional converters are present, DC-side energy may also be accessible from the AC-side, which shifts the relative attractiveness towards AC connections. The ELC is therefore location and context dependent, and periodic reassessment is necessary when connection points, voltage levels, headways, timetables, renewable injections, or the set of connected applications change.

Operational interpretation
The indicator evaluates whether, for a given configuration, the usable benefits of accessing DC-side recuperation and other local DC injections (from RES) exceed the incremental distribution and conversion losses introduced by the chosen connection point and interface. Location on the DC network, distance to the substation, conductor sizing, and the run from the point of connection to the application determine voltage drop and therefore losses. If conversion to a non-native form is required, include those losses explicitly in the ELC. A convenient expression

is

$$\text{ELC} = 1 + \underbrace{\frac{\text{recoverable DC energy}}{\text{delivered energy}}}_{\text{benefit}} - \underbrace{\frac{(\text{distribution losses} + \text{conversion losses})}{\text{delivered energy}}}_{\text{losses}}$$

Definitions:

- *Recoverable DC energy*: Electricity supplied to the application that originates from regenerative braking on the same DC section or other local DC injections.
- *Distribution losses*: Resistive, location-dependent losses along the route from source to application, driven by electrical distance on DC feeders and return conductors, and by downstream service cables from the point of connection to the application.
- *Conversion losses*: Losses in power-electronic or transformer interfaces required to convert between the chosen connection side and the application's native form (rectification, inversion, DC/DC), including auxiliary and standby consumption.
- *Delivered energy*: The energy delivered to the application at its point of use over the assessment horizon (including the application's own consumption).

Interpretation:

- ELC > 1: Favourable — the system operates more efficiently with the application connected.
- ELC ≈ 1: Neutral — the application neither improves nor degrades system efficiency.
- ELC < 1: Unfavourable — additional distribution and conversion losses outweigh usable recovered energy, reducing overall efficiency.

How can it be scored?
Applications can be scored directly using the calculated ELC by, for example, awarding higher points to configurations with higher ELC values and applying neutral or decreasing points as the ELC approaches 1. Stakeholders may set a penalty regime for values well below 1 and may define a rejection threshold, for example for ELC ≤ 0.

Where a quantitative estimate is not desired, feasible, or hard to determine, Table 10.4 provides also qualitative scoring aspects. Specific scales and weights should be set by stakeholders.

Potential scoring aspect	Scoring guidance
Preferred connection point	Use of PTO-preferred connection points or interfaces, for example where physical space, access, and protection coordination are already available, may score higher.
Future recuperation and injections	Locations where substantial regenerative braking energy or local DC injections are expected in the near term, may score higher, or vice versa.
Connection point practicality (Optional)	If the framework does not include the *Installation and Maintenance* component, connection points that are easier to install, operate, and maintain, may score higher.
RES converter path efficiency	If PV or wind generation is injected, compare feeding on the AC-side versus injecting on the DC-side, taking into account connected applications and PTO operations; score the more efficient route higher.
Increasing receptivity	If the application increases the increasing receptivity to regenerative braking, it may score higher.

Table 10.4: Technical component: Suggested scoring approaches for the Effective Load Coefficient (ELC)

Connection points that are intrinsically difficult to realise, should actually be scored under the *Installation and Maintenance* component, however, when that component is not included in the framework, it could be scored within this component.

Additional note: The law also stipulates that, read *disproportionate modifications*, when a PTO holds Closed System recognition, it is not obliged to undertake complex or costly technical modifications to connect an application that, in its current form, could not ordinarily be connected. If such modifications would be required merely to obtain a favourable ELC score, the application may be screened out ex ante as unsuitable for connection and need not be pursued.

Additional Technical Components

These components are additional and case-specific; their relevance depends on the organisation and location. Therefore, organisations must decide for themselves whether they want to incorporate these components. Some aspects across these components may overlap, this is intentional because the components are optional. Including the overlapping aspects here provides a safety net, ensuring they are still considered if stakeholders decide not to include the other component(s) in the prioritisation framework.

Installation and Maintenance

Installation and maintenance concerns the practical feasibility of installing, operating, and maintaining the application within the PTO's asset management and operational regime, including available budget and staffing capacity, and its practical integration into day-to-day operations. The objective is to assess the effort, burden, and obligations that the application places on the PTO. The importance of this component depends on internal capacity, the specific challenges stakeholders face, and the financial resources available to procure external capacity or expertise for installation and maintenance.

Stakeholders consistently identified installation and maintenance as relevant.

Analysis that accounts for the component
Given stakeholder emphasis, this component is included as an additional, case-dependent dimension. PTOs are ultimately responsible for assets connected to their networks, therefore practical considerations about installation, operations, repair work, and maintenance should be reflected, even if the literature and experts attached less weight to this component.

Explanation of the component
Installation and maintenance concerns the practical feasibility of installing, operating, maintaining, and, where applicable, relocating the application within the PTO's asset management and operations regime, including available budget and workforce capacity. The objective is to score the effort, burden, and obligations that the application imposes on the PTO.

A heavier burden reduces the focus and resources available to safeguard transport operations or to connect additional applications. Conversely, simpler, well-integrated solutions that match existing staff skills and use common spare parts reduce risk and recurring cost, and are easier to sustain over time.

Some aspects in this section may partially overlap with those in other components of the *technical* and *societal* themes, however they are included here for clarity and completeness. Table 10.5 summarises the aspects to assess.

Aspect	Aspect description
Required adaptations at the point of connection	Need for additional converters, transformers, metering, protection coordination upgrades, or control integration, and whether an AC or DC connection or PAP or SAP connection is preferable from a practical viewpoint.
Constructibility and access	Space availability, cable routing, civil works, and safe access for installation and maintenance.
Outage needs and sequencing	Duration and timing of planned outages on the host network to install, maintain, or repair the application and its connection, and coordination with transport operations.
Spare parts commonality	Similarity of connection and application spare parts to the host network's standard components, enabling faster restoration and familiar installation methods.
Temporary disconnection	Ease of isolating the application during PTO maintenance, repairs, or upgrades, and the application's tolerance to being disconnected for a period.
Maintainability and repair work	Required periodic maintenance, inspection intervals, fault response, typical repair tasks, and the skills needed in-house or via external contractors.
Internal capacity	Availability of PTO staff, tools, and processes to install, operate, maintain, repair, or relocate the application, or the financial capacity to outsource these tasks.
Contractual burden	Service levels, metering, data overviews, and other contractual obligations that place demands on the PTO.
Safety implications	Implications for extra safety systems.
Protection settings and coordination	Impact on protection settings and the effort required to coordinate them with the host network.

Table 10.5: Technical component: Aspects that might determine Installation and Maintenance

How can it be scored?

Applications can be scored across multiple topics. Ultimately, the PTO or network operator should determine which topics are most relevant in their context and assign their relative importance. Specific scales and weights should be set by stakeholders. Table 10.6 summarises suggested scoring aspects.

Potential scoring aspect	Scoring guidance
Scope of adaptations	Fewer and simpler adaptations at the point of connection, or SAP over PAP, may score higher.
Constructibility and access	Clear cable routes, adequate space, and minimal civil works, may score higher.
Outage exposure	Ability to implement or repair without interrupting the host network, may score higher.
Integration and operation	Straightforward metering, control integration, contract formulation, and maintenance procedures, may score higher.
Spare parts commonality	Use of host standard components, may score higher.
Maintainability and repairability	Predictable maintenance, simple procedures, and short downtime to repair, may score higher.
Internal capacity	Ability to use in-house skilled staff and tools, reducing reliance on external capacity, may score higher.
Safety implications	The need for extra (new) safety systems or the alignment with existing safety systems, may score higher.
Temporary disconnection	Applications that allow temporary disconnection during public transport electricity infrastructure maintenance, may score higher.
Contractor availability	High availability of qualified contractors with strong service support, may score higher.

Table 10.6: Technical component: Suggested scoring aspects for the Installation and Maintenance

Additional note: When PTOs or other organisations apply a framework, they should ensure that aspects do not overlap with aspects across components, to avoid double scoring.

Scalability

This component is case specific and should be included only if decision-makers consider it relevant. Scalability concerns the extent to which an application or connection can be expanded in phases and replicated across multiple locations, and the extent to which knowledge is created and shared so that other PTOs or organisations can accelerate similar connections on their networks. It can also be implicated as a Societal component, since it also included aspects which will benefit the society in general.

Analysis that accounts for the component

In an exploratory consultation (read: 3.3), an expert suggested that scalability should be prioritised across both applications and methods when quick, large-scale impact is desired. Stakeholders, however, generally viewed it as less central for prioritisation. According to the stakeholders, applications with a straightforward, replicable implementation path that deliver clear, demonstrable benefits should be prioritised. Design, construction, operation and maintenance should be as uniform as possible, since uniformity reduces cost and complexity and accelerates rollout.

In an exploratory consultation (read: 3.3), an expert suggested prioritising scalability across both applications and methods when rapid, large scale impact is desired. Stakeholders generally considered it less critical, yet indicated that applications with straightforward, replicable implementation paths and clear, demonstrable benefits are preferable. Design, construction, operations, and maintenance should be as uniform as practicable, since uniformity reduces cost and complexity and accelerates rollout.

Explanation of the component

Scalability is the extent to which an application or connection can be expanded in phases and replicated across sites without disproportionate additional works. The objective is to enable faster roll-out where many instances are desirable, while keeping engineering effort, delivery time, and operational burden manageable. Whether this is important depends on stakeholder priorities. The emphasis in the component reflects expert advice that sector-wide deployment benefits from solutions and methods that can be repeated efficiently.

Because scalability can overlap with other aspects within the *technical* and *societal* themes, care should be taken to avoid double counting when this component is included. Table 10.7 summarises the aspects to assess.

Aspect	Aspect description
Replicability	Applicability across multiple networks or locations within the same network, including across different network types, with limited redesign.
Expansion	Ability to scale power or the number of units with minimal rework to connections, protections, and controls.
Standardisation	Use of standard designs, common spare parts, and consistent connection, operations, and maintenance procedures that existing teams and tools can execute.
Supply chain readiness	Availability of components and qualified contractors at the required scale and lead times.
Learning and sharing	Contribution to documented procedures, templates, and knowledge sharing that other PTOs or organisations can adopt.

Table 10.7: Technical component: Aspects that might determine Scalability

How can it be scored?

Applications can be scored across multiple topics. The PTO or network operator should determine which topics are most relevant in their context and assign their relative importance. Specific scales and weights should be set by stakeholders. Table 10.8 summarises suggested scoring aspects.

Potential scoring aspect	Scoring guidance
Ease of replication	Applications that can be connected at other sites and on other networks with limited redesign, may score higher.
Modularity and phased growth	Applications with scalable loads and, or modular units that enable staged expansion, may score higher.
Standard procedures	Applications that use standardised designs, common spare parts, and consistent connection, operations, and maintenance procedures, may score higher.
Supply chain readiness	Applications supported by widely available components and multiple qualified contractors that can deliver at the required scale, may score higher.
Documentation and knowledge transfer	Applications that contribute reusable documentation and lessons that enable adoption by other PTOs or partners, may score higher.

Table 10.8: Technical component: Suggested scoring aspects for the Scalability

Scores should reflect how readily an application can be replicated across sites or networks, and the extent to which methods can be adopted by other PTOs or organisations. Additional credit may be warranted where the application introduces new technology or demonstrably increases learning among stakeholders, thereby enabling deployment at larger scale.

Additional note: When PTOs or other organisations apply a framework, they should ensure that aspects do not overlap with aspects across components, to avoid double scoring.

10.2.2. Societal Theme

Stakeholders from municipalities and provinces placed greater emphasis on *Sustainability* components than on *Social* components, with sustainability considered roughly twice as important. They highlighted three components as most important, *Prevention of pollution*, *Alignment with development goals*, and *Impact within the organisation (PTO)*. Expert consultations and the literature did not identify additional societal components that should be included within this theme. One expert noted that scalability should be prioritised across both applications and methods when quick, large scale impact is desired, which means it can be viewed as contributing to societal value. Since *Scalability* is already treated within the Technical theme, it can support societal value indirectly through that route. It should also be noted that stakeholders ranked the *Community and society impact* component within the Social sub-theme lowest in importance, which suggests they are probably less interested in scalability as a primary societal lever.

Several individual aspects nevertheless received high importance in the surveys, even when their broader component did not. These aspects are therefore included as *additional* items under the Social and Sustainability sub-themes:

- *Social sub-theme, additional aspects:*
    - The application improves local air or water quality.
    - The application is sited where grid congestion is most severe.
- *Sustainability sub-theme, additional aspects:*
    - The application improves energy efficiency or enables additional renewable generation.
    - The application delivers a comparatively large reduction in greenhouse gases (CO_2, CH_4, N_2O).
    - The application contributes to sustainable area development.

Each PTO should decide which components to include in its own framework. These constitute the most general components and aspects, and they were also identified by the stakeholders involved as the more important items.

10.2.3. Social Sub-Theme

This sub-theme focuses on the impacts of the application that matter directly for people, which include, staff, users, and communities.

Impact within the Organisation (PTO)

This component measures how the application affects the PTO's own workforce and those who work directly with the application. It is included here in more detail because stakeholders ranked it as the most important social component.

Explanation of the component

This component focuses on the application's effects on PTO staff who operate, maintain, work near, are involved with or are affected by it. It aims to improve working conditions and operations and reduce risks. Table 10.9 sets out the assessable aspects, covering employee safety, occupational exposure, noise exposure, and worker participation. Together, these aspects specify where the component applies and what it seeks to achieve.

Aspect	Aspect description
Employee safety	The application improves safety for staff who operate, maintain, or work near it.
Occupational exposure	The application reduces exposure to harmful emissions for staff.
Noise exposure	The application reduces noise exposure for employees.
Worker participation	Employees are meaningfully involved in decision-making in which application to connect, including training and feedback.

Table 10.9: Social component: Aspects that might determine the Impact within the organisation (PTO)

Furthermore, it can be quite important and often advantageous to actively involve employees in decisions, since they work with the application in practice, hold relevant operational knowledge, and can identify changes that improve safety, ease of use, and day to day performance.

How can it be scored?

This component is scored against qualitative or quantitative improvements in staff outcomes and the quality of participation processes. Table 10.10 summarises suggested scoring aspects. Stakeholders should set scales and weights that reflect their context, the intent is to reward applications that measurably improve safety and working conditions, and that embed meaningful worker participation, may score higher.

Potential scoring aspect	Scoring guidance
Employee safety improvements	Applications that contribute to increasing safety in the workplace or enhance safety in other ways may score higher.
Reduced occupational exposure	Applications that (measurable or credibly modelled) reduce harmful emissions in the workplace, or otherwise reduce exposure to hazardous substances, may score higher.
Noise reduction for staff	Applications that (measurable or credibly modelled) lower the noise levels in the workplace, may score higher.
Meaningful employee participation	Decision-making processes with employee participation, (extensive) training, and active involvement with feedback loops during installation and operation, may score higher.

Table 10.10: Social component: Suggested scoring aspects for the Impact within the organisation (PTO)

In practice, participation can be evidenced through structured dialogue with employees, targeted surveys on preferences and risks, and documented feedback that influences the final design and operating procedures. Where appropriate, a process criterion can award points when informed employee preference aligns with a specific application.

Additional Social component

This component collects individual social aspects that scored highly in the survey, even though their broader component was not prioritised. It aggregates several stand-alone aspects rather than a single overarching construct; stakeholders should determine which of these aspects they wish to include for their context. Some overlap with other components and aspects is possible, so double counting should be avoided.

Explanation of the extra component
This component focuses on local societal benefits that can be realised by siting choices and by targeting pressing local needs. Table 10.11 lists the assessable aspects and clarifies what this component aims to achieve.

The aspect that focuses on local air or water quality improvement is identical to the component prevention of pollution within the sustainability sub-theme, but it has been mentioned in the interest of completeness.

Aspect	Aspect description
Local air or water quality *Similar to a component within the sustainability sub-theme*	The application improves local air or water quality in its surrounding area (e.g., connecting a water treatment facility or making a polluting object more sustainable).
Siting in severe grid congestion areas	The application is located where grid congestion is most severe and thereby provides service in the most constrained areas, or can actively reduce the local impact of grid congestion.

Table 10.11: Additional social component: Aspects that might improve the applications decision-making

How can it be scored?
Scoring should reflect measurable improvements in local environmental quality and the degree to which the application targets locations with severe grid constraints. Table 10.12 summarises suggested scoring aspects; specific scales and weights should be set by stakeholders.

Potential scoring aspect	Scoring guidance
Local air or water quality improvements *Similar to a component within the sustainability sub-theme*	Quantified improvements to air or water quality in its surrounding area (local focus), may score higher.
Targeting severe grid congestion	Demonstrable relief at locations with severe grid congestion, may score higher.

Table 10.12: Additional social component: Suggested scoring aspects that might improve application decision-making

Additional note: When PTOs or other organisations apply a framework, they should ensure that aspects do not overlap with aspects across components, to avoid double scoring. As could be the case with the *Local air or water quality* aspect.

10.2.4. Sustainability Sub-Theme

This sub-theme focuses on how the application contributes to sustainability and environmental improvements.

Prevention of pollution

Within the sustainability theme, stakeholders ranked this as the most important sustainability component. It measures the extent to which the application prevents harmful emissions to air and water, including heavy metals and local air pollutants.

Explanation of the component
This component focuses on preventing harmful releases to air and water associated with the application during installation and operation. It aims to prioritise options that avoid or reduces pollution. The assessable aspects are listed in Table 10.13, which specifies where this component applies and what it seeks to achieve. For completeness, note that this component is also included as an additional aspect under the Societal, *Additional Social component*, therefore care is needed to avoid double counting.

Aspect	Aspect description
Heavy metals prevention	The application prevents, directly or indirectly, the emission or release of heavy metals during installation and operation.
Local air pollution reduction	The application reduces local emissions or concentrations of harmful air pollutants, for example NO_x and particulate matter.
Water pollution (prevention)	The application prevents or reduces water pollution, for example through containment, treatment, or avoidance measures.

Table 10.13: Sustainability component: Aspects that might determine the Prevention of pollution

How can it be scored?

This component is scored on verified outcomes and the effectiveness of prevention measures. Table 10.14 summarises suggested scoring aspects. Stakeholders should set scales and weights that fit their context. The intent is to reward applications that demonstrably avoid releases and improve local environmental quality, may score higher.

Potential scoring aspect	Scoring guidance
Heavy metals risk reduction	Designs and processes that avoid release pathways, may score higher.
Local air pollution reduction	Verified reductions in NO_x and particulate matter near the site, may score higher.
Water quality outcomes	Effective measures that prevent pollution and protect receiving waters, may score higher.

Table 10.14: Sustainability component: Suggested scoring aspects for the Prevention of pollution

Additional note: When PTOs or other organisations apply a framework, they should ensure that aspects do not overlap with aspects across components, to avoid double scoring.

Alignment with development goals

Within the sustainability theme, stakeholders also prioritised alignment with internal and external sustainability objectives. Accordingly, this component tests whether an application contributes to, or aligns with, those objectives.

Explanation of the component

This component focuses on the fit between applications and adopted public objectives. The specific goals must be provided by the municipality or province when applying a framework. If contributions to the United Nations SDGs are desired, the public authority should specify which SDG targets are in scope and how compliance will be assessed. Table 10.15 lists the assessable aspects and clarifies what this component aims to achieve.

Goals may also be social in nature, and this component can be used to pursue social objectives as defined by the municipality or province.

Aspect	Aspect description
Municipal and provincial goals	The application aligns with municipal or provincial social and environmental objectives.
United Nations SDGs	The application contributes to relevant United Nations Sustainable Development Goals.

Table 10.15: Sustainability component: Aspects that might determine the Alignment with development goals

How can it be scored?

Scoring should reflect alignment with adopted policy and internal goals and, where applicable, SDG targets. Table 10.16 summarises suggested scoring aspects. Stakeholders should set transparent scales, weights, and evidence requirements that fit their context.

Potential scoring aspect	**Scoring guidance**
Municipal and provincial goals	Applications that demonstrably align with adopted municipal or provincial objectives, and where relevant national policy targets, may score higher.
Contribution to SDGs	Applications that map to material SDG targets and indicators with credible evidence of contribution, may score higher.

Table 10.16: Sustainability component: Suggested scoring aspects for the Alignment with development goals

The municipality or province should supply the relevant goals and define clear scoring criteria and evidence rules so that these objectives are weighted appropriately in the decision framework, and in a transparent manner.

Additional Sustainability component

This component collects individual sustainability aspects that scored highly in the survey, while their broader components were not prioritised. Some overlap with technical aspects is possible, so double counting should be avoided.

Explanation of the extra component

This extra component bundles stand-alone sustainability aspects that stakeholders rated highly, even when their broader component was not prioritised. It focuses on energy efficiency, renewable integration, greenhouse-gas reduction, and contributions to sustainable area development. Table 10.17 lists the assessable aspects and clarifies where this component applies and what it seeks to achieve.

Aspect	**Aspect description**
Energy efficiency and direct renewables	The application improves energy efficiency or enables additional renewable generation, for example regenerative braking or direct coupling to on-site generation.
Greenhouse gas (GHG) reduction	The application delivers a comparatively large reduction in CO_2, CH_4, and N_2O.
Sustainable area development	The application contributes to sustainable development of the surrounding area.

Table 10.17: Additional sustainability component: Aspects that might improve the applications decision-making

How can it be scored?

Scoring should reflect demonstrated gains in efficiency and renewables, verified GHG reductions, and clear contributions to local sustainable development. Table 10.18 summarises suggested scoring aspects. Stakeholders should define scales and weights that fit their context; the intent is to reward applications that deliver measurable improvements, may score higher.

Potential scoring aspect	**Scoring guidance**
Energy efficiency and renewables	Applications with demonstrable gains in efficiency or enabling additional on site renewables, may score higher.
GHG reduction	Larger, verifiable reductions in CO_2, CH_4, and N_2O per unit, may score higher.
Area development	Clear contribution to local sustainable development objectives, may score higher.

Table 10.18: Additional sustainability component: Suggested scoring aspects that might improve application decision-making

Additional note: When applying this theme, ensure that aspects are not included twice across components or themes, to avoid double scoring.

10.2.5. Legal

Prioritisation based on legal criteria is not appropriate. The choice of a legal construct is treated as an implementation instrument to realise the connection and should therefore not be assessed within a prioritisation framework, as reasoned in the conclusion of *Chapter Conclusion*. Applications should not be preferred over one another on the basis of legal criteria.

10.3. Synthesis, Outline for a Future Prioritisation Framework

This section, summarizes the consolidated outputs and gives the outline for a future prioritisation framework. It assembled by synthesising stakeholder inputs from interviews and surveys, relevant literature, expert judgment, and the preceding analyses and the outputs of the previous research questions. It explains how a framework should be developed, clarifies for whom it is intended, outlines what must be done before prioritising applications, describes how it can be applied in practice, identifies which actors should be involved, and indicates what users of the framework still need to tailor for their own network and context, and contractual agreements with the DSO/TSO.

Purpose and development

The outline for a prioritisation framework functions as a recommendation. The stakeholders that are consulted are the municipalities, provinces, a PTO, a PTA, and a DSO. The municipalities and provinces were particularly important, as they are closely involved with the PTO: they often, indirectly, award the concessions, (in some cases) own the PTO and/or its electricity infrastructure, and commonly hold interests in the DSO and, in some cases, the PTA. The DSOs are likewise critical, as they are best placed to indicate how PTOs can most effectively help to relieve grid congestion. No fixed scores or weighting principles are included, since these depend on local objectives and network characteristics and require further work. This leaves room for stakeholders, including network owners, the PTO, and local authorities such as the municipality, province, and PTA, to decide what matters most in their context and in light of their electricity infrastructure and operations.

The outline for the framework is designed to be generally applicable. The main focus PTOs and municipalities with traction power networks, but due to the generality of the framework it is applicable to all types of organisations, from PTOs to any municipality, province or other (commercial) organisation. The themes and aspects were formulated at a generic level, with emphasis on technical topics that are relevant across different network types, stakeholder configurations, and contexts.

The framework should be applied in specific sequence. First, application (types) should be solely assessed against technical aspects. This can be exploratory by investigating whether there is a technical constraint and investigate whether there is sufficient headroom, spatial capacity and potential within the network and which types of applications are most suitable. After this orientation and the testing of specific applications, the most suitable options/ energy applications can then be assessed against societal aspects.

The study identified many aspects, with some more important than others. This is expected, since each network has its own characteristics, context, and stakeholder set, which must always be considered. The outline for the framework lists aspects that are generally applicable across network types and municipal or provincial contexts. Nevertheless, users of the framework should still review which components are applicable to their system, add or omit aspects when required, and adapt the framework to their context. Since the survey revealed that some other components for some stakeholders were also assessed as important to varying degrees, therefore each PTO or organisation should decide whether they are essential to include in their context.

Framework structure

The framework should consists of one Technical theme and one Societal theme. The Societal theme comprises a social and a sustainability sub-theme. Each theme and component is explained and justified in this chapter. The Technical theme includes two optional components that can be added when relevant. For each component, guidance is provided on possible scoring approaches. Scoring and weighing criteria are not included, table 10.19 presents the consolidated overview.

Theme	**Technical**	**Societal**	
Sub-theme		*Social*	*Sustainability*
Components	Controllability	Impact within the organisation (PTO)	Prevention of pollution
	Effective Load Coefficient (ELC)	Additional Social component	Alignment with development goals
			Additional Sustainability component
	Installation and Maintenance ×		
	Scalability ×		

Table 10.19: Outline overview with the themes and components for a future Prioritisation Framework.

× These components are optional additions and may be included in the Prioritisation Framework when the operator deems them important.

During the interviews, stakeholders indicated that they are still determining how they wish to prioritise societal objectives, and that such choices should preferably be made democratically. They agreed that technical considerations must have priority over social choices, since PTO operations always come first and the grid impact must remain within acceptable limits. The technical theme is broadly applicable across PTO traction power networks, mainly because experts, the literature, and stakeholders all converged on the main importance of an application's impact on the PTO/host network, which is explicitly addressed through two components within the theme. On the other hand, societal objectives are best to be more specified per municipality or province for their network, location, and context, through a democratic process. Expert support is recommended when formulating those (additional) societal criteria.

11

Outline for a Future Prioritisation Framework

The definitive outline is based on the outputs of Chapter *Qualitative Analysis* and consists of two themes arranged in a clear sequence, first a *Technical* theme that safeguards network integrity and service continuity, next a *Societal* theme that reflects democratically mandated objectives, and finally a legal feasibility check that functions as an implementation choice rather than a scoring dimension. It is recommended to develop s MCDA framework with clear rules for scores and weights to ensure transparency, and to keep the framework as simple as possible so that non-experts can also understand and use it. The themes are elaborated in the following sections.

11.1. Technical theme

Within the Technical theme, two components form the backbone of prioritisation. Based on the expert input and the technical stakeholders *Controllability* and *Grid Impact* were assigned as the most import components. Accordingly, the component *Controllability* is defined to capture the capability to modulate the applications its import and export directly constraining adverse grid impact, and can even support with positive contributions to network stability, and protecting public transport operations. In practice this means favouring applications that demonstrate flexible power limits, load shifting capability, acceptable rates of change of power, feeding or absorbing capability where relevant, storage or buffering where helpful, tolerance for curtailment, and robustness to electrical disturbances. These properties provide operational headroom to mitigate voltage, current, and protection constraints during normal and degraded states. A second component is the *Effective Load Coefficient (ELC)*, introduced to capture both efficiency and the influence of siting and connection type, thereby affecting the application's grid impact, and indicating whether the application makes the overall system more energy efficient. It is expressed in a dimensionless indicator, the ELC. Using ELC within the technical screen distinguishes between applications that appear similar in power yet impose very different effective loads due to losses, conversion paths, recuperation, and preferred connection points on AC or DC sides. In this way, *Controllability* provides the means to shape behaviour in real time, while *ELC* captures structural consequences of where and how the application connects.

Together these components can also positively contribute with achieving societal objectives, such as improving the systems energy efficiency or connecting RES to the system. Characteristics of applications which then are very helpful are storage options, non (time) critical energy demand, and the ability to (quickly) regulate the power flow of the applications. The *technical expert* also indicated that local storage is very useful to support in DC traction environments to dampen voltage fluctuations, buffers regenerative peaks, improves power quality and increases controllability, especially when the coupling point is further away from the substation and the distance and conductor size losses increase. Furthermore, he mentioned that the effectiveness of an application is also dependent on the siting and connection point of the application within the system. Finally, the right ESS and its characteristics can also contribute in achieving the that regenerative braking energy is not wasted.

Two other technical components, *Installation and Maintenance* and *Scalability* also were also indicated as quite important by either the stakeholders and/or experts and are therefore added as supplementary components to allow operators to add them where decision relevance is high due to local context, when finalising the prioritisation framework. *Installation and Maintenance* received comparatively high importance from stakeholders, and it reflects practical feasibility, access, outage planning, protection coordination, metering and control integration, and the capacity to operate and maintain the application, while *Scalability* by contrast, was highlighted by an expert as relatively important, yet given lower importance by stakeholders, it reflects replication and phased growth, standardisation, supply chain readiness, and learning effects. Because these components are either case specific, and therefore not universally applicable across PTOs, or were assigned lower importance by stakeholders, they are developed as additions alongside the main framework. *Relocatability* received limited emphasis from both experts and stakeholders, and therefore it is not further developed and included within the prioritisation framework.

11.2. Societal theme

The Societal theme is solely derived from stakeholder inputs. Respondents indicate that the *Sustainability* sub-theme is valued at roughly twice the importance of the *Social* sub-theme, which suggests that roughly two thirds of societal weight should fall on environmental outcomes. Based on the derived themes in the previous stage of this research, the societal theme also builds on ISO 26000 guidance to translate broad public objectives into concrete, assessable components. In addition, several stand-alone aspects received high importance irrespective of their overarching component and will therefore be integrated within an additional component within each sub-theme.

The Societal theme is also intentionally modular so that municipalities and provinces can map their own objectives within the framework, align them with the SDGs or adjust it to its local context.

11.2.1. Social Sub-Theme

Stakeholders ranked *Impact within the organisation (PTO)* the highest. This emphasises to attach importance to employee safety, reduced occupational exposure to harmful emissions, reduced noise exposure, and meaningful worker participation in adoption and operation.

Although the *Community and society component* ranked lower overall, particular aspects scored highly and should still influence prioritisation. Stakeholders favoured applications that improve *local air or water quality* and *applications at sites with the most severe grid congestion*.Therefore, these aspects are integrated within an additional social sub-theme.

11.2.2. Sustainability Sub-Theme

Within Sustainability, stakeholders ranked *Prevention of pollution* the highest, followed by *Alignment with development goals*. Practically, this means prioritising applications that reduce local air pollution, and, prevent heavy metal and water pollution. While the alignment with development goals can contribute to achieves municipal or provincial goals, as well as to the UN SDGs.

Furthermore, some particular aspects also scored high within the sustainability, independent of its overarching component. Therefore, the sustainability sub-theme has also an additional component that includes *improving energy efficiency or enabling additional renewable generation*, *achieving comparatively large reductions in greenhouse gases* $\mathrm{CO_2}$*,* $\mathrm{CH_4}$*, and* $\mathrm{N_2O}$, and contributing to *sustainable area development*. To improve the energy efficiency, the ELC component within the technical theme, becomes also more important, since this helps to achieve this objective.

11.3. Operational Implications for the Framework

The prioritisation of applications is largely independent of the stakeholder structure and of whether a PTO or a municipality owns or operates the network. Difficulties arise, however, when the municipality as asset owner wishes to connect energy applications. In that case the municipality needs information on load profiles, measurements, and perhaps own the energy contracts to consult with the DSO and to define scores and weights for the technical theme in relation to the network. This information is held by the PTO, and a private PTO with limited ties to the municipality may be unwilling to share these details or the underlying energy contract.

Other implications before utilising the framework are:

1. The PTO or the municipality with a traction power network should consult jointly with the DSO and, where relevant, the TSO, to agree how the public transport electricity infrastructure can contribute most effectively to reduce grid congestion.
2. The PTO or the municipality with a traction power network should finalise themes and components within their specific framework, including developing the scoring methods and the weighs for each sub-theme, components, aspects, with the municipality and province/PTA for the *Societal* theme, and with its internal technical department for the *Technical* theme, while avoiding double counting where societal aspects overlap with each other or with technical components. Advices to assign twice as much weight for the sustainability sub-theme as the social sub-theme.

3. Before assessing the applications, the applications must pass the defined preconditions.
4. To effectively prioritise the applications, sequence matters. The technical screening should precede the societal scoring, since uninterrupted public transport service is a binding constraint that can filter out applications with weak performance on technical components.

Where a Closed System recognition is active, transparency and equal treatment is required, which calls for objective criteria and documented decision rules. Periodic reassessment is also necessary, since network conditions, recuperation patterns, and policy objectives may change.

11.4. Boundary Conditions and Transferability

The framework prioritises potential applications that could be connected to public transport electricity infrastructure. The binding constraint is operational continuity. The approach is intended to be transferable to other Dutch PTOs and to organisations that manage electricity infrastructures or hold multiple connections to the public grid, for example ports, campuses, and municipalities with several connection points. To apply the framework, the user should select the technical components that are most relevant to their local context, and first consult the DSO and, where appropriate, the TSO to agree how the network can contribute most effectively. Societal objectives may also differ across organisations and locations, the societal theme should be confirmed with the stakeholders who hold ownership or stewardship responsibilities, and with local authorities who can articulate specific objectives with the area of the network.

Although the outline for the framework is designed for general use, the final prioritisation depends on network topology, rolling stock, recuperation settings, traffic patterns and timetables, spatial constraints, and governance structures, therefore scoring methods, thresholds, and weights must be set locally to ensure that the prioritisation framework can prioritise the correct applications based on the context of the framework user.

11.5. Legal Assessment for Connection Constructions

The legal layer acts as a gate that determines whether a technically and societally attractive application can lawfully be connected, and under which responsibilities. In this assessment, legal constructs are treated as implementation choices rather than as prioritisation criteria. Applications should first be ranked using the technical and societal components. Only for the highest scoring applications is it useful to investigate how they could be connected legally. Treating legal as an enabling layer, instead of as a separate theme, keeps the prioritisation focused on value creation and technical and operational feasibility.

Legal considerations are nevertheless crucial, because the selected connection construction can strongly affect the organisation. The choice of legal method determines how much control the PTO or municipality retains over the consumption of the energy application, the contractual and administrative burden that follows from the chosen construction, and the degree of freedom the PTO or municipality keeps to use its own network and residual capacity after the energy application(s) has/have been connected.

Making the legal track the starting point of the process would slow progress considerably. The topic is still relatively new, many legal questions do not yet have definitive answers, and ACM cannot provide complete guidance for every situation. ACM supervises legal constructs and assesses applications within the boundaries of the law, which means that organisations must secure their own legal expertise when preparing requests. Each case is specific, there are rarely immediate answers,and therefore ranking every energy application specifically and working them out requires too much time and money. For this reason, the PTO or the municipality as network owner should first apply the prioritisation framework tailored to their network and context, rank the applications, and only then examine the top candidates for legal feasibility once a concrete connection is being pursued.

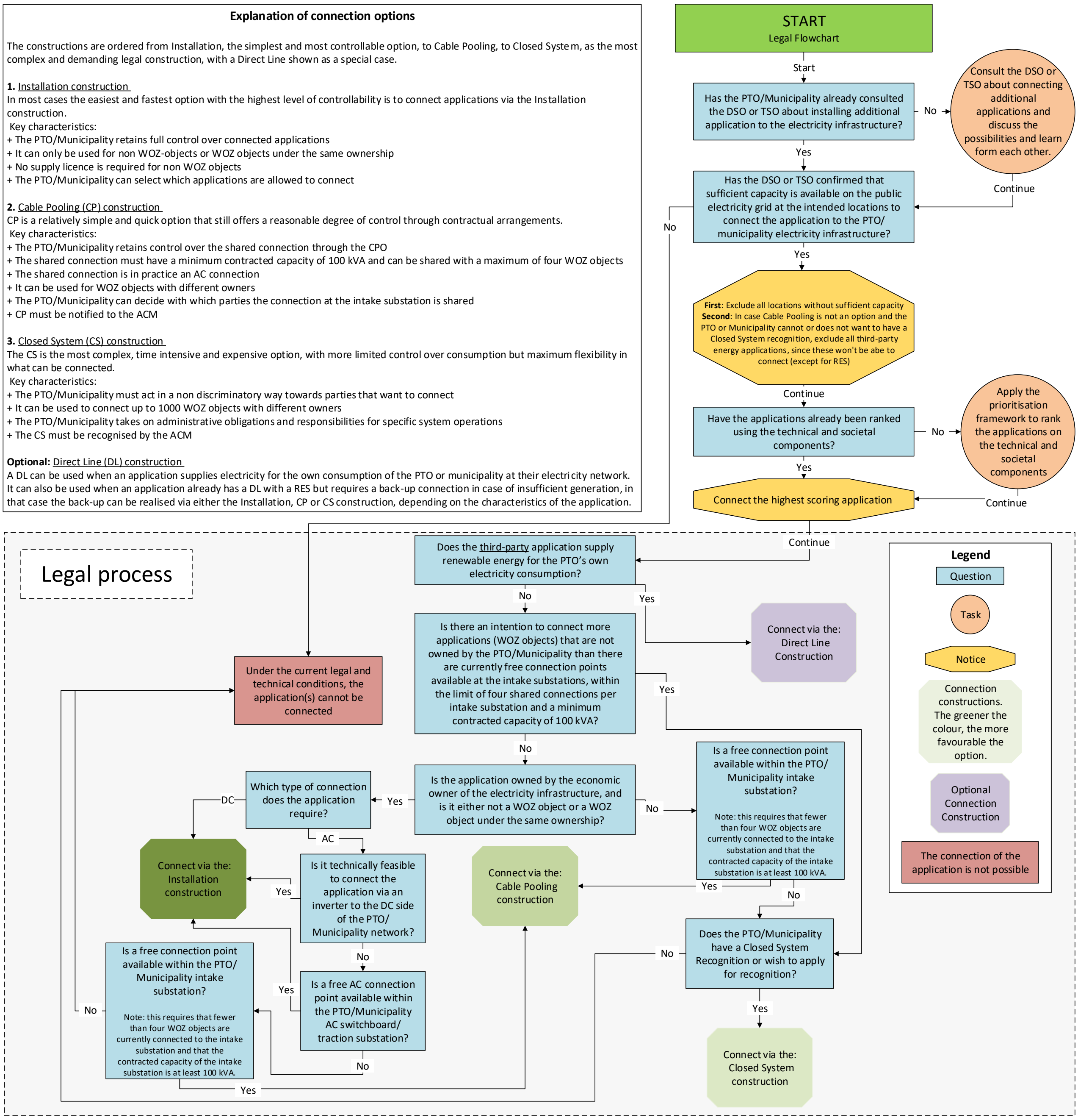
From a technical perspective, it does also change whether to the technical theme first. A practical example illustrates this sequencing. An application may initially be envisaged as a DC connection, but a detailed technical analysis can reveal voltage problems that make a DC connection infeasible. The application then needs to be connected on the AC side instead, for example via Cable Pooling, which in turn implies a different legal construction than originally assumed. Starting with legal arrangements in such a case would mean investing effort in a legal solution for a technical configuration that later proves impossible. Beginning with the technical assessment therefore avoids redundant legal work and keeps the process efficient.

As could be seen in the *Stakeholder Perspectives* Chapter, in many cases, the highest ranking applications selected by municipalities and provinces or PTAs can be connected via the Installation method. This is usually the simplest and most straightforward construction to implement. If an application can be realised as an Installation, it is often inefficient to invest significant effort in exploring more complex alternatives. Where the Installation route is not feasible, Cable Pooling may provide a workable alternative.

Before applying the legal decision logic, the network owner should coordinate with the DSO and, where relevant, the TSO to understand what is technically and operationally realistic, and how the traction power network can be used most effectively. At locations where it is technically impossible to connect applications, or where there is insufficient capacity either on the DSO grid or within the PTO or municipal network, energy applications can be excluded upfront. The decision logic also acknowledges that an organisation may deliberately choose not to pursue Closed System recognition, for example because of the additional obligations and external burdens this entails. If, in addition, there are also no suitable free connection points available at the intake substation for Cable Pooling, or if the other conditions for Cable Pooling are not met (such as a contracted capacity above 100 kVA and a maximum of four WOZ-objects), all third-party energy applications can be excluded from consideration, except those that generate renewable energy (RES). This preliminary filtering reduces the number of applications that require a detailed technical and societal assessment and later a legal assessment and speeds up the subsequent ranking process.

The legal decision flowchart in Figure 11.1 supports PTOs and municipalities in selecting the most appropriate legal construction for each application and provides a concise explanation of the four connection constructions. It assumes that applications have already been ranked using the technical and societal components and that sufficient grid capacity is available. The flowchart then guides practitioners through a sequence of questions, including ownership and WOZ-status, whether the connection is AC or DC, and whether free connection points are available within the substation or at intake substations. Depending on the characteristics of the application, the flowchart indicates whether it can be connected via an Installation, Cable Pooling, Closed System, or Direct Line construction.

At the same time, different legal constructions can co-exist within one network, so that some applications are connected via Cable Pooling or a Direct Line, while others use the Installation method. The flowchart is designed to guide practitioners towards the most suitable and least complex option, and to identify cases where a connection is technically or legally not feasible for the specific application. The greener colours assigned to the legal constructions indicate more favourable options in terms of controllability, implementation effort, operational burden, and flexibility.



Explanation of connection options

The constructions are ordered from Installation, the simplest and most controllable option, to Cable Pooling, to Closed System, as the most complex and demanding legal construction, with a Direct Line shown as a special case.

1. Installation construction
In most cases the easiest and fastest option with the highest level of controllability is to connect applications via the Installation construction.
Key characteristics:
+ The PTO/Municipality retains full control over connected applications
+ It can only be used for non WOZ-objects or WOZ objects under the same ownership
+ No supply licence is required for non WOZ objects
+ The PTO/Municipality can select which applications are allowed to connect

2. Cable Pooling (CP) construction
CP is a relatively simple and quick option that still offers a reasonable degree of control through contractual arrangements.
Key characteristics:
+ The PTO/Municipality retains control over the shared connection through the CPO
+ The shared connection must have a minimum contracted capacity of 100 kVA and can be shared with a maximum of four WOZ objects
+ The shared connection is in practice an AC connection
+ It can be used for WOZ objects with different owners
+ The PTO/Municipality can decide with which parties the connection at the intake substation is shared
+ CP must be notified to the ACM

3. Closed System (CS) construction
The CS is the most complex, time intensive and expensive option, with more limited control over consumption but maximum flexibility in what can be connected.
Key characteristics:
+ The PTO/Municipality must act in a non discriminatory way towards parties that want to connect
+ It can be used to connect up to 1000 WOZ objects with different owners
+ The PTO/Municipality takes on administrative obligations and responsibilities for specific system operations
+ The CS must be recognised by the ACM

Optional: Direct Line (DL) construction
A DL can be used when an application supplies electricity for the own consumption of the PTO or municipality at their electricity network. It can also be used when an application already has a DL with a RES but requires a back-up connection in case of insufficient generation, in that case the back-up can be realised via either the Installation, CP or CS construction, depending on the characteristics of the application.

Figure 11.1: Legal decision flowchart for selecting an appropriate connection construction

11.6. Intended Users and Application Context

The advise for the framework is developed for PTOs and municipalities with a traction power network, reflecting the current demand from local government and society to leverage these electricity systems, and because such networks offer strong opportunities to connect applications. Several PTOs already hold Closed System recognition or use the Installation Method, and their infrastructures are extensive, often located in areas with severe grid congestion, with multiple DSO intake points that enable many potential connections.

As mentioned, the outline itself does not prescribe specific aspects, scoring rules, or weights. Those must be determined by PTOs and/or municipalities or partner organisations, or be developed through future research. For defining the scoring and weighting methods, one option is to use a positive-negative scale that assigns negative scores where an application has adverse effects on a given aspect (with larger penalties for greater detriment) and positive scores where an application delivers benefits, for example by providing energy storage, improving grid stability through strong controllability, or acting as a receptive sink. The stronger the contribution, the higher the score, which makes the direction and magnitude of impact transparent. This approach also clearly indicates an application's strengths and its weaker attributes. For more qualitative aspects, decision makers may alternatively apply a democratic voting procedure, although this is more difficult to reconcile with the transparency and equal-treatment requirements that apply when a network operates under Closed System recognition.

For transparency and equal treatment, especially when a network receives a Closed System recognition, the framework should be applied objectively and transparent, so that applications can be refused in accordance with the rule of law when they obtain a lower score than alternatives. These requirements should be formulated precisely and in detail, as indicated in the interview with *Regulatory Expert (1)*.

Whenever applications are connected via a Direct Line, the Installation Method, or Cable Pooling, owners retain freedom of choice regarding whom to connect or with whom to share a public grid connection.

11.7. Preliminary Steps Before Connecting Applications

A prioritisation framework can be valuable, yet it does not by itself enable a PTO or municipality to just connect applications, since the research shows that stakeholders often move too quickly to solutions while silo-thinking persists and some PTO are not yet ready to start connecting applications. A step by step guidance is provided in Section *Stepwise process to understand how to use the public transport electricity infrastructure the most effective* in the *Discussion* Chapter.

Practical options to discuss and investigate jointly with the DSO and TSO include assessing the availability of Cable Pooling at intake substations, space for shared connections, and the feasibility of implementing bidirectional substations where relevant. According to the DSO, in some areas, particularly around Amsterdam, The Hague, and Rotterdam, there is sufficient capacity to feed electricity back into the grid, while the primary constraint lies in supply, see also Figure 3.4. Furthermore, together partners can identify where on the public transport electricity infrastructure sufficient electrical capacity, physical space, and practical potential exist to install and couple applications and the required equipment.

11.8. Operational Use of the Framework

Once stakeholders have jointly agreed to connect applications to a public transport electricity infrastructure, a prioritisation framework can be used. Proceed as follows:

1. **Pre-conditions**: Check whether the application satisfies the decision tree, only when the network does not have a Closed System recognition.
2. **Technical prioritisation - FIRST**: Prioritise applications using the technical theme. Thresholds for acceptance or progression are to be set by the parties, with system knowledge, who further elaborate and apply the framework.
3. **Societal prioritisation - SECOND**: Applications that pass the technical theme are then prioritised using the societal theme, on social and sustainability aspects as defined by the relevant public authorities.
4. **Legal assessment - THIRD**: For applications that have scored high on both themes, it should be determined how the connection can be realised legally. Two situations occur. First, if the PTO or organisation has already chosen a specific construct, consisting of, the Installation Method, a Closed System, or Cable Pooling, or, for connecting RES to the public transport electricity infrastructure, a Direct Line, then non-eligible applications can be filtered out upfront, see Table 6.5 in the answer to RQ3, which provides an overview of which applications are likely, subject to conditions, to be connectable under each legal construct. Second, if no construct has been chosen in advance, first complete the prioritisation, then select the appropriate (most simplest) legal method.

Selecting the simplest viable connection method is recommended, since operating as a (light-) grid operator is not a core task of a PTO, municipality or most other organisations, and DSOs prefer that other parties do not assume grid operator roles. The practical order of preference is therefore: Installation Method first, then Cable Pooling, then Closed System, see a *summary of construct difficulty*.

At this moment, PTO's and municipality (and provinces) are still exploring which legal methods are possible and preferable. Because the legal domain is complex and time consuming, it is more efficient to prioritise the applications first on the two themes. Stakeholder preferences already show interest in applications that can be connected via the Installation Method, which underscores the value of deferring the legal choice until after prioritisation. If a higher ranked application would require a more complex construct that proves infeasible, a slightly lower ranked application that is feasible via a simpler method can be selected instead.

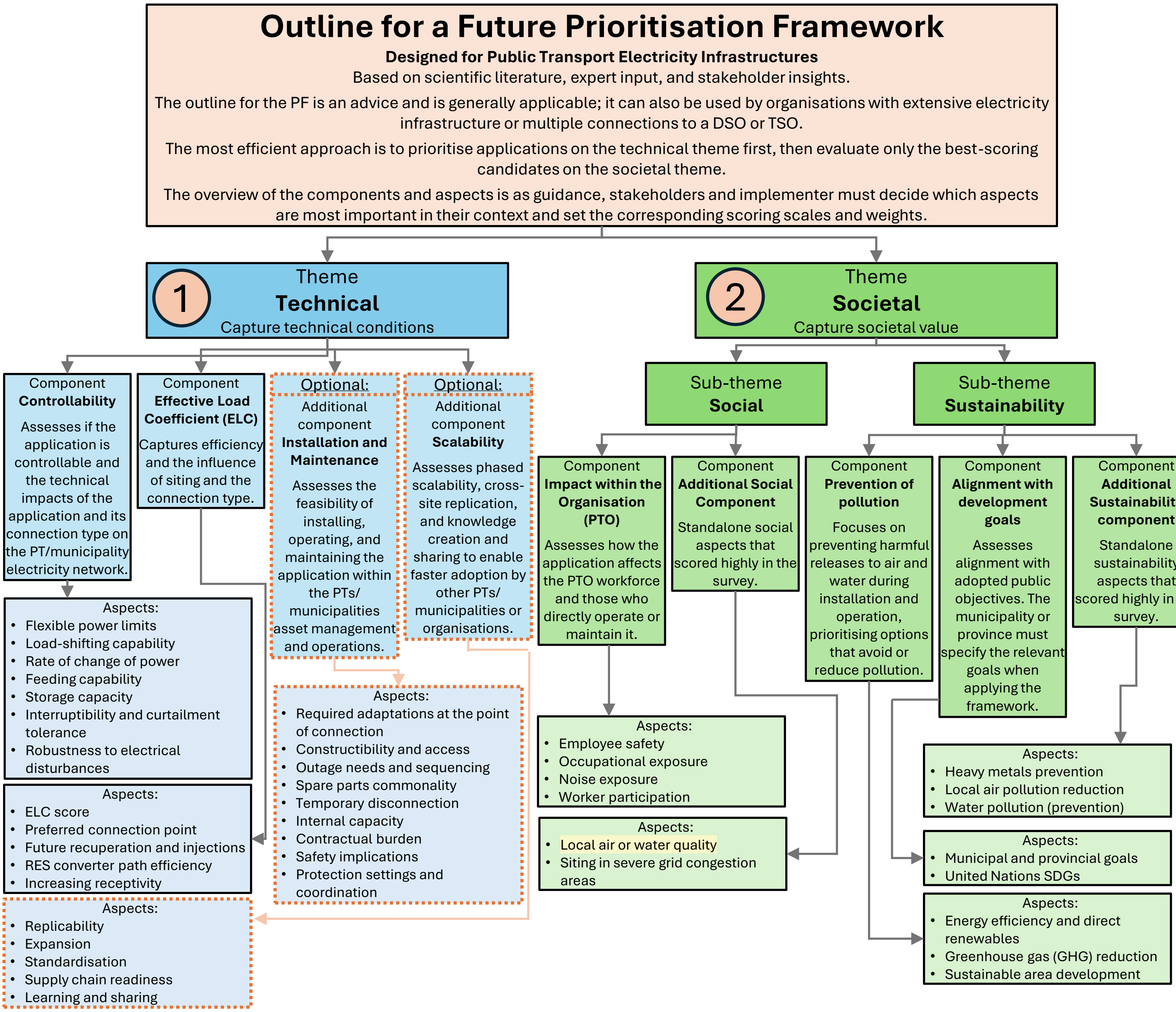
When applying a framework, ensure that identical aspects are not included twice across components.

Figure 11.2 provides the complete outline for a future prioritisation framework, including a small description of suggested aspects.

11.9. Concluding Remarks for the Prioritisation Framework

The outline for a prioritisation framework is generally applicable and is recommended on the basis of technical aspects that are broadly relevant across network types and that safeguard operational priorities. The societal theme reflects what the currently involved stakeholders consider most relevant, yet, for each network where a framework is applied, these societal elements should be reconsidered with the local stakeholders.

Furthermore, the PTOs and partner organisations should decide how to operationalise the components, which aspects to include, the scoring and weighing procedures. If municipal or provincial objectives are to be reflected, translate those into explicit criteria and evidence rules. Each PTO or municipality (with a private PTO) should review which technical aspects are most important for its network, identify potential adverse effects on operations, and adjust the framework accordingly, and discuss these with the DSO and TSO, to determine how the PTO or organisation can best help reduce grid congestion. When new insights emerge, whether technical, legal, societal, or concerning costs and benefits, they should be integrated into the framework.



Outline for a Future Prioritisation Framework

Designed for Public Transport Electricity Infrastructures

Based on scientific literature, expert input, and stakeholder insights.

The outline for the PF is an advice and is generally applicable; it can also be used by organisations with extensive electricity infrastructure or multiple connections to a DSO or TSO.

The most efficient approach is to prioritise applications on the technical theme first, then evaluate only the best-scoring candidates on the societal theme.

The overview of the components and aspects is as guidance, stakeholders and implementer must decide which aspects are most important in their context and set the corresponding scoring scales and weights.

1 Theme **Technical** Capture technical conditions

Component **Controllability**

Assesses if the application is controllable and the technical impacts of the application and its connection type on the PT/municipality electricity network.

Aspects:
- Flexible power limits
- Load-shifting capability
- Rate of change of power
- Feeding capability
- Storage capacity
- Interruptibility and curtailment tolerance
- Robustness to electrical disturbances

Component **Effective Load Coefficient (ELC)**

Captures efficiency and the influence of siting and the connection type.

Aspects:
- ELC score
- Preferred connection point
- Future recuperation and injections
- RES converter path efficiency
- Increasing receptivity

Optional: Additional component **Installation and Maintenance**

Assesses the feasibility of installing, operating, and maintaining the application within the PTs/ municipalities asset management and operations.

Aspects:
- Required adaptations at the point of connection
- Constructibility and access
- Outage needs and sequencing
- Spare parts commonality
- Temporary disconnection
- Internal capacity
- Contractual burden
- Safety implications
- Protection settings and coordination

Optional: Additional component **Scalability**

Assesses phased scalability, cross-site replication, and knowledge creation and sharing to enable faster adoption by other PTs/ municipalities or organisations.

Aspects:
- Replicability
- Expansion
- Standardisation
- Supply chain readiness
- Learning and sharing

2 Theme **Societal** Capture societal value

Sub-theme **Social**

Component **Impact within the Organisation (PTO)**

Assesses how the application affects the PTO workforce and those who directly operate or maintain it.

Aspects:
- Employee safety
- Occupational exposure
- Noise exposure
- Worker participation

Component **Additional Social Component**

Standalone social aspects that scored highly in the survey.

Aspects:
- Local air or water quality
- Siting in severe grid congestion areas

Sub-theme **Sustainability**

Component **Prevention of pollution**

Focuses on preventing harmful releases to air and water during installation and operation, prioritising options that avoid or reduce pollution.

Aspects:
- Energy efficiency and direct renewables
- Greenhouse gas (GHG) reduction
- Sustainable area development

Component **Alignment with development goals**

Assesses alignment with adopted public objectives. The municipality or province must specify the relevant goals when applying the framework.

Aspects:
- Municipal and provincial goals
- United Nations SDGs

Component **Additional Sustainability component**

Standalone sustainability aspects that scored highly in the survey.

Aspects:
- Heavy metals prevention
- Local air pollution reduction
- Water pollution (prevention)

Figure 11.2: Recommended prioritisation framework for connecting (third-party) energy applications to Public Transport Electricity Infrastructures, with a technical theme applied first, followed by a societal theme, then a legal feasibility check. Optional technical components can be included where relevant.

12

Discussion

This chapter brings together and synthesises the findings of the study. Over the course of the research, a range of interrelated issues emerged, and these are brought together and discussed here. The chapter revisits the empirical material from the preceding work, including interviews, expert consultations, documentary sources, legislation, and academic literature, and uses an integrative qualitative synthesis to clarify the problem space and identify what needs to be organised and understood in order to use public transport electricity infrastructures in a robust and effective way. The synthesis characterises the current system, offers and integrated view of enabling conditions, identifies key differences, problems and ambiguities, and specifies the conditions under which these infrastructures can be used responsibly and effectively, so that well founded advice can be provided for stakeholders to act upon.

The discussion addresses the updated main research question and the newly formulated research objectives by comparing areas of convergence and divergence between literature, technical and legal expertise, and stakeholder perspectives. On this basis, it organises the diverse outputs into a coherent narrative, explains how the accumulated evidence leads to a more realistic understanding of the current situation, and distils practice oriented insights and advice for PTOs, municipalities, and other actors.

The chapter is structured in four parts. First, each sub-research question is briefly revisited at an aggregate level, with references to the detailed analysis in earlier chapters. Second, the chapter compares the proposed outline for a prioritisation framework with existing prioritisation frameworks. Third, it discusses the additional research objectives that emerged during the study and clarifies the research results, thereby improving the understanding of the system, the current situation and the enabling conditions that together form the answer to the main research question. Finally, the chapter brings these elements together in a consolidated overview of stakeholder roles, impact and involvement, and offers practical guidance on how to proceed so that public transport electricity infrastructures can be used as effectively as possible.

Throughout, the discussion draws on triangulated evidence from multiple independent sources, which strengthens the robustness of the findings. The chapter also forms the bridge to the subsequent sections on limitations, conclusions, and recommendations for stakeholders and for future research.

12.1. Revisiting the Sub-Research Questions

RQ1

Who should be involved, and what are their roles and influence

Prioritising (third-party) energy applications works best when public value judgement and technical feasibility judgement are owned by the actors mandated to make them. Where the municipality owns the PTO, the municipality or the province/PTA leads the societal assessment, defines ranking criteria that align with policy, and represents the public interest. In many cases, the municipality or the province is also a shareholder in the PTO, the PTA, and the DSO, which increases its leverage to align objectives across programmes and to convene parties to work toward shared goals. The PTO leads the technical assessment and safeguards traction operations and safety, and together they can formulate a well established prioritisation framework and deliver a ranked list of applications.

Before establishing and applying the framework, the DSO, and where relevant the TSO, should be engaged early to verify headroom, connection conditions, and interface constraints. These system operators can block or constrain an application on objective network grounds, yet they do not adjudicate societal value. The ACM interprets or confirms the legal route for connection, for example the Installation method, Cable Pooling, or a Closed System, and may grant exemptions where the law allows, but it does not decide which applications are more desirable. National ministries set the policy horizon and can enable experiments by adapting legislation or by funding special projects, although they are not the appropriate actors to design a local framework or to set case by case priorities.

The PTA ensures compatibility with concession obligations and can adjust contract conditions once a framework exists. However, since they are the concession provider they should be incorporated with the development of a framework. The primary mandate of a PTA is to secure the best possible public transport service in its concession area, which can introduce a bias when judging the use of public transport electricity infrastructures for (third-party) energy applications. Therefore, it should be safeguard that the public interest is set as highest priority, and thereby also keeps the framework generalisable and accessible to organisations beyond public transport, and reduces the complexity of aggregating many objectives.

This division of participation reflects what each actor contributes and the decisions each is best placed to make. Municipalities and provinces/PTA steer societal objectives and local fit. The PTO steers technical demands and limitations and holds a practical veto on grounds of safety, continuity of service, and operational feasibility. The DSO and the TSO hold a system capacity veto at the interface. The ACM holds a legality veto within statutory boundaries. The PTA can enable implementation through concession terms and funding. Keeping roles distinct, and scheduling input at defined decision gates, prevents circular debate, reduces transaction costs, and supports timely and transparent decisions.

RQ2

What type of applications can be connected or are viable, and what characterizes these applications

This research contributes by making stakeholders aware of the broader set of energy applications types and their implications. Because the framework should be designed to identify the most suitable application within the PTO and local context, based on technical and societal objectives, selecting a single best option in advance is neither feasible nor desirable. Categorising and mapping the different types of applications offer a practical way to build an upfront understanding of which technical aspects matter, how the technical theme can be formulated, and where applications diverge. A structured overview of application types and their characteristics enables more productive discussions with stakeholders, clarifies the range of feasible options, helps identify the legal pathways that may be available, and supports a shared view of which aspects belong in the assessment.

RQ3

Which legal approaches are available, what do they require, and what are their main advantages and disadvantages

Legal constructs are implementation routes rather than value criteria, therefore they should function as procedural gates in the assessment. Prior to this research, stakeholders and the PTO were mainly familiar with two routes, the Installation method and the Closed System route. Awareness of alternatives was limited, and in several cases misconceptions existed about their scope and requirements. In practice, four routes are relevant. *Installation* applies when the PTO owns the application or when the application qualifies as a non WOZ-object, it is comparatively fast and cost efficient, it preserves full operational control, however it does not permit third-party WOZ-objects. *Cable Pooling* allows a small set of proximate Installations to share a main connection, it requires a joint connection and transport agreement as well as a Cable Pooling agreement that sets binding arrangements between parties, it can be realized quicker than a Closed System and provides contractual levers that offer some control over third-party usage. *Closed System* recognition enables multiple third-party WOZ-objects to operate behind a single private system, it supports non-discriminatory access and bidirectional power flows and can substantially alleviate congestion, yet it entails operator obligations, administrative workload, and longer delivery timelines. *Direct Line* creates a dedicated link between a renewable producer and a user, either fully off grid or with exactly one public grid connection, it is useful for coupling local renewables to a large consumer or to the PTO's own demand, any backup supplied via the public transport electricity infrastructure must then follow the regime of Installation, Cable Pooling, or Closed System.

RQ4

Which themes and components are relevant for prioritising (third-party) energy applications

A prioritisation framework should be organised around two themes, Technical and Societal, with Legal treated as an enabling tool rather than a theme, and Cost captured in part through technical feasibility. Each theme consists of components, with optional aspects to further describe a component from different perspectives. The societal theme is grounded in the Triple Bottom Line literature, therefore it comprises the *Sustainability* and *Social* sub-themes. Cost is not included as a sub-theme and only partly included because reliable data and experience are currently limited, which makes full and correct integration into the framework difficult. These themes and components were later used in the research to structure discussions with PTOs, municipalities, and provinces/PTA.

The Technical theme safeguards the PTO's operations and network quality and contains six components. *Grid Impact* captures the effect an application can have on the public transport electricity infrastructure, for example voltage and current fluctuations, electrical distance and point of connection, losses, power factor, and any positive contributions to network performance. *Efficiency* addresses avoidable conversion and cable losses, on site use of recuperated and local renewable energy, and the shaping of demand profiles. *Scalability* considers replication across sites and the increase of applications or consumption within a single network, while accounting for portfolio effects, more homogeneous portfolios can reduce engineering complexity and delivery time, more diverse portfolios can spread peaks and improve resilience. *Controllability* specifies the levers available to the PTO, including limits on import and export, schedulability, and the role of storage. *Installation and Maintenance* covers required adaptations, component choices and metering, construction effort, maintainability, and fault response, including what can be handled in house. *Relocatability* assesses the practical ability to move an application to increase flexibility and reuse components so that scarce capacity can be redeployed.

The Societal theme follows ISO 26000 guidance adapted to ensure general applicability and practical relevance within the PTO's corporate social responsibility context and consists of a Social sub-theme and a Sustainability sub-theme. The Social sub-theme contains three components, *Impact within the Organisation*, which considers worker safety and participation, *Passenger and Customer Impact*, which covers service and user benefits, and *Community and Society Impact*, which includes quantifiable effects such as air and water quality, noise, spatial footprint, local employment and economy, grid congestion relief, direct renewable coupling, and reusability of connections, as well as qualitative effects such as participation and governance, innovation and learning, and a hybrid aspect for connection duration and flexibility. The Sustainability sub-theme contains five components, *Prevention of Pollution*, *Sustainable Resource Use*, *Climate Change Mitigation*, *Protection of the Local Environment*, and *Alignment with Development Goals*, including municipal and provincial targets and the relevant Sustainable Development Goals.

RQ5

How do stakeholders perceive and prioritise the components

Across interviews and surveys, respondents all agree on one overarching principle, the public transport operator's own operations take precedence. As a result, a technical assessment should precede the societal assessment, in order to screen out applications that are technically least desirable. Respondents also indicated which components are more important to them, based on their expertise, their network, internal objectives and their context.

From the perspective of technical staff within PTOs and asset managers within municipalities, the highest importance is assigned to *Controllability*, followed by *Grid Impact* and *Installation and Maintenance*. *Efficiency*, *Scalability*, and *Relocatability* are viewed as context dependent enablers rather than universal requirements. Several respondents note that external delivery partners can alleviate constraints in Installation, operation, and maintenance capacity, therefore practical treatment of *Installation and Maintenance* is case specific. The central insight remains, with adequate controllability the grid impact can be minimised or actively shaped, enabling the application to contribute to network stability rather than only imposing additional stress. These findings are consistent with the literature and expert judgment, which jointly emphasise *Grid Impact* and *Controllability* as the most critical components.

Stakeholders from municipalities and provinces/PTA, on average, assign roughly twice as much importance to the *Sustainability* sub-theme as to the *Social* sub-theme, implying a stronger weight on sustainability within the societal theme. Within *Social*, *Impact within the Organisation* ranks first, followed by *Passenger and Customer Impact*, then *Community and Society Impact*. Within *Sustainability*, *Prevention of Pollution* ranks first, followed by *Alignment with Development Goals*, with *Climate Change Mitigation* and *Sustainable Resource Use* in the middle, and *Protection of the Local Environment* lowest. Some aspects within lower scoring components nevertheless receive consistently high support and should be retained as standalone assessment items.

12.2. Comparison Outline to other Prioritisation Framework

The outline for prioritising energy applications on public transport electricity infrastructures builds on the general MCDA insights and examples discussed in the *Research Methodology* Chapter. In particular, it draws on the design principles distilled from the World Bank Infrastructure Prioritization Framework (IPF) [7], the Dutch MIEK assessment framework [9], and the review of MCDA applications for sustainability assessment in the food sector by Ferla et al. [10]. This section briefly compares the outline with these existing approaches, highlighting where it is aligned with established practice and where it deliberately diverges or remains less developed.

In the *Outline for a Future Prioritisation Framework* chapter, the final outline of the prioritisation framework is presented and it is recommended that this outline be implemented as a MCDA based tool.

Convergence with existing frameworks

- **Work with a limited number of core dimensions**
  The outline follows the principle of working with a limited number of core dimensions. Similar to IPF and MIEK, which structure decisions around a small set of composite indices, the outline is built around two main themes with underlying components rather than a long list of ungrouped criteria. This keeps the framework manageable for practitioners while still capturing the most important technical and societal aspects that influence whether an application should be connected.
- **Make scarcity and system constraints explicit in the assessment**
  The outline reflects the recommendation to make scarcity and system constraints explicit in the assessment. In line with IPF and MIEK, it proposes to define hard preconditions up front, for example minimum technical requirements or grid capacity thresholds, and to discuss the technical situation with the DSO before scoring applications. By integrating such technical preconditions prior to the framework, applications that cannot realistically be connected are filtered out early, so that the scoring process focuses on feasible candidates only.
- **Use a standardised project fiche as the entry point**
  The outline adopts the idea of using a standardised entry format similar to the MIEK project fiche. It recommends that each energy application should be described in a consistent way, with information on location, technical profile, expected use, and societal objectives. This helps PTOs or municipalities to assess applications against the same set of aspects and to apply the themes and components in a comparable way across different cases.
- **Link technical requirements to financial and system impact**
  Instead of linking technical requirements to financial and system impact, this outline links the financial impact to the technical requirements. Since detailed monetised cost benefit information is typically not available at the application level. Where explicit economic data is lacking, technically driven cost and feasibility considerations are incorporated into the technical theme, for example by giving low scores to applications that would require disproportionate investment or that are clearly not economically feasible in the given context. This joint treatment of technical, financial, and grid impact is consistent with the way IPF group indicators that drive system costs and risks into broader dimensions.
- **Design the framework for transparency and accountability**
  The design of the outline is motivated by transparency and accountability. As in IPF, MIEK and the MCDA applications reviewed by Ferla et al. [10], the aim is to formulate criteria and scoring rules in a way that is understandable for non-experts and that can be used to justify decisions to boards, regulators, and, when required, the ACM. This is particularly important in legal constructs such as Closed Systems, where operators must demonstrate non-discriminatory treatment and be able to explain why particular applications were selected or rejected.
- **Involve stakeholders in criteria definition, weighting and validation**
  Stakeholder involvement is an explicit part of the outline. The formulation of themes and components is intended to be co-developed with representatives from relevant departments within PTOs and municipalities, as well as with grid operators and, where appropriate, regulators. This mirrors the role of stakeholder engagement in the frameworks discussed in the *Research Methodology* Chapter and is intended to enhance both the legitimacy and the practical relevance of the resulting prioritisation framework.
- **Treat the framework as an iterative stepping stone rather than a final model**
  Finally, the outline is explicitly positioned as an iterative stepping stone rather than as a definitive model. Similar to IPF and MIEK, it is meant to structure decisions under incomplete information and local institutional constraints, while at the same time revealing data gaps and design weaknesses that can be addressed in later application rounds. Even once a first full version is implemented, the framework should be periodically reviewed and refined rather than blindly applied. An important nuance is that, in settings

where a Closed System recognition has been obtained, the framework may need to be followed more strictly, because it underpins non-discriminatory and transparent decision-making that can be tested by the ACM.

Differences and remaining limitations

There are also clear differences between the outline and the more mature frameworks discussed in the literature.

- **Aggregate indicators and plot them**
  A difference concerns the aggregation and visualisation of results. IPF, for example, aggregates indicators into two composite indices and plots projects in a two dimensional space against a budget line, which is particularly useful when multiple ministries must jointly agree on a portfolio of projects. In the present context, the outline does not yet specify a similar plotting approach. This is partly because the outline is still at an early stage of development, and partly because the decision context is different: most decisions will be taken by a single network operator, usually the public PTO or municipality, that first needs to check technical feasibility and only then assess societal contributions. In such a setting, a two dimensional plot for negotiation between many stakeholders is less critical, since a first selection will be made on the technical assessment.
- **Allow for simple and partly qualitative indicators when data are incomplete**
  Another difference is that the outline does not yet fully operationalise the use of simple and partly qualitative indicators when data are incomplete, even though this is recommended in the design principles. The outline remains at the level of themes and components and does not prescribe specific indicator sets, scoring scales, or semi quantitative judgement rules. It therefore cannot yet demonstrate in detail how qualitative and quantitative information will be combined, although the intention is to work with basic scales and clearly documented assumptions that can be refined over time.
- **Normalise indicators and apply explicit weights**
  Finally, the outline has not yet fixed explicit normalisation procedures and weighting schemes. Existing frameworks such as IPF and many MCDA applications in the sustainability literature show how indicators can be mapped to a common scale and combined with transparent weights that can be discussed and tested. In this thesis, it is only advised that future implementations should normalise indicators and assign explicit weights to themes and components, so that the influence of weighting on the ranking can be explained. Concrete choices about scales and weights are left to future work and to co design with practitioners.

In summary, the outline is well aligned with several core design principles found in established MCDA based prioritisation frameworks, particularly with regard to the use of a small number of themes, the explicit treatment of scarcity and system constraints, the emphasis on transparency, and the role of stakeholder involvement. At the same time, it remains less developed in terms of detailed indicator design, aggregation and visualisation of results, and explicit normalisation and weighting procedures. These elements provide a clear agenda for further work when the outline is translated into a fully operational prioritisation framework for public transport electricity infrastructures.

12.3. Emergent Insights and Implications to Understand the System and its Situational Context

During the study, several findings emerged that had not been formulated as explicit research objectives at the outset, but that proved influential for both the scope of the work and for understanding the system in which any future prioritisation framework would have to operate. As these issues became more visible, the focus of the research shifted from constructing a complete prioritisation framework towards mapping the system, including the technical, legal and institutional context, and formulating design principles that can inform later framework development. Therefore, this section first deepens the insights over the research objectives and then introduces several additional aspects that emerged during the work, in order to prepare the ground for the practical guidance that closes the chapter. These insights, which are partly discussed in *Qualitative Analysis* and *Stakeholder Perspectives*, are complemented with cross-cutting patterns on stakeholder expectations and silo mentality, knowledge sharing and learning, legal options and platform selection, and the treatment of costs.

Differences between public transport electricity infrastructures and stakeholder contexts

The research reveals that public transport electricity infrastructures and their institutional environments differ significantly between cases. These differences concern not only the technical characteristics of networks such as metro, tram, trolleybus or rail, but also the roles, expectations, shared knowledge, and capacities of the actors involved. Collaboration is still limited and silo mentality remains pervasive. Three aspects are particularly relevant for understanding the context in which any future prioritisation framework must function.

Unequal expectations, fragmented knowledge and siloed practices

The surveys and joint consultations show that stakeholders hold divergent views on what should be done with public transport electricity systems, both technically and societally. On the technical side, there is limited shared understanding of how each other's systems work, what constraints and flexibilities exist, and what is realistically possible in terms of connecting additional applications. Actors who do not operate the traction network often lack insight into load profiles, headroom and operational constraints. In some organisations, even internal technical knowledge is fragmented or simply missing. This weakens the ability to assess options, to design a robust prioritisation framework, and, more fundamentally, to operate and maintain the network and connected applications responsibly and effectively, with all associated duties and liabilities.

On the societal side, stakeholders differ in the extent to which they expect the network to contribute to broader goals such as supporting the energy transition or relieving grid congestion. Public transport operators may prioritise improving their own energy efficiency, for example by using regenerative braking energy more effectively, and may prefer to supply this to connected applications or third parties without always knowing whether this is technically and legally permissible. Municipal departments are not always aware of the legal, technical and administrative burden for the operator of a network that is opened up to third-party connections.

These tensions are amplified by the diversity of stakeholders involved. They have different statutory tasks, strategic visions and internal structures, and knowledge is often fragmented across departments as well. As a result, actors not only misunderstand each other's systems, but sometimes also speak with multiple, internally inconsistent voices: different departments within the same organisation can hold different views and pursue different actions. Within the municipality of Amsterdam, for instance, some departments prioritise safeguarding core transport operations, while others favour an active role in enabling external connections. DSOs generally prefer predictable loads and peak reduction rather than filling troughs with additional consumption. PTOs seek a credible business case and clarity on future demand and expansion, and would like to find ways to utilise regenerative energy instead of dissipating it in braking resistors, for example by supplying it to connected applications. Overall, there is a substantial misalignment of expectations, visions, preferences and knowledge. This misalignment has to be addressed per infrastructure context before it makes sense to develop and implement a concrete prioritisation framework or to make long-term plans on how the networks should be used.

These patterns connect directly to silo mentality as described in *Silo mentality*. Many actors still focus on their own problems and search for solutions within organisational boundaries, with limited knowledge of how other systems work or how mutual support could create better system-level solutions. This reinforces a narrow, actor-specific perspective and constrains collaboration on shared objectives, such as using public transport electricity networks to alleviate grid congestion. Such siloed thinking leads to suboptimal choices and missed synergies. Yet, the initiatives such as *Energy in the PT* (Dutch: *Energie in het OV*) and the knowledge programme *Grid congestion & PT* (Dutch: *Netcongestie & OV*) [110, 111], are starting to bringing stakeholders together and to start sharing knowledge, which is also required because currently a more integrated and system-oriented perspective is still needed if the potential of these infrastructures is to be realised.

Public PTOs and private PTOs

A second emergent insight concerns the difference between privately operated public transport operators (private PTOs) and PTOs in which the municipality holds shares (public PTOs). In both contexts the municipality typically owns the traction power infrastructure, and the PTO usually holds the energy contracts and controls access to operational data. Public PTOs are more directly aligned with municipal objectives, tend to adopt a broader societal perspective, and are generally more willing to cooperate in using their networks to help relieve grid congestion, especially where they hold a long-term, directly awarded concession. Private PTOs, however, bear greater commercial risk because they operate entirely on their own account: although they may be willing in principle to cooperate, they are less inclined to take on additional risk or jeopardise their core business.

In any case, when the municipality neither holds the energy contracts nor has negotiated access to network data through the concession conditions, its insight into consumption profiles, available capacity and opportunities for connecting additional applications is significantly limited. This challenge is particularly pronounced in concessions with private PTOs, where commercial sensitivities and competitive considerations make operators more cautious about sharing detailed data or committing to projects that lie outside their core transport tasks, and risking there commercial operations. By contrast, public PTOs are generally more inclined to collaborate on data sharing and on exploring (third-party) energy applications, especially when municipal shareholders explicitly request this. These differences in governance and incentives are crucial when considering how a future prioritisation framework could be implemented in practice.

At the same time, municipalities cannot simply instruct even a public PTO to cooperate. In practice, steering occurs primarily through concession contracts rather than through shareholding. If collaboration on connecting (third-party) energy applications or sharing data is not explicitly embedded in the concession, both public and private PTOs retain the right to refuse. In tendered concessions with private PTOs this is particularly strict: if cooperation on grid congestion is not specified, it is unlikely to materialise. This has direct implications for governance and for the preconditions under which a future prioritisation framework could be applied. Future concession contracts need to explicitly require collaboration on data sharing and on facilitating third-party energy connections if public transport networks are expected to contribute to reducing grid congestion. Alternatively, concessions can stipulate that the municipality, rather than the PTO, holds the energy contracts and the associated rights to data access and metering.

In situations where the public PTO operates the traction power network, holds the energy contracts and develops the prioritisation framework, the municipality should, in network access terms, be treated as an external party. In that case, the PTO decides which applicants can be connected, and municipal projects must pass through the same prioritisation framework as all other applications, even if the municipality owns the infrastructure or is a shareholder in the PTO.

Coordination with the DSO and TSO

A third aspect is the coordination with the distribution system operator (DSO) and, where relevant, the transmission system operator (TSO). The joint consultations and supporting reports underline that DSOs and TSOs are not yet well aligned with PTOs and municipalities on the role of public transport electricity infrastructures. There is often insufficient understanding of each other's infrastructures, of the functioning and constraints of each system, and of the context of the problems at stake. Moreover, both actors frequently lack access to each other's load profiles and operational data, which makes it difficult to assess how these networks can contribute most effectively to relieving grid congestion. At the same time, inappropriate use of the networks can actually worsen congestion.

An additional complication is that DSOs have in some cases already allocated part of the contracted transport capacity of PTO connections to other customers, because PTOs structurally use less capacity than they have been allocated. In such situations, adding new applications to the PTO connection is not automatically beneficial or even feasible. Extra demand on the connection can conflict with the way the DSO now uses that capacity elsewhere, and may aggravate congestion rather than relieve it. Whether connecting new applications is desirable therefore depends not only on the technical potential of the traction power network, but also on how the DSO has planned and allocated capacity in the wider public grid.

For these reasons, early and structured coordination between PTOs or municipalities and DSOs is essential. Without this, actors do not know how public transport electricity infrastructures can contribute most effectively to alleviating congestion, and there is a real risk that poorly designed uses of the network exacerbate bottlenecks. Such coordination should clarify the current situation, explore how public transport electricity infrastructures can contribute most effectively, and agree on workable congestion management options and on whether and how third parties could be connected. This includes discussing headroom, interface conditions, expected load profiles, possible flexibility measures, safe operating practices, the status and use of the contracted transport capacity, and better communication about expected future consumption. Making this a standard process helps avoid solutions that inadvertently increase congestion and supports a shared understanding of the challenges and capacities on both sides. It also directly addresses siloed practices by creating a joint problem framing and by using each other's knowledge to arrive at more effective system solutions, which is a necessary precondition for any later prioritisation framework.

Knowledge gaps, uncertainties, and institutional bottlenecks

The study also uncovers several knowledge gaps and institutional bottlenecks that were not fully anticipated at the outset. Some initial assumptions proved to be inappropriate, for example the expectation that assessing legal components of an applications would need to be via a separate theme in the ranking, or the assumption that there was already substantial knowledge sharing across cases. Clarifying these gaps is valuable in its own right, because it indicates what needs to be addressed before more formalised prioritisation tools can be meaningfully developed and applied.

Limited knowledge sharing and learning across cases

Although some pilots and projects exist, knowledge sharing remains limited. Stakeholders do not yet have access to a common set of guidelines, frequently asked questions or reference cases that would allow them to quickly understand options and pitfalls. There is currently no dedicated design team that concentrates the necessary expertise on connecting energy applications and can support parties that wish to do so. Instead, each actor largely investigates possibilities for itself, often with similar questions and uncertainties. Lessons from one case are not systematically captured or transferred, which means that actors repeatedly reinvent solutions and promising options are not compared or weighed in a structured way. This finding aligns with the pattern of limited cross case learning and reinforces the call for sector wide knowledge development, so that choices are less dependent on isolated experiences or partial information.

Concrete case documentation could already help, for example if PTOs such as RET or HTM were to systematically record their experiences with Closed System applications, Installation method connections, and the associated legal and technical trade-offs, or share this information with an independent knowledge institute or platform. A more structured exchange of such experiences would lower the barrier for other municipalities and PTOs to understand the landscape, and be able to use their infrastructure to connect energy applications and relief grid congestion as well.

Limited understanding of each other's systems

As discussed above, the study shows that stakeholders often have only a partial understanding of each other’s systems. This not only concerns technical parameters such as voltages, loading patterns and redundancy, but also more general knowledge of how these systems work and how they could be combined to find better solutions. For instance, PTO networks are in some cases well equipped to absorb high peaks or to help transport energy, while PTOs may not fully understand the underlying problems on the DSO or TSO side that their systems could help address. Without a better shared grasp of what the PTO and the DSO can and cannot facilitate, and without clear communication to other stakeholders such as provinces and municipalities about what is technically realistic, there is a risk that actors invest in technically undesirable or unfeasible projects.

Without this shared understanding, it is difficult to even specify what a realistic prioritisation framework would have to take into account. Joint learning and co-creation are therefore important: by exploring each other’s systems together, actors can identify where capacities complement each other, where constraints are binding, and where the traction power network can meaningfully support or relieve the public grid.

Legal options and a narrowed focus

Another emergent insight concerns the way in which legal options are perceived and used. Many stakeholders initially focused almost exclusively on the examples of Rotterdam (Closed System) and The Hague (Installation method), implicitly assuming that these two routes were the only relevant ones. Alternatives such as Cable Pooling, Direct Lines or coordinated Congestion Management were often overlooked or only considered late in the process. This narrow focus risks copying solutions from visible frontrunners without critically assessing whether these routes fit the local context and objectives.

The thesis therefore makes the available legal options explicit, based on interviews with experts including the regulator, and argues that legal form should not be treated as a separate ranking theme in a future prioritisation framework. In many cases, applications that are considered promising the municipal perspective can be realised under the Installation method. Only when top ranked applications cannot be accommodated that way does it become necessary to explore more complex legal routes such as a Closed System or the more easy method Cable Pooling. Highlighting this narrow focus is important, so that future stakeholders remain aware of it and deliberately maintain an open view of the legal solution space and other options outside their scope.

Most suitable infrastructures for connecting applications

From a technical system perspective, the study suggests that not all public transport electricity infrastructures are equally suited for facilitating (third-party) energy applications. Metro (and train) infrastructures often prove more promising, because their demand is more predictable, regenerative energy volumes are higher and nominal voltages are higher, which together increase the potential for stable and manageable connections. Tram (or trolleybus) networks, by contrast, operate at lower voltage, consist of more substations and exhibit less predictable profiles due to urban operations, braking and acceleration cycles and re-routings, which complicates technical facilitation. Legal feasibility for obtaining Closed System recognition on tram networks also appears more challenging and less favourable. By analogy, trolleybus networks are likely to be less suitable than metro networks, whereas national rail networks, where governance and access permit, are well suited as well.

Platform selection, therefore remains a case specific choice that should be made jointly with grid operators and asset owners. From a legal perspective, metro and heavy rail networks are generally suitable candidates for Closed System recognition, as illustrated by ProRail and RET Metro, which already hold such recognitions in the form of a GDS until 31 December 2025, which then will be considered a Closed System. The implication for practice is that stakeholders should be cautious about investing effort in complex Closed System constructions for tram and trolleybus networks, and instead focus on Installation method, Cable Pooling connections where appropriate. A Direct Line or Congestion Management are suitable approaches for all types of networks or electricity infrastructure.

Additional valuable results

Finally, two additional insights concern how to deal with legal pathways and with costs and benefits in the context of possible future frameworks.

Prioritising legal and procedural routes pragmatically

Technical respondents often consider a Closed System to be a powerful legal route, but they also acknowledge that it entails variable timelines and significant obligations. Societal respondents express mixed views on the additional burden for public transport operators when they are expected to connect (third-party) energy applications. At the same time, many stakeholders prefer application types that are feasible under the Installation method, which is usually more straightforward to implement.

These findings support the design choice in this thesis to treat the legal layer as an enabling gate rather than as a separate ranking theme. Legal constructs are seen as implementation choices that determine whether and how a technically and societally attractive application can lawfully be connected, and under which responsibilities. They strongly affect how much control the public PTO or municipality retains over the consumption of the energy application, the contractual and administrative burden that follows from the chosen construction, and the degree of freedom the public PTO or municipality keeps to use its own network and residual capacity after the energy application has been connected. Making the legal track the starting point of the process would slow progress considerably, because the topic is still relatively new, many legal questions do not yet have definitive answers, and the regulator can only assess concrete proposals within the boundaries of the law. Furthermore, it would require substantial time and money to examine every legal construct in detail for every individual application, so it is more efficient to do this only for a small set of applications that score highly on the technical and societal themes. Each case is also specific, and ranking every energy application individually on detailed legal aspects would require disproportionate time and resources. There is also a technical argument for starting with the technical assessment. An application may initially be envisaged as a DC connection that could in principle be realised via the Installation construction, but a subsequent technical analysis may reveal, for example, voltage problems that make a DC connection infeasible. In that case the application would instead have to be connected on the AC side, which means that the Installation construction is no longer appropriate and that, for example, Cable Pooling is required. Starting with a detailed legal assessment of all applications in such a situation would therefore be inefficient, because the technical analysis can subsequently rule out the initially envisaged option and necessitate a different legal construction.

This thesis therefore suggests a pragmatic sequencing for future practice, with the technical assessment first, the societal assessment second, and a legal assessment only at the end. Before applying the assessment and prioritisation framework, however, the network owner should coordinate with the DSO and, where relevant, the TSO to understand what is technically and operationally realistic and where capacity is available. At locations where it is technically impossible to connect applications, or where there is insufficient capacity either on the DSO (or TSO) grid or within the PTO or municipal network, energy applications can be excluded upfront. Organisations may also deliberately decide not to pursue Closed System recognition because of the additional obligations and external burdens it entails. If there are no suitable free connection points available at the intake substation for Cable Pooling, or if key conditions for Cable Pooling are not met, all third-party energy applications except those that generate renewable energy can be excluded from further consideration.

After this is done, public PTOs and municipalities working with a private PTO should first apply the prioritisation framework, a context-specific assessment, to identify the most valuable application types in their situation, ranked on technical and societal aspects. These are likely to be connectable via the Installation method, which accelerates implementation and avoids unnecessary effort on less suitable legal routes. If top-ranked options involve third-party owned WOZ-assets, stakeholders can then specifically investigate first if Cable Pooling is a potential solution and otherwise discuss within the organisation and stakeholders if the organisation should apply for a Closed System recognition to connect that specific set of applications. Where appropriate, Direct Line should be used to connect RES.

In this way, legal routes follow from substantive prioritisation rather than dominating it. The legal decision flowchart presented in this thesis, Figure 11.1, builds on these principles and supports PTOs and municipalities in selecting the most appropriate legal construction for each application. It assumes that applications have already been ranked using technical and societal components and that sufficient grid capacity is available. It then guides practitioners through a sequence of questions on ownership, WOZ-status, current type and the availability of free connection points, and indicates whether an application can be connected via the Installation method, Cable Pooling, a Closed System or a Direct Line. Different legal constructions can co-exist within one network, and the flowchart is designed to guide practitioners towards the most suitable and least complex option, and to identify cases where a connection is technically or legally not feasible. This pragmatic, enabling view of legal options is an important implication of the study for any future prioritisation framework.

Treating costs as a feasibility filter instead of being an independent ranking theme

The study also indicates that there is currently no complete overview of costs and benefits for the different application types and legal constructions. Including costs as a separate ranking theme in a detailed scoring model would, therefore give a false impression of precision. Following the spirit of the IPF, it is more practical in this context to treat costs as part of technical and organisational feasibility rather than as an independent dimension in the scoring.

In practice this means that, for example, controllability is assessed in light of the measures required to achieve it. If an application would only be controllable with a very expensive energy storage system that exceeds realistic budgetary thresholds, it should be classified as not realistically controllable and its technical score reduced or the option excluded from further consideration. This keeps any future framework workable, avoids detailed analysis of technically possible but financially implausible options, and leaves full cost benefit assessments to later project stages or future research.

Societal priorities require democratic choice

The research also shows that, for the societal theme, municipalities and provinces or PTAs are not yet aligned on which objectives should be given most weight. Survey responses and interviews indicate that public authorities see the need for a framework, but prefer to decide detailed societal criteria and weights through political or democratic processes, for example in council decisions or regional energy strategies. This means that the thesis can propose candidate components and design principles, but cannot prescribe a single societal weighting scheme. This insight is important, because it clarifies that finalising the societal theme is primarily a governance task for public authorities.

The ACM has a more limited and focused role than initially assumed

In the early stages of the research, the ACM was often imagined as a central partner throughout the design of the framework. Interviews and legal analysis show that this is neither realistic nor desirable. The ACM's mandate is to interpret and enforce legislation, assess exemption applications and supervise tariffs and non-discrimination, not to help with co-designing a local prioritisation frameworks. The study clarifies that the ACM should be involved selectively, with well formulated questions on specific legal constructs or exemption routes, and at the moment when a concrete proposal is ready. This more focused role reduces expectations of continuous ACM involvement and places primary responsibility with PTOs, municipalities and PTAs.

Taken together, these emergent insights clarify the institutional context, legal and technical context that must be understood before robust prioritisation frameworks for public transport electricity infrastructures can be developed. They highlight that differences between infrastructures, governance models and legal routes are not peripheral details, but central factors that should shape future work on such frameworks.

Practical guidance for organising the connection of applications

The findings of this research suggest that connecting (third-party) energy applications to public transport electricity infrastructure is as much an organisational and governance challenge as it is a technical or legal one. This subsection translates those insights into practical guidance on how stakeholders can jointly organise the process, in which order key steps should be taken, and why collaboration and knowledge sharing are essential if traction power networks are to be used effectively.

Interviews and the stakeholder survey show that stakeholders are not yet consistently aligned on how a PTO network should be used, which parties should be involved at which stage, and what each party can or cannot contribute. To move from isolated initiatives to sector-wide solutions, both the timing and the scope of stakeholder involvement need to be recalibrated. A clear overview of stakeholders, their roles, their points of influence, and their expected contributions is required to prioritise applications effectively and to identify how public transport electricity infrastructure can most usefully help relieve grid congestion. Figure 10.1 summarises this by positioning stakeholders according to their impact on the outcome and the level of involvement that is required in the process. As a complement to this figure, the list in the section underneath explains for each stakeholder why their involvement is required, at which stages of the process their input is needed, and how their impact and level of involvement should be interpreted.

Positioning stakeholders in the process

Stakeholder roles, influence and involvement.

- **Public PTO**

  Role: Primary operational decision maker and day-to-day operator of the traction power network.

  Why involve: The public PTO controls, operates and maintains the infrastructure, has the most detailed technical knowledge and data, and is responsible for running the public transport concession while applications are connected or congestion management measures are implemented. It is also the party that must implement and live with the outcomes of any prioritisation framework.

  How and when to involve: From the very beginning, in order to

  - share technical knowledge with the DSO, including load profiles, operational limits, safety requirements and expected future operations
  - discuss with the DSO what is technically feasible and desirable, and how the traction infrastructure can be used most effectively
  - participate in joint consultations with the DSO, municipality and PTA or province to align ambitions and agree a shared direction for how the network will be used
  - explore generally, together with legal experts or ACM where necessary, which legal constructs are realistic
  - indicate whether the PTO is willing and able to act as Closed System operator
  - co-design the technical theme and components of the prioritisation framework
  - formulate technical preconditions that applications must satisfy before they are eligible to apply for a connection
  - help design a standardised application fiche specifying the technical, legal and societal information that applicants must provide
  - apply the prioritisation framework to candidate applications and assess whether they are technically, operationally and societally feasible
  - translate prioritised applications into concrete connection projects and operational protocols.

  Impact: High. The public PTO shapes how the network is actually used and must ensure that transport operations remain safe and reliable.

Involvement: High. The public PTO needs to be involved throughout, both in the design of the framework and in its application.

- **Private PTO**

  Role: Concession holder and operator whose core public transport activities must not be undermined.

  Why involve: A private PTO holds the operational knowledge and metering data and carries commercial risk. It has to operate its services while the municipality uses the network to connect applications or apply congestion management, and therefore has a legitimate interest in how the infrastructure is used.

  How and when to involve: From the very beginning, in order to

  - clarify which technical data and load profiles can be shared under the concession and under what conditions
  - identify operational risks and minimum conditions under which the PTO is willing to host (third-party) energy applications
  - participate in joint consultations with the DSO, municipality and PTA or province to align expectations about how the network will be used
  - discuss how day-to-day operations can continue safely and reliably, and which tasks might be transferred to the municipality if it assumes more responsibility for the network
  - where the private PTO holds the energy contracts, either transfer those contracts to the municipality or provide sufficient contract and load profile data so that the municipality can discuss technical feasibility with the DSO.

  Impact: Potentially high. Where concession conditions require cooperation, the PTO must contribute. Where such clauses are absent, a private PTO can resist sharing data or facilitating applications in order to protect its core business. In all cases, its input is essential for understanding what is technically and operationally acceptable.

  Involvement: Medium to high. The municipality should lead the development of the framework, while the private PTO is consulted regularly to ensure that proposed measures do not jeopardise public transport operations.

- **DSO (and, where relevant the TSO)**

  Role: Grid operator responsible for the public connection and transport capacity, and technical expert on the wider electricity system.

  Why involve: The DSO knows the contracted capacity, connection conditions and system obligations that determine what is feasible on the public grid side, and it has a system-wide view of where congestion occurs and what type of support is most valuable. The DSO can also act as the main contact point with the TSO where necessary.

  How and when to involve: From the very beginning, in order to

  - explain to the public PTO or municipality what is currently permitted under the connection contract and what would require a contract change
  - indicate how much additional power or flexibility can realistically be accommodated at which locations and under which time profiles
  - take part in joint consultations with PTO, municipality and PTA or province to align expectations about the contribution of the traction network to relieving congestion
  - co-design workable congestion management arrangements, curtailment rules or flexibility products for PTO connections
  - warn when proposed uses of the traction network could worsen congestion elsewhere in the system
  - share relevant technical knowledge about grid behaviour and interface requirements
  - where needed, negotiate and conclude new energy or connection contracts, for example under cable pooling or specific congestion management arrangements.

Impact: High. The DSO determines what is feasible from a grid capacity and system security perspective and can point out where the public transport infrastructure can contribute most effectively.

Involvement: Medium. Intensive involvement is required in the early diagnostic and design phases; later, the DSO mainly reviews proposals, updates capacity information and concludes or adjusts contracts.

◦ **Municipality with public PTO**

Role: Owner of the public transport infrastructure and local public authority that sets spatial and societal priorities.

Why involve: The municipality defines local societal objectives, spatial plans and climate policies. When it is also owner or shareholder of a public PTO, these objectives can be aligned directly with the operator's use of the network.

How and when to involve: In the early joint consultations, in order to

- participate in joint discussions with DSO, PTO and PTA or province on how the network should contribute to relieving congestion and supporting local goals
- define which societal objectives the municipality wants connected applications to support
- explore how the municipality can help accelerate implementation, for example by facilitating permitting or providing co-funding
- act, where relevant, as an applicant itself that must still pass through the prioritisation framework on the same basis as other parties
- reflect agreed objectives in new concession requirements, together with the PTA or province.

Impact: Medium to high. As infrastructure owner, the municipality has a say in how the network is used, but in a public PTO setting this typically happens in close partnership and with mutual trust between PTO and municipality.

Involvement: Medium to high. The municipality is central for defining the societal theme and for embedding objectives in concession requirements, but does not take over day-to-day network operations.

◦ **Municipality with private PTO**

Role: Owner of the public transport infrastructure and prospective operator or coordinator of its use for wider energy purposes.

Why involve: In this configuration the municipality owns the assets and is the natural party to take long-term responsibility for using the network to relieve grid congestion, while ensuring that public transport operations remain protected.

How and when to involve: From the very beginning, in order to

- build or strengthen internal departments with technical knowledge and asset management capacity for the traction power network
- obtain technical knowledge and data from the private PTO and understand its operational constraints
- exercise more control over its network, for instance by deploying its own energy management systems (EMS)
- identify conditions under which the private PTO is willing to host (third-party) energy applications or flexibility measures
- agree how operational responsibilities are divided between PTO and municipality
- share technical information with the DSO and discuss what is technically feasible and desirable
- participate in joint consultations with DSO, PTO and PTA or province to align ambitions and expectations
- explore generally, together with legal experts or ACM where necessary, which legal constructs are realistic
- co-design both the technical and societal themes of the prioritisation framework
- formulate preconditions that applications must meet before they are eligible to apply

  - develop a standardised application fiche that captures all technical, legal and societal data required for assessment
  - apply the prioritisation framework and translate prioritised applications into concrete projects and operational protocols
  - where the private PTO holds the energy contracts, negotiate transfer or structured data access so that the municipality can discuss feasibility with the DSO
  - negotiate with PTA or province and the private PTO on including cooperation, data sharing and facilitation duties in future concessions.

  Impact: High. The municipality decides whether and how its network will be used as an energy asset and must ensure that responsibilities, risks and benefits are allocated appropriately.

  Involvement: High. The municipality leads the process, coordinates stakeholders and ultimately bears responsibility for the framework and its application.

- **Province / PTA (concession provider)**

  Role: Concession-granting authority that can embed cooperation and data-sharing duties in concession conditions.

  Why involve: The PTA or province determines concession requirements and can turn desired collaboration and transparency into formal obligations for PTOs and other parties.

  How and when to involve: In the early joint consultations, in order to

  - participate in joint discussions with DSO, PTO and municipality on how the network should be used and how this relates to public transport objectives
  - help shape a viable business case for PTOs or municipalities that take on additional tasks, including by providing funding where appropriate
  - include clear requirements on data sharing, participation in congestion management and use of the prioritisation framework in concession documents
  - formulate the societal objectives for which the network should be used, together with municipalities
  - balance regional public transport needs with the use of PTO networks as energy assets
  - coordinate between multiple PTOs and municipalities within the same region to avoid fragmented approaches.

  Impact: High. By defining concession conditions, the PTA can strongly influence whether cooperation, data access and prioritisation practices become standard.

  Involvement: Medium to high. Intensive involvement is needed when revising concession requirements and aligning regional strategies and societal objectives.

- **ACM**

  Role: Regulatory interpreter and supervisor, not a project partner.

  Why involve: ACM clarifies how the law applies to specific constructions and can grant recognitions or exemptions where justified. It also monitors non-discrimination, transparency and tariff rules.

  How and when to involve: Selectively and with focused questions, in order to

  - decide whether intended legal routes (Installation method, Cable Pooling, Closed System, Direct Line) fit within existing rules
  - discuss conditions and required documentation for a Closed System recognition or for registering a Direct Line
  - clarify specific legal questions that arise in concrete cases
  - formally notify ACM when certain legal constructions are implemented and when required by law.

Impact: Medium. ACM can effectively give a green or red light for specific legal constructs within the boundaries of existing legislation, but it does not set local policy or project priorities.

Involvement: Low. ACM is consulted at key legal decision points and in formal procedures, but is not part of the ongoing multi-stakeholder process.

- **National government**

  Role: Legislator and programme owner at national level.

  Why involve: Ministries can amend primary and secondary legislation, set national policy frameworks and funding programmes, and establish knowledge platforms that support the use of infrastructures to relieve grid congestion.

  How and when to involve: Primarily at a strategic level, in order to

  - establish knowledge programmes and guidance on using existing infrastructures for congestion relief
  - develop or adjust national instruments and subsidies that improve the business case for PTOs and municipalities
  - work with ACM on regulatory changes where pilots reveal structural legal barriers
  - provide targeted funding for pilots or strategic projects that test new legal constructs in practice.

  Impact: Low. The national government can change the legal and financial context, but this is time-consuming and will therefore not directly steer individual projects.

  Involvement: Low and mainly indirect. Involvement is through national programmes, legislative changes and funding instruments, rather than through case-specific decision making.

In this positioning, DSOs have a high impact and should be involved early. They are key to understanding where the public distribution grid has headroom, where it is structurally congested, and how the traction power network could support congestion relief. At locations where transmission constraints are also relevant, the TSO should be consulted through or alongside the DSO. If necessary, a general exploratory meeting with the ACM might be possible to arrange, to get advise and recommendations on specific legal questions, for example how certain application types can be connected under the new Energy Act or which exemptions might be feasible. The ACM can clarify interpretations and, where justified, grant exemptions, but should not be embedded as a day to day participant in the process. Similarly, the national government is not required in operational decision making about individual connections, because legal changes and exemptions follow formal policy and regulatory procedures that are primarily channelled through the ACM. Municipalities, provinces and PTAs, by contrast, play an important role in shaping societal priorities and concession conditions, and therefore have substantial influence on the societal theme of the framework.

Based on these roles, a practical sequence of steps can be derived. This sequence is outlined in the section below.

Stepwise process to understand how to use the public transport electricity infrastructure the most effective

1. **Develop a joint understanding of technical possibilities and constraints**
   As a first step, the public PTO or, in concessions with a private PTO, the municipal asset owner together with the PTO that operates the network, should analyse with the DSO and, where relevant, the TSO what is technically possible. This requires sharing data on current and expected future load profiles, system capacities and operational constraints of both the public grid and the traction power network. In the case of a private PTO, the municipality depends on the PTO to obtain these data and operational insights. The goal is to identify where and how the traction power network could best contribute to reducing congestion, which locations are technically suitable for connecting applications, and how to safeguard core public transport operations and internal PTO objectives. This step also serves as a reality check for the technical theme of the framework, ensuring that its components capture the key technical risks and system effects for the specific network and context. Discuss also the technical feasibility of bi-directional inverters to feed-in braking energy into the public grid.

In parallel, the public PTO or municipality should work on building or strengthening or collaboration with partners on technical teams that are able to perform the required electrical engineering calculations, design and on a team that is able to realise new connection points, and manage, maintain and repair the additional assets. They should also assess whether there is sufficient internal capacity to take on the administrative tasks associated with connecting external applications, such as contract management, metering, billing and data handling. If, in practice, it is collaboratively is decided that few or no external applications will ne connected, the size and scope of these teams can be scaled down.

2. **Jointly explore ambitions and possible ways to deploy the network**
Once there is a shared (DSO and public PTO and municipality) understanding of the technical possibilities, the PTO, the network operator (often the PTO itself or, in future, the municipality with a private PTO), the asset owner (often the municipality or, in some cases, the province or PTA), the DSO (and where relevant the TSO), the province or PTA, and where possible a legal expert should jointly discuss whether and how the traction power network should be used beyond its core transport function. In concessions with a private PTO, that PTO should be involved as the operational expert and concession holder whose core business must not be undermined. In this stage, stakeholders exchange views on needs and ambitions, potential contributions to congestion relief, and shared objectives for the area. It should also be discussed whether connecting external applications is actually desirable, or whether alternative measures, such as congestion management on the existing connection, are preferable at specific sites, based on the outcomes of the discussion of the previous step (*Develop a joint understanding of technical possibilities and constraints*). The aim of this step is to develop a shared picture of what the network could do, what each stakeholder expects, and to build a common agenda rather than separate, silo based plans.
3. **Decide on the preferred strategy: connecting applications, congestion management, a combination, or do nothing**
At this stage, based on the outcomes of the joint consultations and the options identified in the technical consultations, the stakeholders (PTO, municipality, PTA/Province, DSO) decide whether to focus primarily on connecting energy applications, on applying congestion management measures within the existing connection, on a combination of both, or do nothing. This step links the technical opportunities to the internal objectives of the PTO and the societal priorities of public authorities, and results in a strategic choice about the role of the traction power network. When is decided to connect (third-party) energy applications,

continue with the following steps:

Advise: Assume that the installation method will probably work for the highest scoring types of applications that will be connected, based on the preferences of the municipalities and PTAs/provinces.

4. **Develop the technical and societal themes, define the preconditions and formulate the application form**
If stakeholders decide to pursue the connection of energy applications, the technical departments of the public PTO or municipality should jointly elaborate the technical theme together with the DSO. Using shared detailed information about load profiles, system capacities, limits and asset characteristics, to translate these into concrete components and scoring rules. At the same time, the municipality, province and/or PTA further specify the societal theme, by agreeing on which societal effects are most important and how they should be reflected in the framework. Examples of societal objectives that connected applications should serve could be decarbonisation, supporting local employment, or improving spatial quality and investigate whether congestion conditions or political priorities have changed.

   On the basis of these discussions, preconditions for applications can be formulated, with minimum technical requirements, specific locations, or societal criteria and legal information that applications must meet to be considered. An application form must also be developed that applicants must complete in order for their application to be scored. This fiche should include all data needed to check preconditions, to score applications on technical and societal themes, and to determine which legal construct might be used for connection. Examples of technical information that needs to be included in the fiche are among other, expected load profiles, preferred connection points, growth plans, expected connection periods, controllability measures, storage provisions, criticality or continuous energy needs, and import and export details

5. **Support the development, explore funding and concession conditions**
   The municipality, PTA and province should how they can support the development of using the network the relief grid congestion, and investigate whether funding programmes are available for financial support or other instruments are available to make business cases more viable. Concession requirements can be adjusted in future tender rounds to improve data access for the municipality, clarify whether the municipality may manage energy contracts, and to require PTOs to cooperate in congestion management or in connecting applications where this is aligned with policy goals.
6. **Implement the framework, assess applications and choose the legal construct**
   Once the preconditions, themes and templates are in place, applications can be submitted and prioritised. The framework is then used to rank applications and to identify those that best fit the technical and societal objectives. The framework should be applied in the sequence of: technical first, then societal. Since technical is a key theme, all the low scoring applications should be removed, before the societal scoring is done. For the highest scoring applications, a legal assessment needs to be done. The public PTO or municipality (, together with legal advisors,) should determine which legal construct is appropriate: Installation, Cable Pooling, Closed System, or Direct Line. Where needed, the ACM should be consulted, for example when applying for Cable Pooling, seeking a Closed System recognition, clarifying the status of an Installation, or registering a Direct Line. New agreements with the DSO (or TSO) may be required to implement the chosen legal construct and to update connection and transport contracts.
7. **Learn, share knowledge and iteratively improve the framework**
   Throughout the process, lessons should be collected and shared. Internally, PTOs and municipalities can establish a small knowledge team with expertise in grid operations, legal frameworks, planning and finance to support cases and to act as a link between technical practice and the framework. Externally, experiences can be exchanged with other regions via DSO, PTA or national programmes. As new insights emerge, components, preconditions and scoring rules in the framework should be refined, and when better data become available, additional themes, such as explicit economic criteria, can be incorporated. Aggregated experiences from multiple regions can also inform ministries and the ACM when considering adjustments to legislation, codes or national support instruments.

Taken together, these steps underline that effectively using the public transport electricity infrastructure is a collaborative and iterative process rather than solely a technical decision by the PTO. The guidance proposed in this thesis can structure that process, but its success depends on timely involvement of the right stakeholders, clear agreements on roles and information sharing, and a willingness to move beyond siloed practices. These insights are translated into a concise overview that specifies for each stakeholder what is expected, which information they should provide, and at which stages of the process they should be involved.

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Limitations

This chapter outlines the main limitations of the study, explains their implications for interpreting the findings, and indicates how future work can address them.

Scope change

Due to the scope change during the project, the thesis became substantially broader. This enlargement meant that the newly formulated research objectives could not all be explored with the same depth as would have been possible if they had been the primary focus from the outset. At the same time, the need for this shift only became visible while the work progressed and it became clear how complex and context dependent the situation is. Mapping that complexity has value in itself, because it has produced a clearer picture of the system and its context, which now gives stakeholders a better basis from which to proceed.

Sample size of survey respondents

To test the themes and components thoroughly across stakeholder groups with technical expertise, PTO operational insight, or municipal and provincial policy responsibilities, a larger respondent pool would have been preferable. For both surveys, technical and societal, only four respondents participated, so 8 in total. With more stakeholders contributing their expertise and perspectives, stronger analyses and firmer conclusions could have been drawn about the relative importance of themes and aspects. Recruitment proved difficult, as many invitees indicated limited time, an insufficient mandate to respond, or did not reply. The interview programme and the reasoning provided by respondents nevertheless yielded useful insights that inform implementation and can give direction to future research, yet the small sample constrains generalisability across (multiple) PTO cases. In addition, triangulation with expert judgement and the literature review provides stronger evidence for the importance of the technical themes.

Literature base for the technical components

There is relatively little academic literature on traction power systems, in particular on the influence that external connections may have on such networks. With a broader literature base, additional technical components might have been identified. To mitigate this gap, an interview with a traction power network expert and researcher was conducted to obtain advice and to deepen the understanding of technical properties of traction power networks in the PTO context, including candidate components for assessing applications. This additional source strengthens the justification of the selected aspects, and, importantly, survey participants with technical expertise converged on the most critical aspects to include in the prioritisation framework.

Literature base for the societal components

In retrospect, more targeted literature research could have been conducted on how to operationalise the societal theme. The initial focus was on the Triple Bottom Line, with an emphasis on practical applicability. Given time constraints, substantial effort was directed toward the technical theme, the legal landscape for connection constructions, and the inventory of applications and stakeholders. The impact of this limitation on the final framework is modest, since stakeholders indicated a preference to determine societal priorities democratically. Even if alternative societal components or sub-themes had been explored, the expectation is that municipalities and provinces would still choose to decide these elements internally. The current work, therefore serves as a practical set of components and themes, helping stakeholders to consider where applications might be prioritised and which aspects could be used to do so, while contributing to corporate social responsibility objectives.

Context Dependent

The study focuses on PTOs and municipalities that own public transport electricity infrastructure, but there are also private PTOs and other organisations that own or operate traction power networks or other electricity infrastructure as well. For these parties, the results remain still relevant. The study provides a structured overview of the system, explains key concepts, and offers an outline that they can also use for the development of a prioritisation framework in their own setting. In particular, the technical theme is formulated broadly so that it can be used across different network types. The societal theme is, by its nature, context specific and should be co defined together with the relevant municipalities and provinces or PTAs. The technical theme is also dependent, to a degree, on contractual arrangements that determine available headroom, on operational characteristics such as timetable and rolling stock, and on the preferences of the local DSO regarding how the public transport electricity infrastructure is used to support the public grid.

The examples also reflect only the Dutch context, and the outputs from the organisations and legal conditions are subject to change. These risks were mitigated by setting preconditions and by recommending that users of the framework formulate their own scoring methods, thresholds and weightings based on the local context and, once again, review the various themes together with local authorities and the internal technical department to see whether the themes best fit the context of the PTO.

PTA involvement

It can be debated if the PTAs fully in act in the public interest, since their primary focus is on transport service provision within the PTA area. Engaging municipalities and provinces was practical here, since they take a broader perspective that may enable more effective relief of grid congestion than solutions considered within a mobility-only scope. The provinces are also often the PTA for a specific area and can therefore both align the vision from its position as a PTA and as province to achieve the highest societal interest. In case where the PTA is not the province, the vision and objectives can be more biased towards improving public transport in the concession area or by supporting other PTOs within that area, instead of achieving the highest societal impact for community in general.

Costs and benefits

The study did not include a dedicated costs-and-benefits theme, although this is recommended by an expert and follows from the Triple Bottom Line. A structured economic analysis was not feasible due to the limited availability of pilots and empirical data, and the context-dependent nature of the costs of so many different types of items, including legal arrangements, staffing for legal analysis and applications, customer management and communications in case of Closed System recognitions, potential new departments for installation and maintenance or for legal affairs, safety planning and insurance, installation and maintenance related costs, risk in calculations, and construct-specific expenditures. Nor was there a reliable overview of potential benefits. As a partial safeguard within the technical theme, applications should not be scored as highly controllable if achieving that controllability would be prohibitively expensive in the given context. The absence of a full economic treatment weakens the framework, therefore future work should develop a robust approach to costs and benefits to support business case formation, see also 3.3. The technical theme also implies that connections that are only technically feasible at disproportionate cost and with limited benefit should already be filtered out or downgraded.

Legal assumptions

Several legal interpretations in this study could not be verified with the ACM and were, therefore treated as assumptions. Examples include whether a mobile energy bank constitutes as a WOZ-object, and whether, in some cases, an application connected via a Direct Line could have a back-up connection to the public transport electricity infrastructure. These were reasoned possibilities that could help relieve congestion, yet they were not confirmed. The ACM could not provide definitive answers within the scope of this research, and external legal expertise would be required for a conclusive assessment. This does not affect the final prioritisation framework, since legal aspects are not part of the framework itself.

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Conclusion

This study was motivated by structural congestion on the Dutch electricity grid and the emerging idea that public transport electricity infrastructures could help alleviate this congestion by hosting (third-party) energy applications. The work focused on the electricity infrastructures used by Dutch public transport operators and explored under which conditions these networks can be used for connecting energy applications without jeopardising the core public transport service.

The initial ambition was to provide advice for a practical prioritisation framework that would help municipalities and PTOs decide which applications to connect to their networks. As the research progressed, the empirical work showed that the system in which such a framework would have to operate is technically and institutionally complex, with large differences between types of networks, governance settings and legal options, and undefined societal objectives. It became clear that before a fully realistic operational prioritisation framework can be developed, a more basic level of shared understanding is needed about how the system works, what the current problems are, who is responsible for what, which legal routes exist, and which types of applications could potentially be connected to public transport electricity infrastructures.

A clear overview of the system is essential to ensure that the public transport service remains the first priority, that the network is used as effectively as possible, and that actors do not commit to unnecessarily complex or unsuitable legal constructions without delivering proportional benefits. At the start of this research there was limited shared understanding of which aspects should be assessed, which parties should be involved at which stage, and how priorities should be set across competing applications. This thesis addresses those gaps by advising a set of technical and societal themes and components for future prioritisation frameworks, clarifying stakeholder roles and involvement, mapping viable application types, and explaining legal implementation routes. The work also surfaces system level lessons about platform suitability, governance, knowledge sharing and the sequencing of decisions.

Building on this foundation, the remainder of this chapter first answers the sub-research questions, then answers the main research question, and finally presents the definitive outline for a future prioritisation framework and the contribution of the thesis to literature and practice.

14.1. Answers to the Sub-Research Questions

Research Question 1

> *Which stakeholders should be involved in order to effectively connect (third-party) energy applications, and what are their roles and influence?*

Two stakeholder groups are central for determining how the traction power network can be used most effectively: the operator of the network and the DSO. The operator is either the public PTO or, in concessions with a private PTO, the municipality that holds the energy contracts and access to technical data such as load profiles, in close collaboration with the private PTO. Together with the DSO they bring together the technical knowledge of the traction power system and the public grid and are best placed to judge what is technically feasible and desirable. On this basis they jointly identify how the network can be used as effectively as possible to relief grid congestion.

The group that designs the final prioritisation framework should mirror this division of tasks. The technical theme should be developed and owned by the operator of the traction power network, which is either the public PTO or the municipality acting as network operator, because this party holds the detailed technical expertise and operational responsibility. The societal theme should be developed by the municipality in collaboration with the province or PTA. The municipality and or province or PTA leads the societal judgement and represents the public interest, while the PTO or municipal network operator leads the technical judgement and safeguards traction operations and safety. Together they make the prioritisation decisions.

The DSO and, where relevant, the TSO are consulted to confirm available capacity, interface conditions and operational constraints and to identify how the PTO network can most usefully contribute, but they do not adjudicate societal value. The ACM interprets and confirms the lawful route for connection and grants recognitions or exemptions within the law. It holds a legality veto but does not set priorities. In this way, substantive judgement is concentrated with accountable owners, while capacity and legality function as gates, which results in a governable and transparent process.

Research Question 2

> *What types of (third-party) energy applications are currently being connected, or are viable candidates for connection, and what characterizes them?*

Ten different types of application were identified and categorised, *Energy Storage Systems (ESS)*, *EV-chargers*, *street lighting (and public space loads)*, *zero-emission equipment*, *industry*, *business park and commercial facilities*, *PTO offices, depots, and workshops*, *building service systems*, *event and temporary installations*, and *local generation*, with *bi-directional inverters* treated as an enabling tool rather than a standalone application. Applications were characterised by coupling side, size range, predictability, criticality, direction of power flow, presence of storage, relocatability, temporariness, and ability to regulate power. This categorisation provides a consistent basis for screening and prioritisation across sites and hosts, see Table 4.2. Storage frequently improves controllability and grid stability, increases system efficiency, and can capture regenerative braking energy instead of dissipating it, when the ESS type matches the traction environment and released loads.

Research Question 3

> *Which legal constructions are available for connecting (third-party) energy applications to public transport electricity infrastructure, what requirements do they entail, and what are their main advantages and disadvantages?*

Four implementation routes are relevant. The *Installation* method is the most straightforward for PTOs, it applies to PTO owned assets or non WOZ-objects, preserves control, and is comparatively fast and cost efficient. *Cable Pooling* allows a maximum of 4 proximate installations to share one main connection (GTV > 100 KVA) under a joint connection and transport agreement (ATO) and a Cable Pooling agreement (CPO), and should be faster to realise than a Closed System recognition. *Closed System* recognition enables multiple third-party WOZ-objects to operate behind a single private system within a defined site, but the operator should support non-discriminatory access and it brings operator duties. A *Direct Line* links a renewable energy producer to one or more users, either fully off grid or with exactly one public grid connection, and can couple local renewables to a large consumer, with a backup-connection to the public transport electricity infrastructure, or for the PTOs own demand. Beyond these routes, coordinated congestion management can in some contexts relieve stress on the public grid through operational alignment, it is a procedural option rather than a separate legal construct.

Figure 11.1 summarises the recommended legal assessment. It guides practitioners through a sequence of questions to determine which legal construction is applicable and proposes the least complex viable route as the default choice. Table 6.3 compares the main characteristics of the legal constructions, while Table 6.4 clarifies how each option affects network control and the associated administrative and operational burdens. Table 6.5 links application types to the legal constructions under which they can be connected.

Research Question 4

> *Which decision-making themes and corresponding components are relevant for understanding and assessing the feasibility of connecting (third-party) energy applications?*

Two themes structure the framework, *Technical* and *Societal*. *Legal* is treated as an enabling gate rather than a scoring theme. Each theme contains components, with optional aspects that allow further tailoring. The full overview appears in Table 8.12. The themes were developed from literature and expert input, to be later tested and refined with stakeholders to confirm relevance and practical value.

Research Question 5

> *How do internal, external stakeholders and experts perceive and assess these components, and where do perspectives align or diverge?*

Stakeholders from technical departments assign the greatest weight to *Controllability*, followed by *Grid Impact*, with *Installation and Maintenance* close behind. Municipal and provincial stakeholders emphasise that within the societal theme, *Sustainability* should carry roughly twice the weight of the *Social* sub-theme. Within Social, *Impact within the Organisation* ranks highest. Within Sustainability, *Prevention of Pollution* and *Alignment with democratically established goals* rank highest. Several stand-alone societal aspects receive consistently high support, therefore they should be included explicitly in the advice for the framework.

The resulting outline for a future prioritisation framework and its intended use are described in more detail in Section *Definitive Outline for a Future Prioritisation Framework*.

14.2. Answer to the Main Research Question

> *What needs to be understood and organised in terms of technical, organisational, and legal conditions so that Dutch public transport electricity infrastructures can effectively be used to connect (third-party) energy applications to help relief congestion on the public electricity grid?*

The thesis shows that effectively using public transport electricity infrastructures to host (third-party) energy applications is not primarily a question of finding a single best technical solution or delivering a fully specified prioritisation framework that can be applied everywhere. The starting point is to understand a heterogeneous and institutionally fragmented system, and to organise the conditions under which responsible decisions can be taken in specific contexts. As discussed in Section *Emergent Insights and Implications to Understand the System and its Situational Context*, the empirical work clarifies how the current system functions, identifies the main problems, and specifies which conditions need to be in place before a fully operational prioritisation framework becomes realistic.

The thesis concludes that, given the variations in the contexts around public transport electricity infrastructures, the persistence of siloed practices, the lack of alignment on objectives and roles, knowledge gaps and limited understanding of each other's systems, the structural differences between networks and whether public PTOs or private PTOs are operating, the misinterpretations about who should be involved at which stage, and the current narrowed legal focus, a fully specified and generally applicable prioritisation framework is not yet achievable. Instead, the main contribution is to provide an integrated overview of this complex system, explain the key differences between cases, and clarify what needs to be understood and what needs to be organised. In addition, the thesis offers an outline for a future MCDA based framework that PTOs and municipalities can adapt to their own context; this outline should be regarded as a supporting starting point rather than as the main contribution of the research.

On that basis, this section answers the main research question by distinguishing what needs to be *understood* and what needs to be *organised*.

What needs to be understood

System complexity and network suitability

A first insight is that Dutch public transport electricity infrastructures and their institutional environments differ substantially between cases. Networks for metro, heavy rail, tram and trolleybus operate at different voltages, have different topologies, and exhibit distinct load profiles and regenerative energy patterns. Metro and train networks generally offer greater potential for connecting (third-party) energy applications, because their demand is more predictable, nominal voltages are higher, and regenerative volumes are larger. Tram and trolleybus networks tend to be more fragmented and operationally volatile, which makes them technically and legally more complex and less attractive candidates for connecting (third-party) energy applications and for legal constructions such as Closed Systems. For these networks, it is usually more practical to work with the Installation method, Cable Pooling, and where appropriate a Direct Line, rather than aiming for ambitious multi-user constructs.

Understanding this diversity is essential, since there is no single technical solution or universal framework that can be applied across all PTO networks, since each combination of infrastructure and its characteristics, locations, stakeholder context and public grid conditions presents distinct possibilities and constraints.

Stakeholder roles and alignment

Second, the research clarifies which stakeholders must be involved, what they contribute, and when their input is needed. Municipalities and provinces or PTAs steer societal objectives and concession conditions. PTOs, whether public or private, are responsible for traction operations and hold currently a veto on grounds of operational feasibility, safety and reliability. DSOs and, where relevant, TSOs have an important system capacity overview of the public grid and the interface between the traction power networks. Provinces and/or the PTA have the responsibility for the public transport operations in the region and awards the concessions. The ACM holds a legality veto within the boundaries of energy legislation and secondary regulation.

The study shows that stakeholders are currently not well aligned on how PTO networks should be used, which roles they should play and when they should be involved. Expectations and priorities diverge, both between organisations and within them, and in several cases there is misinterpretation of who is available or mandated to help at each step. To use public transport electricity infrastructures effectively, actors must first share a clear understanding of this division of power, each other responsibilities, and the available knowledge and agree on when each party is expected to contribute and collaborate.

Differences between public and private PTO contexts

A third element that must be understood is the structural difference between contexts with a public PTO and those with a private PTO. In both settings the municipality commonly owns the infrastructure, but the position of the operator and the allocation of risks differ. Public PTOs are generally more strongly connected with municipality and hold long-term concessions, and are therefore more strongly aligned with municipal goals, and generally more willing to cooperate in connecting (third-party) energy applications, and share technical data more easily. Private PTOs operate at their own commercial risk and are understandably more cautious about additional tasks, when they are not specified in the concession requirements, that may jeopardise their core business.

Where a private PTO holds the energy contracts and controls access to metering and operational data, municipalities have limited insight into load profiles, headroom and flexibility. This severely restricts their ability to discuss options with the DSO, to determine how the network could help relieve grid congestion by connecting energy applications, and to design the technical theme for a prioritisation framework. The research therefore underlines that understanding who holds the energy contracts, who has operational control over the network, and who has data access rights is not a detail, but a central precondition for being able to connect energy applications in a structured way.

Narrowed legal focus and legal not as a theme

Fourth, the study clarifies the legal solution space. Before this research, many stakeholders focused almost exclusively on two already implemented examples, the Installation and the Closed System method, mirroring the cases of HTM and RET. As a result, other suitable alternatives were often not considered. The research shows that four implementation routes are relevant: the Installation method, Cable Pooling, Closed Systems and Direct Lines, complemented by Congestion Management as an additional lever to relieve grid congestion. Each route has its own requirements, responsibilities and implications for control, administrative burden and delivery time.

A key insight is that legal constructs are implementation tools rather than prioritisation criteria. They should act as enabling gates at the end of the process, not as a separate theme in the ranking of applications. Applications should not be scored on legal details. Instead, once technically and societally high scoring applications have been identified, the most suitable and least complex legal route should be selected for those top ranked options. This also avoids a narrowed focus on Closed Systems or on the Installation method as the preferred solutions, and opens the path to more pragmatic combinations of Installation, Cable Pooling, Direct Lines and, where appropriate, Congestion Management.

Legal decision making therefore needs to be sequenced pragmatically. Instead of trying to resolve all legal questions up front, PTOs and municipalities should first identify and rank applications on technical and societal grounds. Only for the highest ranked applications should they invest in determining the most appropriate legal construction and, where necessary, consult the ACM for specific questions. Making the legal track the starting point would slow progress considerably, because the topic is still relatively new, many legal questions do not yet have definitive answers, and the regulator can only assess concrete proposals within the boundaries of the law. It would also require substantial time and money to examine every legal construct in detail for every individual application, which is disproportionate compared to assessing only the best scoring options.

There is also a technical argument for starting with the technical assessment. An application may initially be envisaged as a DC connection that could in principle be realised via the Installation construction, but a subsequent technical analysis may reveal, for example, voltage problems that make a DC connection infeasible. In that case the application would instead have to be connected on the AC side, which means in some cases that the Installation construction might be no longer appropriate and that Cable Pooling is required. Starting with a detailed legal assessment of all applications in such a situation would therefore be inefficient, because the technical analysis can subsequently rule out the initially envisaged option and necessitate a different legal construction.

Stakeholders also emphasise that they prefer applications that are feasible under the Installation method. It is therefore sensible to concentrate first on finalising the framework and ranking applications, which can accelerate the connection of applications, and to assume that in many cases the simplest connection construction will be sufficient. It would be inefficient to invest heavily in exploring all legal options and complex routes such as Closed System recognition for every individual application, or to preselect a Closed System with all its disadvantages when it may not even be required.

Knowledge gaps, silos and mutual understanding of systems

Fifth, the study shows that knowledge sharing is still limited and siloed practices in this sector still persist. Stakeholders often lack insight into each other's systems, constraints and objectives. DSOs do not always have a clear picture of what PTO networks can offer, or have already allocated part of the GTV of the PTO their connection to other customers, or do not understand what the intentions are from the PTO, while PTOs and municipalities do not always understand the precise nature of congestion on the public grid or the conditions under which DSOs would welcome support. Within organisations, knowledge of traction networks and legal options is sometimes fragmented or missing.

This fragmented knowledge is one of the main reasons why a fully comprehensive prioritisation framework is not yet realistic. Before such a framework can be meaningfully implemented, actors need a shared understanding of technical possibilities and constraints on both the PTO network and the public grid, and must jointly investigate how the public transport electricity infrastructure should be used. Only afterwards does it make sense to consider in more detail how connections can be realised in legal terms. Finally, there needs to be a more systematic way of capturing and sharing lessons from pilots, legal implementations and projects, so that solutions are not reinvented case by case.

Note: At this moment of publishing, knowledge sharing is beginning to improve, for example through TKI Urban Energy's knowledge programme *Grid congestion & PT* (Dutch: *Netcongestie & OV*), which brings stakeholders together and coordinates the sharing of insights and experiences on flexibility, smart contracts and innovation, with the aim of using scarce grid capacity more efficiently for a future proof public transport sector.

Decision themes and the sequence of assessment

Finally, the research clarifies which decision themes matter when assessing applications and in which order they should be applied. Municipalities, provinces or PTAs and PTOs all consistently agree that PTO operations come first. A future prioritisation framework should therefore centre first on the Technical theme that safeguards traction operations and network quality, followed by a Societal theme that covers social and sustainability aspects.

The Technical theme should ultimately be fully developed and configured by the actor that operates the network and holds the technical knowledge and data on load profiles and network characteristics, that is the PTO or the municipality acting as network operator. The Societal theme should be developed in collaboration between municipalities and provinces or PTAs, since they represent the public interest and set policy priorities. Legal aspects should not be treated as a separate theme in the framework. There should be a legal assessment only for the highest scoring applications, in order to determine which legal construction fits best for those specific applications and for the context of the public PTO or municipality. Costs are treated as part of technical and organisational feasibility rather than as a separate theme.

A more detailed overview of the themes and their components is presented in the outline in Section *Definitive Outline for a Future Prioritisation Framework*.

What needs to be organised

Governance, concessions and access to data

On the organisational side, several conditions must be arranged before public transport electricity infrastructures can reliably host (third-party) energy applications. First of al, it is important to have the energy contracts and/or control over the network and data access. Where a private PTO operates on municipal infrastructure, the municipality should either hold the energy contracts itself or secure control over the network and data access to metering data and load profiles through concession requirements. The concession requirements for the private

PTO should also include clear obligations for cooperation on connecting applications and potential participating in Congestion Management. Without such provisions, a private PTO can easily block cooperation or delay projects, even when the municipality owns the physical assets.

Concession requirements are therefore a powerful instrument. Future concessions should specify duties on data sharing, collaboration with municipalities and DSOs, and the conditions under which PTO networks should be used to host (third-party) energy applications or deliver flexibility services. In addition, municipalities that expect to use their networks structurally as energy assets should take on more direct control, for example by deploying their own energy management systems to monitor and steer loads on the traction network.

Internal capacity building and operational capacity

A second organisational requirement is capacity building. Many public PTOs and municipalities currently lack sufficient internal capacity to perform electrical studies, and to design and evaluate connection options. In addition, specialised departments are required that can connect, operate, maintain and realise the connections and that can manage the legal and administrative consequences of connecting (third-party) energy applications. External consultants or technical service companies can support individual projects, but a minimum level of in-house expertise is needed to make robust decisions over time while keeping PTO operations safe and reliable.

The research therefore argues that PTOs and municipalities should invest in technical teams that can perform or commission the necessary electrical engineering calculations, design and implement metering and protection, and manage, maintain and repair additional assets. They also need legal and administrative capacity to handle contracts, metering, billing and data handling, or to manage outsourced service providers. Over time, external knowledge teams or sector wide groups can support projects, capture lessons and translate them back into improved procedures and frameworks.

A joint, stepwise process to utilise the infrastructure as effectively as possible

Third, the process of using public transport electricity infrastructures as effectively as possible to help relieve congestion must be organised in a joint and stepwise way. The thesis proposes a practical guidance.

As a first step, the public PTO or, in concessions with a private PTO, the municipal asset owner together with the PTO, should analyse with the DSO and, where relevant, the TSO what is technically and operationally possible. This requires sharing data on current and expected future load profiles, system capacities and constraints on both the public grid and the traction network. The aim is to identify where the traction system could meaningfully contribute to reducing congestion, which locations are technically suitable for connecting applications, and where Congestion Management on the existing connection might be a more effective lever than connecting new energy applications, since additional loads can also worsen congestion if they are not connected at the right location.

Once there is a joint technical picture, the PTO, municipality, PTA or province, DSO and, where appropriate, legal experts should explore together how they want to utilise the network and what is technically and legally feasible for the network and the stakeholders. In this stage, stakeholders discuss ambitions, internal capacities, internal objectives and societal priorities, and decide whether to focus on connecting applications, on Congestion Management, on a combination, or on not taking additional measures at all. This joint discussion reduces silo practices, ensures that everyone understands why certain choices are made or not made, and creates shared agreement on the way forward. It also provides a basis for making plans about which departments need to do what and which teams should collaborate.

Only after this strategic choice does it make sense to co-develop the technical and societal themes, define preconditions for applications, and design a standardised application fiche that captures all relevant technical, legal and societal information of the application that wants to be connected.

On that basis, applications can be collected and assessed. The framework should be applied sequentially, with a technical ranking first, followed by a societal ranking, so that low scoring or technically unrealistic options are filtered out early. For the highest scoring applications, stakeholders can then select the appropriate legal construction, starting from the simplest option. In many cases, particularly for applications owned by the PTO or non WOZ-objects, the Installation method will be sufficient and can be implemented relatively quickly. It is therefore recommended to assume that this method will often be adequate and otherwise to consider Cable Pooling as a next option. So far, the applications that municipalities and provinces or PTAs would like to see connected are predominantly applications that can be connected under the Installation method.

When third-party energy applications that qualify as WOZ-objects need to be connected and the Installation route is not possible, Cable Pooling can be a suitable connection method where the conditions are met. Where Cable Pooling is not possible and the potential impact justifies the effort, Closed System recognition can be considered. Direct Lines can be used to couple applications that generate local renewable energy to the public transport electricity infrastructure or to large consumers.

Knowledge sharing and institutional learning

A fourth organisational task is to institutionalise knowledge sharing and learning, both within and across organisations. PTOs, municipalities, DSOs and PTAs should ensure that lessons from pilots and projects are documented and accessible, and that teams responsible for technical design and operations, societal objectives, legal affairs and policy have structured opportunities to exchange experiences. These experiences should be shared through sector platforms, knowledge programmes, PTAs and other bilateral exchanges.

Early and regular coordination between the PTO or the municipality and the DSOs and, where relevant, the TSOs should become standard practice rather than an exception. This creates a shared understanding of how PTO networks can best support the public grid and helps avoid solutions that inadvertently worsen congestion elsewhere.

Sequencing legal decisions and focusing the role of the ACM

Fifth, legal choices need to be made in a pragmatic sequence. In some cases, already before applying the framework, it is possible to filter out third-party energy applications that would necessarily require complex legal constructs. For example, if joint consultations between the public PTO or municipality and the DSO show that Cable Pooling is not an option at the given intake substations, and if the operator of the system decides in advance that it does not wish to obtain Closed System recognition, then third-party energy applications that would rely on these routes can be excluded early, except for specific renewable generation projects that might still merit further investigation.

In other situations, the choice between legal constructions should be made after applications have been ranked. This legal assessment is set out in Figure 11.1, that shows the decision tree for selecting the appropriate and most easiest legal construct . This decision aid assumes that sufficient capacity is available and that applications have already been prioritised on technical and societal grounds, and then guides practitioners towards the most appropriate and least complex construction.

The ACM has a focused role and can clarify interpretations and, where justified, grant exemptions, but should not be embedded as a day-to-day participant in the process. It interprets and enforces legislation, assesses concrete exemption applications and supervises non-discrimination, but it is neither equipped nor mandated to co-design local frameworks or to answer a continuous stream of hypothetical questions. Organising legal work in this way reduces delays, concentrates effort on the most promising applications, and makes more efficient use of regulatory attention.

From system understanding to organising

In summary, Dutch public transport electricity infrastructures can only be used effectively for connecting (third-party) energy applications when stakeholders first build a shared understanding of the diversity of networks, stakeholder roles, legal options and decision themes, and then organise governance, capacities, joint processes and knowledge sharing accordingly. The study provides this integrated understanding and translates it into practical guidance and an outline for a future prioritisation framework, which together form a foundation on which stakeholders can now move the process forward themselves and subsequently develop and refine their own context specific prioritisation framework.

14.3. Definitive Outline for a Future Prioritisation Framework

The proposed outline for a prioritisation framework is intended to be operationalised as a Multi-Criteria Decision Analysis (MCDA) tool. It is supposed to be a modular framework and distinguishes two themes that should be applied in sequence. First, applications are prioritised on the basis of a *Technical* theme that screens for operational feasibility and protection of network integrity. Second, the remaining applications are assessed on a *Societal* theme with a *Sustainability* sub-theme and a *Social* sub-theme. For the highest scoring applications, it is then examined how they can be connected in practice, using *Legal* as an enabling gate rather than as a separate scoring dimension.

Because networks, stakeholder setting and governance arrangements differ between cases, the framework remains inherently context specific. Users must therefore define which aspects are specifically applicable to their context and formulate concrete scoring methods, thresholds and weights that fit their own situation, and must take care to avoid double counting where societal aspects overlap with each other or with technical components. A complete overview of the framework, including suggested aspects, is provided in Figure 11.2, which is repeated below for convenience.

The recommended outline for a framework is generic in structure and locally configurable in scoring and weights. With coordinated engagement of grid operators, systematic knowledge sharing, staged stakeholder involvement, careful platform selection, and pragmatic legal implementation, PTOs or municipalities and their public partners can make better choices under constrained networks and evolving policy goals, and connect applications that contribute credibly and transparently to relieving grid congestion.

The themes, components and associated aspects were derived by synthesising stakeholder input, expert consultations and the literature review.

Technical theme

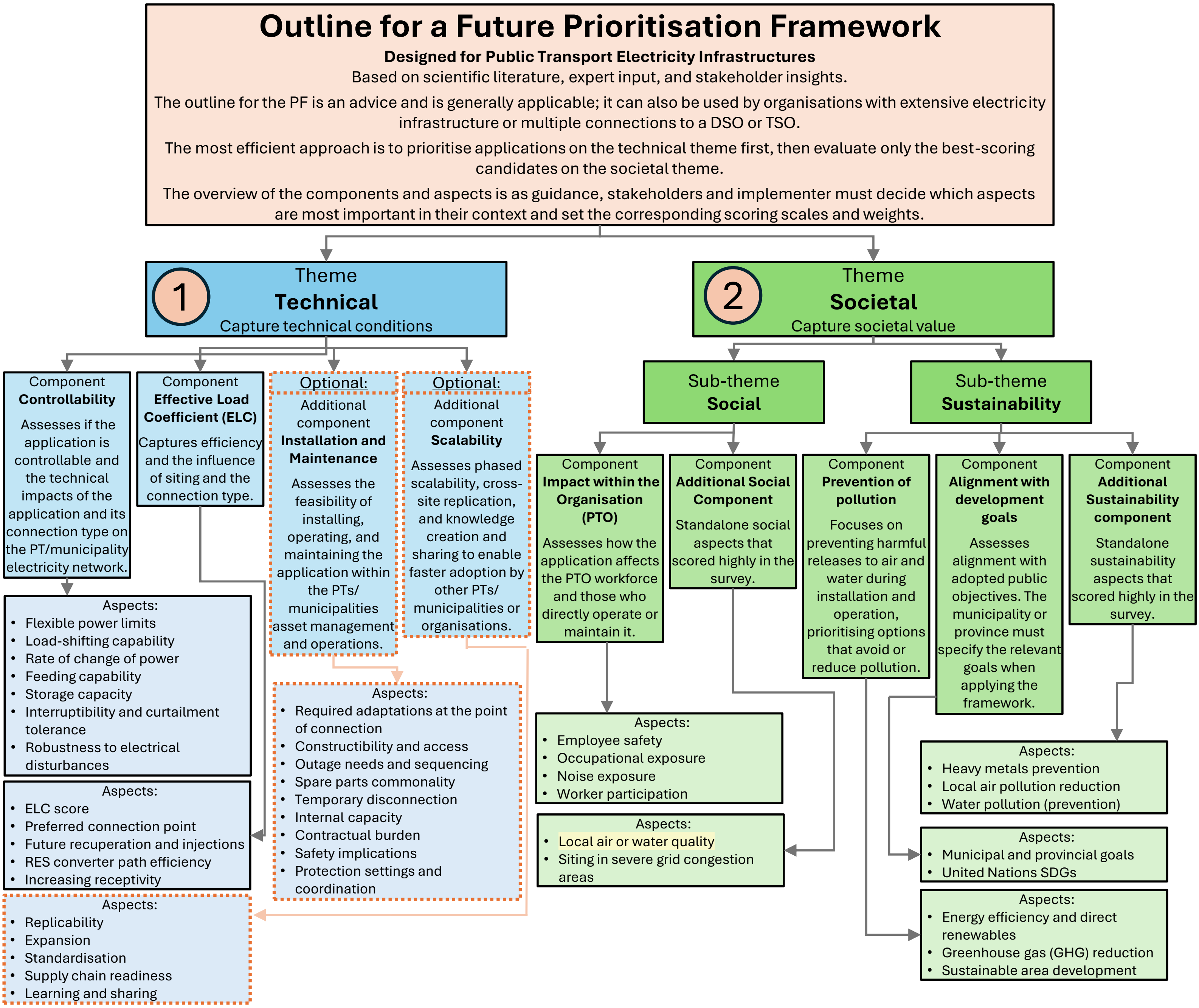
Two components form the backbone of technical prioritisation. *Controllability* captures the capability to modulate import and export, and could even help with positive contributions to network performance. These properties provide operational headroom to mitigate voltage, current constraints and reduce induced losses, and to protect public transport operations. The *Effective Load Coefficient, ELC* captures structural consequences of siting and connection point and the efficiency of system with the application connected, including cable and conversion losses, recuperation, and the choice between (AC or DC) connection points. Together, Controllability manages behaviour in real time, and ELC tests distinguishes seemingly similar applications that in practice impose different effective loads.

Two supplemental technical components should be available for inclusion where decision relevance is high in the local context. *Installation and Maintenance* concerns the practical feasibility of installing, operating, and maintaining the application. *Scalability* concerns whether the connection can be expanded, replicated, and the extent to which knowledge is created and shared.

Societal theme

Stakeholders indicate that *Sustainability* should weigh roughly twice as much as *Social*. The Social sub-theme includes *Impact within the Organisation*, and additional aspects that scores whether the application is within a location that is facing severe grid congestion and whether it improves local air and water quality. The Sustainability sub-theme includes *Prevention of Pollution* and *Alignment with Development Goals*, and additional aspects that scores whether the application improves energy efficiency of the system, reduces GHG and support sustainable area development.

The societal theme is modular by design so that municipalities and provinces can map their own democratically established objectives and adapt the framework to local context.



Outline for a Future Prioritisation Framework

Designed for Public Transport Electricity Infrastructures

Based on scientific literature, expert input, and stakeholder insights.

The outline for the PF is an advice and is generally applicable; it can also be used by organisations with extensive electricity infrastructure or multiple connections to a DSO or TSO.

The most efficient approach is to prioritise applications on the technical theme first, then evaluate only the best-scoring candidates on the societal theme.

The overview of the components and aspects is as guidance, stakeholders and implementer must decide which aspects are most important in their context and set the corresponding scoring scales and weights.

1 Theme **Technical** Capture technical conditions

Component **Controllability**

Assesses if the application is controllable and the technical impacts of the application and its connection type on the PT/municipality electricity network.

Aspects:
- Flexible power limits
- Load-shifting capability
- Rate of change of power
- Feeding capability
- Storage capacity
- Interruptibility and curtailment tolerance
- Robustness to electrical disturbances

Component **Effective Load Coefficient (ELC)**

Captures efficiency and the influence of siting and the connection type.

Aspects:
- ELC score
- Preferred connection point
- Future recuperation and injections
- RES converter path efficiency
- Increasing receptivity

Optional:

Additional component **Installation and Maintenance**

Assesses the feasibility of installing, operating, and maintaining the application within the PTs/ municipalities asset management and operations.

Aspects:
- Required adaptations at the point of connection
- Constructibility and access
- Outage needs and sequencing
- Spare parts commonality
- Temporary disconnection
- Internal capacity
- Contractual burden
- Safety implications
- Protection settings and coordination

Optional:

Additional component **Scalability**

Assesses phased scalability, cross-site replication, and knowledge creation and sharing to enable faster adoption by other PTs/ municipalities or organisations.

Aspects:
- Replicability
- Expansion
- Standardisation
- Supply chain readiness
- Learning and sharing

2 Theme **Societal** Capture societal value

Sub-theme **Social**

Component **Impact within the Organisation (PTO)**

Assesses how the application affects the PTO workforce and those who directly operate or maintain it.

Aspects:
- Employee safety
- Occupational exposure
- Noise exposure
- Worker participation

Component **Additional Social Component**

Standalone social aspects that scored highly in the survey.

Aspects:
- Local air or water quality
- Siting in severe grid congestion areas

Sub-theme **Sustainability**

Component **Prevention of pollution**

Focuses on preventing harmful releases to air and water during installation and operation, prioritising options that avoid or reduce pollution.

Aspects:
- Energy efficiency and direct renewables
- Greenhouse gas (GHG) reduction
- Sustainable area development

Component **Alignment with development goals**

Assesses alignment with adopted public objectives. The municipality or province must specify the relevant goals when applying the framework.

Aspects:
- Municipal and provincial goals
- United Nations SDGs

Component **Additional Sustainability component**

Standalone sustainability aspects that scored highly in the survey.

Aspects:
- Heavy metals prevention
- Local air pollution reduction
- Water pollution (prevention)

Repeat of Figure 11.2

Other Valuable Conclusions for a Future Prioritisation Framework

When a prioritisation framework is developed in the future, it is also important to recognise:

- **Technical implications**. Because Controllability and Grid Impact dominate the Technical theme, already some topics can be considered important:
  - Applications with an ESS are attractive, storage can strongly improve controllability, reduce grid impact, and lower the ELC, while supporting energy efficiency and the use of regenerative braking energy.
  - Ownership matters for control, self-owned applications are easier to control than third-party assets.
  - Critical, (non-controllable) connections are generally infeasible.

        - Predictability of demand of an application is valuable for control and planning.
        - The EMS of an application should also be in a direct link with the EMS of the network to optimise the controllability.
    - **Energy efficiency**. If a more energy efficient system will be a higher priority within the sustainability subtheme, reducing losses and using regenerative energy effectively become more important, which increases the relevance of the ELC in the technical theme.
    - **Partially include costs**. Costs (or benefits) could be pragmatically included within the Technical theme, not as a separate ranking theme. Because full cost data are not yet available, but introduce a proportionality check during feasibility, if controllability relies on measures that exceed agreed thresholds, for example a very expensive ESS to smooth peaks, classify the option as not realistically controllable and reduce its technical score or exclude it, leaving full cost benefit analysis to later stages or future research.
    - **Democratic legitimacy**. Societal choices should be decided through democratic processes. Municipalities and provinces/PTAs, should define what is valuable in their context, resolve internal misalignments, and prepare already societal scoring, so that technically highest scoring applications can be ranked on societal objectives without delay.

14.4. Contribution to Literature and Practice

This thesis contributes to literature and practice with:

1. It clarifies stakeholder roles, showing how municipalities, provinces, PTAs, PTOs, DSOs, TSOs, and the ACM should interact to let public transport electricity infrastructures credibly contribute to relieving grid congestion.
2. It provides an overview of potential application types and characteristics that actors can use as a starting point for case specific screening and framework development.
3. It mapped legal possibilities under the new Energy Act at a practical level, including advantages, limitations, and alternatives that can help to relief grid congestion.
4. It shows that it is a complex situation and provides practical guidance to start making effective use of the public transport electricity infrastructures to relief grid congestion.
5. It evidences the differences between public and private PTO contexts, explains how those differences affect access and cooperation.
6. It documents divergent views within and across stakeholders, which indicates siloed practices and missed opportunities.
7. It demonstrates a decision sequence, technical first then societal, and using a legal assessment tool to find the most appropriate legal construction, that focuses on effective, reliable prioritisation that saves time and reduces transaction costs.
8. It provides a general, configurable advise for an outline that can be used to use as a guidance to develop a prioritisation framework, to prioritise applications using technical and societal criteria that reflect PTO realities and public objectives.

Furthermore, the following Chapter *Recommendations* provides recommendations in the form of practical advice for stakeholders and future research.

15

Recommendations

This chapter presents, the practical recommendations, implications for stakeholders and suggestions for future research.

15.1. Practical Recommendations

Coordinated governance and early alignment

- Let the Public PTO or the municipality, together with the DSO, determine how the network can contribute most effectively. Share knowledge of each other's system designs and operations, align on feasible solutions, and decide whether the most useful contribution is internal congestion management, using the traction power network to transport electricity for the DSO, connecting applications, or a combination of these measures.
- In congested areas, internal congestion management within the public transport electricity infrastructure can, in some cases, reduce grid stress more effectively than adding external applications. Determine this jointly with the DSO by sharing knowledge of system design, operations, and capacity distribution, by aligning on feasible solutions, and choosing between internal congestion management, electricity transfer as a transporter, connecting applications, or a combination.
- Organise joint consultations with the Public PTO, the DSO, the TSO, the municipality, and the province or PTA, to aligns expectations, ambitions, share knowledge. Discuss and explore the possibilities and collaboratively decide how to deploy the electricity infrastructure.
- In dialogue with municipalities and provinces or PTAs, determine which societal objectives should be achieved, choose this democratically, and document the chosen weights and scoring methods.
- Overcome silo mentality. Avoid optimisation per layer, keep system goals central, and organise governance across sectoral boundaries with shared objectives and joint decision-making. Enable sustained collaborative processes, informal cooperation, and clear role agreements.
- Municipalities with private PTO should either hold the energy contracts themselves or control over the network and assets, and secure data access and measurement rights through concession terms to oblige cooperation on third-party connections.

Sharing lessons

- Form a joint knowledge team that can steer toward solutions that work across contexts. Include legal expertise, technical experts, and operational and project managers. Build shared knowledge and help find the right solutions for each network. These teams should span organisations, departments, and disciplines. The initiatives *Energy in the PT* (Dutch: *Energie in het OV*) and *Grid congestion & PT* (Dutch: *Netcongestie & OV*) can support this function. They can assist with the following:
  - Share lessons actively, yet avoid tunnel vision. Learn from reference cases without narrowing the search space to only Closed Systems and the Installation Method, even if RET and HTM provide concrete examples. Stay open to alternative options and new innovations, be well informed about the full set of feasible routes, and do not reinvent the wheel.
  - Document systematically. Exchange ideas on connection options and on components that matter for the assessment, then capture methods, decisions, and outcomes so knowledge is not lost. Develop a living handbook that helps other organisations find answers and reuse workable approaches. Combine lessons from earlier pilots with new knowledge and options, and judge what is optimal for the specific system at hand.
  - Bring stakeholders together.

Network types and operational rules

- When applications are to be connected, start where feasible on the metro or train networks. For tram and trolleybus networks, explore coupling at the intake substation with Cable Pooling, or connect applications via the Installation Method, since a Closed System is often not realistic.
- For every connection, define curtailment rules and priority under scarcity.
- Couple the EMS of the application with a direct link to the EMS of the network to optimise the controllability.
- Jointly assess with the DSO whether installing bidirectional inverters is an appropriate way to feed regenerative braking energy back into the public grid, since feed-in capacity is often less constrained than off-take on the public grid and this can make PTO operations more energy efficient.

Framework development

- Before prioritising energy applications, formalise the framework based on the network characteristics and local context. Formulate the scoring methods, weights, and thresholds. Do this with the stakeholders and departments that has the relevant knowledge and mandate. The technical theme should be completed by the technical department of the Public PTO or the municipality as owner of the system. The societal themes should be aligned with the democratically discussed objectives of the municipality and the province or PTA. Then apply a staged assessment that screens technical feasibility and controllability first, followed by a societal assessment.
- Finalise, together with the DSO, the TSO, the municipality, and the province or PTA, the prioritisation framework tailored to the specific network and context. Apply the framework in the proposed sequence.
- Present an overview of this study's outcomes, with the themes, components, and aspects, to the decision makers and expert in the relevant departments of the organisation and discuss whether the evidence is sufficient or whether specific components or themes require additional work.
- When more knowledge about costs and benefits becomes available, consider including it as a theme in the framework. For now, costs and benefits can partly be considered in the technical feasibility check.

Legal routes

- Pursue the highest scoring applications on technical and societal criteria. If multiple top ranked applications are legally infeasible, to connect with the preferred legal construction(s) consider an alternative legal construct that enables the intended connections. Interviews suggest provinces and municipalities often prefer applications that that can be connected via the Installation Method, which is typically the simplest route.
- Prioritise finalising the framework and ranking applications. Since stakeholders already emphasise a preference for applications feasible under the Installation Method, connection of this applications can be accelerated by enabling the simplest legal route, and not waste time exploring other, more complex constructions in advance.
- Assess whether recognition as a Closed System is truly desired. Consider whether the organisation can meet the associated obligations, and is the recognition could constrain future growth if the PTO needs more capacity for its own operations. Also assess whether the benefits out growth the disadvantages.

Stepwise sequence of recommended actions

The concise sequence below summarises the recommended way to start the process to use the public transport electricity infrastructure to help relieve grid congestion and to organise it in clear, practical steps. For the full guidance and detailed explanation, see Section *Stepwise process to understand how to use the public transport electricity infrastructure the most effective*.

1. **Develop a joint understanding of technical possibilities and constraints**
   Public PTO or municipality, private PTO (where relevant), DSO and, if needed, TSO jointly analyse current and future load profiles, capacities and operational constraints on both the traction network and the public grid. They identify where the network could contribute to relieving congestion and which locations are technically suitable. In parallel, the public PTO or municipality builds or strengthens technical and administrative teams that can design, realise and manage new connections.

2. **Jointly explore ambitions and possible ways to deploy the network**
   On the basis of this shared technical picture, the PTO or municipal network operator, the asset owner, the DSO and TSO, the province or PTA and, where appropriate, a legal expert discuss how far the traction power network should be used beyond its core transport function. They compare needs, ambitions and potential contributions to congestion relief and develop a shared view of what the network should and should not do.
3. **Decide on the preferred strategy**
   Together, PTO, municipality, province or PTA and DSO decide whether to focus mainly on connecting applications, on congestion management on the existing connection, on a combination of both, or on not taking additional measures. If the decision is to connect energy applications, it is reasonable to assume that the Installation method will often be suitable for the most promising application types and to proceed with the next steps.
4. **Develop the framework and preconditions**
   Technical departments and the DSO tailor the Technical theme and define technical preconditions and scoring rules. Municipalities and provinces or PTAs specify the Societal theme and desired societal effects. Together they define preconditions for applications and design a standardised application fiche that collects all required technical, legal and societal information.
5. **Embed support and governance**
   Municipalities and provinces or PTAs explore funding options and adjust concession conditions where needed so that data sharing, cooperation on congestion management and use of the framework are formally secured. PTOs and municipalities ensure that internal technical and administrative teams have the mandate and resources to work with the framework.
6. **Apply the framework and select legal routes**
   Use the framework to screen and rank applications, first on the Technical theme and then on the Societal theme. For the highest scoring applications, use the legal decision flowchart (Figure 11.1) to choose the simplest suitable legal construction (Installation, Cable Pooling, Closed System or Direct Line) and arrange the necessary agreements with the DSO or TSO.
7. **Learn and refine**
   After each application round, collect lessons, share them internally and via sector platforms, and refine components, preconditions and scoring rules as knowledge, data and legal possibilities develop.

How to eventually prioritise applications

Once the consultations with stakeholders are completed and the framework has been configured for the specific network and context, it can be applied in a simple sequence of steps:

1. **Apply preconditions and remove ineligible applications**
   First, apply the legal and technical preconditions agreed beforehand. If, for a given location, stakeholders have decided not to, or cannot use Cable Pooling or do not want to pursue Closed System recognition, then remove third-party energy applications that would depend on those routes. An exception can be made for renewable generation projects that can feed electricity into the PTO or municipal network via a Direct Line.
2. **Perform the technical assessment**
   Score all remaining applications on the Technical theme and remove options that score too low or prove technically infeasible. Rank the remaining applications from highest to lowest technical score.
3. **Perform the societal assessment**
   For the technically acceptable applications, apply the Societal theme. Rank these applications on their societal score and combine both rankings into one ordered list in which technical feasibility remains a hard condition.
4. **Select the legal construction for the highest ranked applications**
   Starting from the top of the legal assessment decision flowchart (Figure 11.1) to determine the simplest suitable legal construction:
   (a) use the Installation method as the preferred option for PTO-owned or non WOZ-applications
   (b) consider Cable Pooling when a regular AC connection is not possible within the Installation method, and/or when Cable Pooling is technically preferable and the conditions for Cable Pooling are met

   (c) consider Closed System recognition only if simpler routes are not possible and the expected benefits justify the additional obligations

   - use a Direct Line for third-party renewable generation that is intended to feed electricity into the PTO or municipal network.

5. **Move to the next application if needed**
   If, after detailed analysis, the highest ranked application cannot be connected in a legally and technically acceptable way, proceed to the next application in the ranking and repeat the legal assessment step.

Implications for Stakeholders

Below, a brief overview is provided of the implications for the main stakeholder groups. A more detailed discussion of stakeholder roles, influence and involvement can be found in Section *Positioning stakeholders in the process*.

For Public PTOs or municipalities with a private PTO

The technical departments within these organisations should:

1. Consult with the DSO, and where relevant the TSO, to determine how the network can best contribute to relieving grid congestion, learn from each other's systems, and identify opportunities.
2. Prepare an overview of locations and specific connection points where applications could be connected.
3. Participate in joint consultations with the DSO, municipality and PTA or province to align ambitions and agree a shared direction for how the network will be used.
4. Develop or commission teams that can perform the required electrical engineering calculations and that can install, operate, maintain and repair new connections, and potential complement with a team that can handle the associated administrative tasks such as contracts, metering, billing and data handling. Installation, maintenance and administrative work can be outsourced.
5. If applications will be connected, finalise the Technical theme. Identify which themes, components, and aspects are most important given network topology, rolling stock, recuperation settings, traffic patterns and timetables, spatial constraints, and governance structures. Develop the scoring methods, thresholds, and weights locally so that prioritisation reflects context and protects traction operations.
6. Define (technical) preconditions that applications must meet before they enter the prioritisation framework and a standardised application fiche.
7. Publish a submission guide for the technical testing for applicants that specifies required information, including expected load profiles, preferred connection points, growth plans, expected connection periods, controllability measures, storage provisions, criticality or continuous energy needs, and import and export details.

On top of that, the Public PTO or the municipality, in the case of a private PTO, should determine how costs and any benefits will be covered, develop a business case, seek funding where appropriate, or allocate investments from existing budgets. In case the Public PTO or municipality does not have the internal capacity to do the technical tasks, consider establishing or expanding internal teams with technical expertise to further develop the Technical theme and to rank applications on technical criteria, to investigate options, and, where applicable, to connect and maintain applications. Outsourcing these activities is also possible.

For municipalities and provinces or PTAs

1. In concessions with a private PTO, build or commission technical and administrative teams that can perform the required electrical engineering calculations and that can install, operate, maintain and administer new connections. Installation, maintenance and administrative tasks can be outsourced.
2. Publish a submission guide for the societal testing for applicants that specifies required information, including application ownership, expected societal and sustainability objectives, future plans, and expected connection periods.
3. Explore funding options or financial incentives for PTOs, that enable contribution to grid congestion relief.

4. In contexts with a private PTO, ensure that the municipality either holds the energy contracts itself or secures control over the network and assets and guaranteed access to metering and operational data.
5. Adjust concession requirements so that private PTOs are obliged to cooperate on data sharing, congestion management and the facilitation of third-party connections where this is aligned with policy goals.

For regulators

1. Explore ways to clarify case specific legal questions more quickly.
2. Provide clear guidance on available legal routes, and highlight new developments such as cable pooling.
3. Support the granting of exemptions where appropriate, and facilitate the exploration of new legal approaches.
4. Organise information sessions with multiple potential parties that aim to connect applications to traction or energy networks.

For DSOs and the TSO

1. Work with the Public PTO, or with municipalities in the case of a private PTO, to determine how the network can contribute to relieving grid congestion, learn from each other's systems, and identify opportunities.
2. Provide an overview of available capacity on the public grid, indicate where the traction power network can host additional load and where it cannot, and identify intake substations at which additional applications could be connected for cable pooling.

15.2. Recommendations for Future Research

- Develop methods to score and weight the themes, components, and aspects in more detail, and to operationalise minimum criteria.
- Explore how to incorporate costs and benefits, and when to defer full cost benefit analysis to later stages.
- Map the precise possibilities and constraints when a direct line is chosen to connect third parties.
- Examine whether a municipality working with a private PTO can hold the energy contracts with the DSO, and arrange settlement with the private PTO under the Installation Method, or whether a Closed System is ultimately required.
- For systems with Closed System recognition, investigate how to design an objective and transparent prioritisation approach so that applications with high societal value and acceptable technical impact can be granted priority when capacity is limited. The ACM prioritisation framework can be studied as a potential reference for lawful prioritisation of applications.
- Assess the added value of diversifying loads, by combining different application types, to keep the network stable and secure.

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A

Appendix - Legal Precedents: HTM and RET

Legal Precedents: HTM and RET

This appendix provides an expanded account of two precedents in which Dutch PTO's enabled external uses on their electricity infrastructure. It goes beyond the concise summary in the main report to give additional procedural context and practical detail for these specific cases. The HTM case documents the installation route for EV charging on tram traction infrastructure based on ACM's assessment [50]. The RET case summarises ACM's 2024 decision granting a closed distribution system exemption, enabling multi user access under defined conditions [57]. The purpose is to improve clarity on how lawful connections were achieved, not to provide legal advice.

HTM

In a letter from the ACM in 2024 [50], the city of The Hague and HTM Personenvervoer N.V. (The Hague's PTO) together with HTM Railinfra B.V. explored the possibility of using existing tram electricity infrastructure for electric vehicle charging. The initiative is part of broader efforts to support the energy transition and improve utilization of existing grid capacity.

According to the legal framework it was concluded that the infrastructure in question qualifies as an installation, not a network, and that no supply license is required to deliver electricity to the charging stations, since, under Article 1, paragraph 1, sub c, of the Electricity Act, they are not regarded as end-users, because the link between a charging point and an electric vehicle does not constitute a connection. For completeness, the ACM notes that a supply license is only required for parties supplying electricity to end-users with a connection of at most 3×80 A, see *Small connection*. The ACM agreed and noted that the proposed new Energy Act introduces no substantive changes to the legal definitions of network and installation.

According to ACM, the infrastructure is owned by HTM Railinfra and connects to the public grid operated by Stedin. HTM Railinfra itself does not use the infrastructure. Instead, HTM Personenvervoer, as the concessionaire, operates the tram system and will use the infrastructure. Under Article 1(2) of the Electricity Act (E-wet), HTM Personenvervoer qualifies as the end-user. Since there are no other connected users, the infrastructure is considered a single-user installation.

HTM Personenvervoer will also construct the connections and operate the charging points, while ownership of both the chargers and the connections will remain with HTM Railinfra. The ACM emphasized that HTM Railinfra owns the infrastructure but does not use it, whereas HTM Personenvervoer is the sole user and operator of both the tram system and the electric vehicle chargers. This qualifies the system as an installation rather than a network. Furthermore, the ACM also stated that the connection between a charging point and an electric vehicle does not qualify as a connection under Article 1.1.b of the Electricity Act, as an electric vehicle is not immovable property under Article 16(a–e) of the Valuation of Immovable Property Act.

In summary, HTM's case demonstrates that only non-WOZ objects or multiple WOZ objects owned by the same entity may be legally connected without a supply license. In this case, HTM Personenvervoer is both the operator and end-user, thereby satisfying the legal requirement of single ownership and control.

RET

According to ACM's formal decision in 2024 [57], the Rotterdamse Elektrische Tram N.V. (RET) has been granted a GDS exemption (translated: GDS-ontheffing) under Article 15 of the Electricity Act 1998 for managing its own electricity grid. This exemption applies to the entire Rotterdam metro network, including the Hoekselijn and the section of the RandstadRail up to station Nootdorp.

The ACM determined that RET's electricity grid meets all legal requirements for classification as a closed distribution system. The grid is located within a geographically bounded area with shared services and operates at voltage levels below the national high-voltage grid. Currently, three non-household end-users are connected: RET, RET Bus B.V., and the municipality of Rotterdam (for emergency backup and future charging hubs). Household users are explicitly excluded.

A core criterion for GDS qualification was that the grid must primarily serve its owner or affiliated entities. RET clearly satisfies this: 100% of electricity currently transported is for RET and RET Bus (a related entity), and even after expansion, more than 90% of consumption will remain within the RET group.

While RET is not the legal owner of all grid segments, ownership is shared with the municipality and Rail Infratrust (RIT), it holds full economic ownership and operational control. The ACM recognized RET as the de facto owner, responsible for maintenance, safety, and investment decisions, supported by legal mandates and delegation from the MRDH (Metropoolregio Rotterdam Den Haag).

RET has submitted extensive documentation, including maintenance schedules, safety protocols, an emergency plan, and an investment roadmap through 2030. The central control center operates 24/7 and maintenance services are continuously available.

Moreover, RET has demonstrated compliance with requirements for third-party access by enabling supplier switching and transparency through standardized electronic data exchange, in line with the applicable Netcode Electricity regulations.

This decision affirms that public transport operators, provided they meet technical and legal standards, can enable shared infrastructure use. ACM's position supports innovation and flexibility in energy use within the mobility sector, without compromising system integrity or market fairness.

Advice by an expert and independent consultancy firm is recommended when applying for the exemption required to operate a GDS, primarily by providing legal advice. Such support is essential given the complexity of the process, as most PTOs do not possess the necessary legal expertise in-house.

B

Appendix - Regulatory and Legal Requirements for the Different Legal Constructions

This appendix provides an overview of all legal regulations for the legal constructions discussed in this study. The overview is based on the new Energy Act that will enter into force on 1 January 2026 and is therefore the most relevant version. The provisions below are taken from the new Energy Act, published on 23 January 2025 [54].

For the most up to date regulatory text, readers can consult the Dutch official legislation database *Overheid.nl Wettenbank*. The consolidated version of the Energy Act can be accessed via this link [113].

B.1. Regulatory and Legal Requirements for Closed Systems (CS)

In order to be allowed to operate a closed system, both the system itself and its operator must comply with a set of legal conditions and requirements. These requirements follow from Dutch and European legislation and are explained below. In addition, several practical aspects that need to be organised in practice are clarified.

To obtain an exemption for a closed system, there must first be a system within the meaning of Article 1.1 [39].

In addition, the system must meet the following requirements under Article 3.7 [39]:

3.7.1d. *het systeem binnen een geografisch afgebakende industriële locatie, commerciële locatie of locatie met gedeelde diensten ligt en dat systeem technische, organisatorische of functionele bindingen heeft* (English: The system is located within a geographically defined industrial site, commercial site or shared services site and that system has technical, organisational or functional links)
Explanation: this requirement means that the network must be located at a site that can be regarded as a spatial and functional unit. In the exemption decision for ProRail, the nationwide electrified main railway infrastructure in the Netherlands was designated as a single geographical location [114].
In the decision for RET, it was sufficient to demonstrate this using a technical description, single line diagrams and cadastral maps on which the network was drawn. The ACM concluded that the application complied with the legal requirement on this point [57].

3.7.1e. *op het systeem minder dan 1.000 aangeslotenen zijn* (English: There are fewer than 1,000 connected users on the system.)
Explanation: this threshold safeguards the closed character of the system.

3.7.1f. *het systeem geen huishoudelijk eindafnemers voorziet, tenzij er sprake is van incidenteel gebruik door een klein aantal huishoudelijk eindafnemers dat werkzaam is bij of vergelijkbare betrekkingen heeft met de eigenaar van het gesloten systeem;* (English: the system does not supply domestic end-users, unless there is incidental use by a small number of domestic end-users who are employed by or have similar relationships with the owner of the closed system;)
Explanation: Only incidental use by household end-users who are employed by, or otherwise linked to, the owner is permitted.

3.7.1g. *de veiligheid en betrouwbaarheid van het systeem naar het oordeel van de Autoriteit Consument en Markt voldoende is gewaarborgd; en* (English: the safety and reliability of the system are sufficiently guaranteed in the opinion of the Netherlands Authority for Consumers and Markets; and)
Explanation: The ACM assesses whether this requirement is met.
In the RET decision, it was sufficient to demonstrate this by taking a number of measures. For example, periodic inspections and checks are carried out by in house technicians following standard work instructions. RET had an emergency response plan that is integrated with the metro network, with the central traffic

control room being permanently staffed and a breakdown service constantly on standby. In the event of an incident, remote switching is possible and all actions are carried out in accordance with the electrotechnical safety manual. To substantiate this, RET submitted documentation on inspections, maintenance, fault procedures, the safety manual and a multi year investment plan. RET had to have a maintenance, breakdown and contingency plan, an investment and replacement plan, and a register of all assets in the electricity network with the corresponding technical data. On this basis, the ACM considered it sufficiently plausible that safety and reliability were safeguarded [57].

3.7.1h. *indien het en transmissie- of distributiesysteem voor elektriciteit betreft, het spanningsniveau van dit systeem ten hoogste 220 kilovolt bedraagt, met uitzondering van leidingen of hulpmiddelen ten behoeve van de omzetting van het spanningsniveau van elektriciteit direct achter de aansluiting van het systeem op een transmissiesysteem voor elektriciteit.* (English: in the case of an electricity transmission or distribution system, the voltage level of this system does not exceed 220 kilovolts, with the exception of lines or equipment used for the conversion of the voltage level of electricity immediately downstream of the connection of the system to an electricity transmission system.)
Explanation: This applies with the exception of conductors or equipment used to convert the voltage level of electricity directly behind the point where the system is connected to a transmission system for electricity.

3.7.2. *De Autoriteit Consument en Markt erkent op aanvraag een systeem dat zal worden aangelegd als een gesloten systeem, indien aan de aanvrager voor de aanleg van dat systeem de daarvoor benodigde vergunningen, ontheffingen en toestemmingen zijn verstrekt en is voldaan aan het eerste lid.* (English: The Netherlands Authority for Consumers and Markets shall, upon request, recognise a system that will be constructed as a closed system, provided that the applicant has been granted the necessary licences, exemptions and permissions for the construction of that system and that the first paragraph has been complied with.)
Explanation: This only applies if the applicant already holds all required permits and complies with conditions 1a up to and including 1h.
This is of limited relevance for Dutch PTOs, because their networks have already been constructed.

Furthermore, a decision must be taken on whether an exemption is granted on the basis of one of the two exemption grounds in Article 3.7 [39]. For a successful exemption application, it is sufficient if one of these grounds applies. For completeness, both grounds are discussed below.

3.7.1c. *het bedrijfs- of productieproces van aangeslotenen op het systeem om specifieke technische of veiligheidsredenen geïntegreerd is met het systeem of het systeem primair elektriciteit of gas distribueert aan de eigenaar van het systeem of daarmee verwante ondernemingen;* (English: the business or production process of those connected to the system is integrated with the system for specific technical or safety reasons, or the system primarily distributes electricity or gas to the owner of the system or related companies;)
Explanation: These are the exemption grounds on which the exemption can be granted. There must be technical or safety reasons for the integration, or electricity must primarily be supplied within the owner's own group.

In practice, this means that an exemption may be granted on the basis of specific technical or safety reasons. An exemption is possible if there is an integrated system in which the business processes of the users are closely intertwined with the system. In the exemption decision for ProRail, the network in question consisted of users with closely interrelated business processes that, for specific technical reasons, required an integrated system. The transport of goods and or passengers by the users could not be separated from the national railway network and the business processes of the users were closely linked to the GDS. The specific technical requirements in this case resulted in a unique way of distributing energy. Concretely, the specific technical reasons under the a ground may relate, among other things, to the type and level of the voltage, the way in which users are connected, the physical characteristics, reliability, operational management and load profile [114].

Alternatively, an exemption can be granted if electricity is primarily supplied to the owner or affiliated undertakings via the system. RET requested an exemption on the basis of this exemption ground and demonstrated with documentation that RET and RET Bus belong to the same group and receive 100% of the electricity. Even with future connections, this share will remain above 91%, taking into account the connection of two park and ride locations. RET therefore comfortably met the ACM requirement that at least 50% must be supplied to affiliated parties [57].

In addition, the applicant for the system must comply with the following requirements under Articles 3.6 and 3.7

[39]:

3.7.1 *De Autoriteit Consument en Markt erkent op aanvraag van de eigenaar van een transmissie- of distributiesysteem voor elektriciteit, of een distributiesysteem voor gas dat systeem als een gesloten systeem indien:* (English: At the request of the owner of an electricity transmission or distribution system, or a gas distribution system, the Netherlands Authority for Consumers and Markets shall recognise that system as a closed system if:)

3.7.1a. *er niet op grond van artikel 3.2, eerste lid, al een beheerder is aangewezen voor het systeem;* (English: an administrator has not already been appointed for the system pursuant to Article 3.2, first paragraph;)
Explanation: No operator may yet have been designated under Article 3.2, first paragraph.

3.7.1b. *de aanvrager geen onderdeel uitmaakt van een infrastructuurgroep;* (English: The applicant is not part of an infrastructure group;)
Explanation: the system must be independent and may not form part of a wider infrastructure group. The applicant (economic or legal owner) may not belong to an infrastructure group, which in the case of a PTO or municipality is usually not an issue.

Finally, a system operator must be designated. The designation of an operator can take place after it has been assessed whether a system has the characteristics of a closed system. If the system meets the requirements, this assessment results in recognition of the system, as set out in Article 3.7. In practice, the two decisions, namely recognition as a closed system and designation of an operator of the closed system, can be combined, but they are two separate decisions. Designation takes place on the basis of Article 3.6 of the new Energy Act [39].

3.6 *De Autoriteit Consument en Markt wijst op aanvraag:* (English: The Authority for Consumers and Markets points out upon request:)

3.6a. *van de eigenaar van een transmissie- of distributiesysteem voor elektriciteit dat krachtens artikel 3.7 is erkend als gesloten systeem een door de eigenaar voorgedragen beheerder aan;* (English: of the owner of a transmission or distribution system for electricity that is recognised as a closed system pursuant to Article 3.7, an administrator nominated by the owner;)
Explanation: Once the system has been recognised as a closed system (Article 3.7), the owner of that system may nominate an operator, who is then designated by the ACM (Article 3.6). If no operator is designated, the system is considered an illegal network.
The legal owners of the system are usually municipalities or other local authorities, who can nominate the PTO (often the economic owner) as operator, or alternatively an external company. The economic owner can also submit the application, so that the PTO itself submits the request. Moreover, it concerns ownership of the connections and conductors, not ownership of the parcels on which the system is located. It is often practical for the PTO to be nominated as operator, because the exemption holder will be responsible for the management and liability relating to the safety and reliability of the network. Since the PTO rather than the municipality has the relevant knowledge of the network, the PTO is often better suited to act as operator than another party.

A closed system operator is subject to a considerably lighter set of obligations and mandatory tasks compared to the obligations and mandatory tasks applicable to transmission and distribution system operators (TSOs and DSOs). Different rules also apply to the tariffs. The tasks and obligations of an operator and the tariff rules are set out in full in Articles 3.24, 3.25, 3.43, 3.44, 3.51, 3.57, 3.77, 3.79, 3.104, 3.105, 3.114, 4.6 and 4.10. Below is a brief overview of the key points concerning the general tasks, obligations and tariffs that apply to a closed system operator under the new Energy Act.

- **Conduct and cooperation**
    - Act in a reasonable, transparent and non-discriminatory manner when performing statutory tasks (Art. 3.24(1)).
    - Cooperate and exchange data with other system operators in order to promote market functioning (Art. 3.24(2)).
- **Operation, maintenance and development**

    - Safeguard the (digital) security, reliability (security of supply) and efficiency of the closed system, taking into account the environment, digitalisation and the energy transition (Art. 3.25(1)).
- ◦ **Transfer points and allocation points**
    - Establish transfer points and (additional) allocation points, taking into account the interests of connected users (Art. 3.43 and 3.44).
- ◦ **Protecting and providing information**
    - Protect confidential data against unauthorised access (Art. 3.77(1)).
    - Provide all information necessary for effective use of the system to the relevant parties (Art. 3.77(3)).
- ◦ **Faults, complaints and switching supplier**
    - Maintain procedures for reporting and handling faults and complaints and facilitate switching or relocation of customers (Art. 3.79).
- ◦ **Metering devices and metering data**
    - Install, replace and manage smart meters on request at transparent, cost based tariffs (Art. 3.51 and Art. 3.104(2)).
    - Collect, validate and establish metering data in accordance with the legal requirements (Art. 3.57).
- ◦ **Tariffs**
    - Apply transparent, pre announced, cost based tariffs (Art. 3.114(1)).
    - Tariffs are subject to ACM supervision, which may intervene if tariffs are not fair (Art. 3.114(2)).
- ◦ **Connection and transport**
    - On request, make an offer for the construction, modification, management, maintenance and use of connections and for the transport of electricity or gas (Art. 3.105(1) and (2)).
    - A reasoned refusal is possible in case of insufficient capacity, both for customers and for suppliers (Art. 3.105(3)).
- ◦ **Data registration and use**
    - Register technical and contractual data relating to connections, transfer points and allocation points, connected users, installations, transport, metering devices and measurements (Art. 4.6).
    - Use data only for statutory tasks (operation, maintenance, tariffs, contracts) (Art. 4.10(1)).
    - Provide data via the central data exchange entity to market parties and other stakeholders (Art. 4.10(2) up to and including (4)).

Finally, the new Energy Act contains provisions in Articles 2.1 and 2.17 that are relevant for the supply of electricity to end-users within a closed system [39].

Article 2.1 provides that every end-user connected to a transmission or distribution system, which also includes closed systems, must conclude a supply contract for the off take of electricity or gas. A key principle is that the end-user is free to choose their supplier. This means that users within a closed system are also free to decide with which supplier they conclude a contract. In addition, the freedom of choice for concluding aggregation contracts (various types of contracts concerning the aggregation of demand response or injected electricity from different active customers with a view to resale) with market parties is laid down explicitly for active customers. The PTO can also be regarded as an active customer, because an active customer is an end-user who sells self generated electricity or participates in flexibility or demand response schemes. Since the PTO feeds braking energy back into the system, it can be regarded as an active customer.

Article 2.17 introduces, in principle, a licensing requirement for suppliers that supply end-users with a small connection. Closed systems, however, are subject to a clear exception: suppliers may, without a licence, supply end-users with a small connection located within a closed system. This provision ensures that the administrative burden for incidental or internal supply within a closed system remains limited, while preserving end-users' rights to free choice of supplier.

B.2. Regulatory and Legal Requirements for Cable Pooling

This section provides an overview of all legal rules for Cable Pooling, based on the new Energy Act that will enter into force on 1 January 2026 and which is therefore the most relevant version.

On the basis of the new Energy Act and the draft Energy Decree (concept Energiebesluit), the following rules can be derived regarding Cable Pooling in the public transport sector. Below is an overview of the relevant provisions, based on Article 1.4 of the new Energy Act and Article 1.2 of the draft Energy Decree:

In addition, the following requirements for Cable Pooling apply under Article 1.4 of the Energy Act [40] and Article 1.2 of the Energy Decree [115]:

1.4.3. *Voor de toepassing van het bij of krachtens deze wet bepaalde worden twee of meer op land gelegen installaties voor productie, opslag, conversie of verbruik van elektriciteit beschouwd als één installatie en één onroerende zaak als bedoeld in artikel 16, onderdelen a tot en met e, van de Wet waardering onroerende zaken, indien:* (English: For the purposes of this Act, two or more land based installations for the production, storage, conversion or consumption of electricity are regarded as one installation and one immovable property as referred to in Article 16(a) to (e) of the Valuation of Immovable Property Act, if:)

1.4.3a. *de installaties zich in elkaars onmiddellijke nabijheid bevinden;* (English: the installations are located in each other's immediate vicinity;)
Explanation: The installations for the production, storage, conversion or consumption of electricity must be located close to one another. This promotes an efficient and joint grid connection.

1.4.3b. *de eigenaren van die installaties gezamenlijk een aansluitovereenkomst en een transportovereenkomst hebben gesloten met de transmissie- of distributiesysteembeheerder voor elektriciteit; en* (English: the owners of those installations have jointly concluded a connection agreement and a transport agreement with the transmission or distribution system operator for electricity; and)
Explanation: There must be joint responsibility for the connection and transport on the electricity grid. Without these agreements, there can be no joint connection.

1.4.3c. *de gevraagde aansluitcapaciteit meer bedraagt dan een bij of krachtens algemene maatregel van bestuur vastgesteld minimum;* (English: the requested connection capacity is greater than a minimum established by, or pursuant to, an order in council;)
Explanation: According to Article 1.2 of the draft Energy Decree, this minimum capacity is set at 100 kVA.

1.4.3d. *het aantal installaties niet meer bedraagt dan een bij of krachtens algemene maatregel van bestuur vastgesteld maximum.* (English: the number of installations does not exceed a maximum established by, or pursuant to, an order in council.)
Explanation: This maximum also follows from Article 1.2 of the draft Energy Decree and is set at a maximum of 4. This safeguards the manageability and controllability of the shared connection.

1.4.4. *De eigenaren van de installaties melden de ingebruikname van een gezamenlijke aansluiting als bedoeld in het derde lid zo spoedig mogelijk aan de Autoriteit Consument en Markt.* (English: The owners of the installations notify the Authority for Consumers and Markets of the commissioning of a joint connection as referred to in the third paragraph as soon as possible.)
Explanation: The owners of the installations must notify the ACM of the commissioning of the joint connection as soon as possible. This allows the regulator to monitor the development and application of Cable Pooling.

Cable Pooling Agreement (CPO)

When a PTO makes its grid connection available to external parties through Cable Pooling, it is essential to lay down clear contractual arrangements in a so called Cable Pooling Agreement (CPO). This agreement forms the legal and operational framework for the shared use of the connection and aims to provide clarity on the allocation of responsibilities, costs, risks and rights.

The CPO specifies how the joint connection is operated and used, because the contract with the grid operator only allows a limited, agreed amount of power to flow through the connection. From a technical perspective, it is often possible to connect more installed capacity than the nominal capacity of the main connection, provided that there is sufficient non simultaneity in production or consumption between the connected parties. In such situations, it is crucial that the control of the installations is properly arranged, so that the combined load never exceeds the maximum connection capacity. This control must therefore be explicitly taken into account in the design and operation of the shared infrastructure. The agreement should specify, among other things, which party may use how much capacity and at what times.

A CPO may, for example, include arrangements on maintenance of the connection and the allocation of operational costs between the PTO and the connected parties. It should also set out how potential production losses or interruptions in consumption due to curtailment or grid constraints are handled and how such losses are compensated or settled.

It is important that the agreement clarifies whether an expansion of one of the connected installations or users is permitted, under which conditions this may take place and what financial implications this has. As a starting point, an expansion, upscaling or modification by one party should not lead to additional costs or operational disadvantages for the other participating parties.

The CPO also includes legal provisions relating to the use of the physical infrastructure. This covers the establishment of property rights such as rights of superficies, easements and rights of way, which are necessary for the construction, operation and maintenance of the shared grid components.

Furthermore, the CPO should provide insight into the way in which costs are allocated. This includes, among other things, the depreciation of the existing connection, recurring grid fees, operation and maintenance costs of the shared installations, metering and administrative costs and the transfer of ownership upon termination of the cooperation, for example in the event of dismantling or bankruptcy of one of the parties.

Additional arrangements must be made regarding any modifications to the electrical infrastructure that are required for sharing the connection. This also concerns the specification of the control system that ensures that the combined load of the connection remains within the contractually agreed limits. If modifications to the intake substation or other parts of the grid connection are necessary, the responsibilities and associated costs must also be laid down in the agreement.

Finally, the CPO should include arrangements on how to deal with potential lost revenues during modifications or works on the connection. By carefully planning and coordinating these works, such losses can be minimised.

The CPO is therefore an essential instrument for a PTO that makes its grid connection available to external parties and contributes to a transparent, reliable and efficient cooperation between all users of the shared infrastructure.

B.3. Regulatory and Legal Requirements for an Installation

This section provides an overview of the legal rules for installations, based on the new Energy Act that will enter into force on 1 January 2026 and which is therefore the most relevant version.

According to Article 1.1 of the Energy Act, an installation is defined as follows [40]:

Installatie: *Leidingen en daarmee duurzaam verbonden elektrotechnisch of gastechnisch materieel dat of apparatuur die* (English: Installation: Pipelines and the electrical or gas technical equipment or apparatus that is permanently connected to them)

a. *zijn bestemd voor of ten dienste staat van het verbruik of de productie van elektriciteit of gas of de opslag van elektriciteit;* (English: is intended for, or serves, the consumption or production of electricity or gas, or the storage of electricity;)
b. *wordt gebruikt of beheerd door een aangeslotene; en* (English: is used or operated by a connected user; and)
c. *zich ten opzichte van een transmissie- of distributiesysteem of een directe lijn bevindt achter het overdrachtspunt of de voorzieningen die de directe lijn beveiligen;* (English: is, in relation to a transmission or distribution system or a direct line, located behind the transfer point or the facilities that protect the direct line;)

From the parliamentary history of the Electricity Act, it follows that the concept of installation must be interpreted broadly [116]. This includes, among other things, the following:

- On the customer side, the installation comprises everything located behind the electricity meter, that is, all equipment and conductors within the customer's home or premises.
- The connection between a customer's premises and the point at which it is connected to the grid is also covered by the concept of installation.

This interpretation implies that everything behind the meter can be regarded as an installation, provided that there is only a single customer behind that meter.

B.4. Regulatory and Legal Requirements for a Direct line

This section provides an overview of the legal rules for a direct line, based on the new Energy Act that will enter into force on 1 January 2026 and which is therefore the most relevant version.

Under Article 3.9 of the Energy Act, a direct line is defined as follows [40]:

3.9.1. *Als directe lijn wordt aangemerkt één of meer leidingen en daarmee verbonden hulpmiddelen ten behoeve van het transport van elektriciteit of gas:* (English: A direct line is defined as one or more conductors and associated equipment used for the transmission of electricity or gas:)

3.9.1a. *die niet verbonden is met een systeem van elektriciteit of gas of met een andere leiding voor het transport en die een geïsoleerde productieinstallatie van een producent rechtstreeks verbindt met een geïsoleerde eindafnemer;* of (English: that is not connected to a system for electricity or gas or to another line for transport and that directly connects an isolated production installation of a producer with an isolated end-user;)
Explanation: This type of direct line operates completely outside the regulated grid and concerns a direct connection between producer and end-user, without any link to other systems or lines.

3.9.1b. *die ten hoogste via de installatie van één aangeslotene op de leidingen is verbonden met een systeem van elektriciteit of gas of met een andere leiding voor het transport en die een productie-installatie voor elektriciteit of gas, met tussenkomst van een leverancier, rechtstreeks verbindt met één of meer eindafnemers, waarbij dit voor een huishoudelijk eindafnemer enkel is toegestaan indien deze werkzaam is bij of vergelijkbare betrekkingen heeft met de eigenaar van de directe lijn.* (English: that is connected to a system for electricity or gas or to another line for transport at most via the installation of a single connected user and that connects a production installation for electricity or gas, via a supplier, directly to one or more end-users, whereby this is only permitted for a household end-user if that end-user is employed by, or has a comparable relationship with, the owner of the direct line.)
Explanation: In this case, the direct line is linked in a limited way to the regular grid via a single intermediate installation. For household end-users, this form is only allowed if they are employed by, or have comparable ties with, the owner of the direct line.

3.9.2. *Een eigenaar van een directe lijn meldt:* (English: An owner of a direct line notifies:)

3.9.2a. *de directe lijn zo spoedig mogelijk na ingebruikname aan de Autoriteit Consument en Markt;* (English: the direct line to the Authority for Consumers and Markets as soon as possible after it has been put into operation;)
Explanation: The ACM supervises direct lines and therefore requires a notification as soon as the line is commissioned. This notification requirement applies regardless of the type of direct line.

3.9.2b. *een significante wijziging ten opzichte van een eerdere melding zo spoedig mogelijk na doorvoering van de betreffende wijziging aan de Autoriteit Consument en Markt.* (English: any significant change compared to a previous notification to the Authority for Consumers and Markets as soon as possible after that change has been implemented.)
Explanation: Significant changes include, for example, changes in route, capacity, connected installations or connected end-users. These notifications are also essential for ACM supervision.

3.9.3. *Bij ministeriële regeling kunnen nadere regels worden gesteld over de inhoud van de meldingen.* (English: Further rules on the content of notifications may be laid down in a ministerial regulation.)
Explanation: Such further rules may concern which data must be provided, the format of the notification and the timeframe within which it must be submitted. This provides flexibility to align the notification procedure with technological and market developments.

C

Appendix - Overview of Obligations, Mandatory Tasks and Tariffs for a Closed System

This appendix contains many references to other provisions in the Energy Act, which is why those provisions have also been included under this article.

The explanations have been supplemented by explanations from the *Explanatory Memorandum to the Energy Act* [45].

✎ **Artikel 3.104** ***overeenkomstige toepassing beheerder gesloten systeem*** (English: Article 3.104 corresponding application for the closed system operator)

3.104.1 De artikelen 3.24, eerste en tweede lid, 3.25, eerste lid, 3.43, 3.44, 3.77, eerste en derde lid, en artikel 3.79, onderdelen a tot en met c, zijn van overeenkomstige toepassing op een beheerder van een gesloten systeem, met dien verstande dat voor "transmissie- of distributiesysteembeheerder", "transmissiesysteembeheerder" of "distributiesysteembeheerder" telkens wordt gelezen "beheerder van een gesloten systeem". (English: Articles 3.24, paragraphs 1 and 2, 3.25, paragraph 1, 3.43, 3.44, 3.77, paragraphs 1 and 3, and Article 3.79, parts a to c, apply correspondingly to a closed system operator, with the proviso that "transmission or distribution system operator", "transmission system operator" or "distribution system operator" is in each case to be read as "closed system operator".)
Explanation: This article stipulates that the relevant obligations from the cited provisions also apply to closed system operators, adapted to their specific role. The terminology is adjusted accordingly so that references to transmission or distribution system operators are read as references to the closed system operator.

3.104.2 De artikelen 3.51, eerste lid en vierde lid, onderdeel b, en 3.57 zijn van overeenkomstige toepassing op een beheerder van een gesloten systeem, met dien verstande dat: (English: Articles 3.51, first paragraph and fourth paragraph, part b, and 3.57 apply mutatis mutandis to an operator of a closed system, on the understanding that:)
a. de beheerder van een gesloten systeem alleen een meetinrichting met communicatiefunctionaliteit plaatst op verzoek; (English: the closed system operator only installs a metering device with communication functionality upon request;)
b. het tarief voor installatie en onderhoud van de meetinrichting in rekening wordt gebracht conform artikel 3.114. (English: the tariff for installation and maintenance of the metering device is charged in accordance with Article 3.114.)
Explanation: Closed system operators are only obliged to install smart meters with communication functionality when this is requested by the connected party and must charge transparent, cost based tariffs for the installation and maintenance of these meters, as laid down in Article 3.114.

✎ **Artikel 3.24** ***handelen en samenwerken transmissie- of distributiesysteembeheerder*** (English: Article 3.24 conduct and cooperation of the transmission or distribution system operator)

3.24.1 Een gesloten systeembeheerder handelt bij de uitoefening van zijn wettelijke taken of verplichtingen redelijk, transparant en niet discriminerend. (English: In performing its statutory tasks or obligations, a closed system operator acts in a reasonable, transparent and non discriminatory manner.)
Explanation: This requires the operator to carry out all actions fairly, openly and without discrimination, including treating third-party connections in an equal and impartial way.

3.24.2 Gesloten systeembeheerders werken bij de uitoefening van hun wettelijke taken of verplichtingen samen en verstrekken elkaar de gegevens die nodig zijn voor de uitvoering van hun wettelijke taken of verplichtingen

of die nodig zijn ter waarborging en stimulering van een effectieve deelname van marktdeelnemers op de elektriciteitsmarkt. (English: In performing their statutory tasks or obligations, closed system operators cooperate and provide each other with the data needed to perform those statutory tasks or obligations, or that is needed to ensure and promote effective participation of market parties in the electricity market.)
Explanation: Operators are required to cooperate and exchange the necessary data so that the energy market can function efficiently and market participants can participate effectively.

✎ **Artikel 3.25** ***beheren, onderhouden en ontwikkelen*** (English: Article 3.25 operation, maintenance and development)

3.25.1 Een beheerder van een gesloten systeem waarborgt dat zijn systeem op de korte en lange termijn kan voldoen aan een redelijke vraag naar transport van elektriciteit en beheert, onderhoudt en ontwikkelt het systeem, onder economische voorwaarden, op zodanige wijze dat de veiligheid, betrouwbaarheid en doelmatigheid van dat systeem is gewaarborgd, en met inachtneming van de belangen van het milieu, digitalisering, energie-efficiëntie, de transitie naar een duurzaam energiesysteem en de werking van de Europese interne markt. (English: A closed system operator ensures that its system can meet a reasonable demand for electricity transport in the short and long term and operates, maintains and develops the system, under economic conditions, in such a way that the safety, reliability and efficiency of that system are ensured, taking into account the interests of the environment, digitalisation, energy efficiency, the transition to a sustainable energy system and the functioning of the European internal market.)
Explanation: System operation and protection must focus on reliability, (digital) security risks, security of supply, sustainability and cost effectiveness, while also taking into account social and environmental interests as well as European market integration.

✎ **Artikel 3.43** ***overdrachtspunten*** (English: Article 3.43 transfer points)

3.43.1 Een beheerder van een gesloten systeem stelt voor een aansluiting op zijn systeem de locatie van het overdrachtspunt vast, rekening houdend met de redelijke belangen van de aangeslotene. (English: For a connection to its system, a closed system operator determines the location of the transfer point, taking into account the reasonable interests of the connected user.)
Explanation: The point at which energy is transferred is determined in a way that fairly reflects the interests of the connected user.

3.43.2 Indien een aansluiting uit meerdere leidingen bestaat, stelt de beheerder per leiding de locatie van het overdrachtspunt vast. (English: If a connection consists of several conductors, the operator determines the location of the transfer point for each conductor.)
Explanation: When there are multiple conductors, each transfer point must be clearly and separately identified.

3.43.3 De betreffende beheerders stellen gezamenlijk het overdrachtspunt van een systeemkoppeling vast. (English: The operators concerned jointly determine the transfer point of a system coupling.)
Explanation: This obliges operators to agree among themselves on the transfer point at locations where systems are interconnected.

✎ **Artikel 3.44** ***allocatiepunten*** (English: Article 3.44 allocation points)

3.44.1 Een beheerder van een gesloten systeem kent ten behoeve van een aansluiting op zijn systeem een primair allocatiepunt toe. (English: For a connection to its system, a closed system operator assigns a primary allocation point.)
Explanation: The operator designates the point at which energy consumption or production is recorded for market settlement.

3.44.2 Indien krachtens artikel 2.46, tweede lid, onderdeel a, is bepaald dat een plaats wordt aangemerkt als een additioneel allocatiepunt, kent de gesloten systeembeheerder aan die plaats een additioneel allocatiepunt toe. (English: If, pursuant to Article 2.46, paragraph 2(a), a location is designated as an additional allocation point, the closed system operator assigns an additional allocation point to that location.)
Explanation: This allows additional metering points to be designated when specific situations arise that require separate settlement.

3.44.3 Indien een aangeslotene op een gesloten systeem meer dan één marktdeelnemer contracteert inzake verbruik of invoeding, kent een transmissie- of distributiesysteembeheerder voor elektriciteit op verzoek van die aangeslotene een of meerdere additionele allocatiepunten toe. (English: If a user connected to a closed system contracts more than one market party for consumption or injection, a transmission or distribution

system operator for electricity assigns, at the request of that user, one or more additional allocation points.)
Explanation: Multiple allocation points can be created when several parties are involved in supplying or taking off energy, so that their positions can be settled separately.

✎ **Artikel 3.77** ***beschermen en verstrekken van informatie*** (English: Article 3.77 protection and provision of information)

3.77.1 Een beheerder van een gesloten systeem die bij de uitvoering van zijn wettelijke taken of verplichtingen de beschikking krijgt over gegevens waarvan hij het vertrouwelijke karakter kent of redelijkerwijs moet vermoeden, draagt er zorg voor dat die gegevens niet ter beschikking komen of kunnen komen van derden, tenzij enig wettelijk voorschrift anders bepaalt. (English: A closed system operator which, in performing its statutory tasks or obligations, obtains data whose confidential nature it knows or should reasonably suspect, ensures that such data do not become, and cannot become, available to third parties, unless a statutory provision provides otherwise.)
Explanation: The operator must protect confidential data against access by unauthorised parties, so that sensitive information is handled and stored with due care.

3.77.3 Een beheerder van een gesloten systeem verstrekt aangeslotenen, netgebruikers en marktdeelnemers en balanceringsverantwoordelijken, de informatie die ze nodig hebben voor een efficiënte toegang tot het gesloten systeem inclusief het gebruik ervan. (English: A closed system operator provides connected users, grid users, market parties and balance responsible parties with the information they need for efficient access to the closed system, including its use.)
Explanation: The operator is obliged to make all relevant information available so that users and market parties can effectively access and use the system.

✎ **Artikel 3.79** ***delegatiegrondslag nadere verplichtingen*** (English: Article 3.79 delegation basis for further obligations)
Bij of krachtens algemene maatregel van bestuur worden regels gesteld over: (English: Rules may be laid down by or pursuant to an order in council on:)

3.79.a Het melden van storingen of onregelmatigheden in het gesloten systeem. (English: the reporting of faults or irregularities in the closed system.)
Explanation: The operator must have procedures in place for detecting and reporting faults or irregularities in the system.

3.79.b Het indienen van klachten en het afhandelen van die klachten door de gesloten systeembeheerders. (English: the submission of complaints and the handling of such complaints by closed system operators.)
Explanation: This requires the operator to maintain a complaints desk and a clear procedure for receiving and dealing with complaints.

3.79.c Het faciliteren van aangeslotenen door de gesloten systeembeheerders bij overstappen naar andere marktdeelnemers of balanceringsverantwoordelijken, verhuizingen of in- en uithuizingen. (English: the facilitation by closed system operators of connected users when switching to other market parties or balance responsible parties, or in the event of moves or changes of occupancy.)
Explanation: The operator must support and properly administer processes related to supplier switching, relocation or changes in occupancy or connection status.

✎ **Artikel 3.51** ***ter beschikking stellen meetinrichting distributiesysteembeheerder*** (English: Article 3.51 provision of metering device by the distribution system operator)

3.51.1 Een beheerder van een gesloten systeem stelt aan een aangeslotene met een kleine aansluiting voor elektriciteit of gas, die op grond van artikel 2.46, eerste lid, over een meetinrichting moet beschikken, een meetinrichting met communicatiefunctionaliteit beschikbaar, installeert deze op of nabij het overdrachtspunt en doet een aanbod om de meetinrichting in gebruik te geven en te beheren. (English: A closed system operator provides a metering device with communication functionality to a connected user with a small electricity or gas connection who, pursuant to Article 2.46, paragraph 1, must have a metering device, installs this device at or near the transfer point and makes an offer to put the device into service and to operate it.)
Explanation: The operator is required to install and operate a smart meter for small connections when the connected user is entitled to one under the law.

3.51.4b Een beheerder van een gesloten systeem doet aan een aangeslotene met een kleine aansluiting voor elektriciteit of gas op diens verzoek een aanbod om binnen vier maanden een meetinrichting met com-

municatiefunctionaliteit ter beschikking te stellen ter vervanging van een meetinrichting zonder communicatiefunctionaliteit. (English: At the request of a connected user with a small electricity or gas connection, a closed system operator makes an offer to provide, within four months, a metering device with communication functionality to replace a metering device without communication functionality.)
Explanation: On request, the operator must offer to replace an older meter without communication functionality with a smart meter within four months.

✎ **Artikel 3.57** ***verzamelen meetgegevens distributiesysteembeheerders*** (English: Article 3.57 collection of metering data by distribution system operators)

3.57.1 Een beheerder van een gesloten systeem verzamelt, valideert en stelt de meetgegevens vast van aangeslotenen met een kleine aansluiting voor elektriciteit, die beschikken over een door een distributiesysteembeheerder op grond van artikel 3.51 geïnstalleerde meetinrichting waarvan de communicatiefunctionaliteit aan staat, indien dit noodzakelijk is voor: (English: A closed system operator collects, validates and determines the metering data of connected users with a small electricity connection who have a metering device installed by a distribution system operator pursuant to Article 3.51 and whose communication functionality is activated, if this is necessary for:)
a. het uitvoeren van de verplichtingen van een marktdeelnemer of balanceringsverantwoordelijke op grond van hoofdstuk 2; (English: performing the obligations of a market party or balance responsible party under Chapter 2;)
b. het uitvoeren van taken of verplichtingen bij of krachtens hoofdstuk 3. (English: performing tasks or obligations under or pursuant to Chapter 3.)
Explanation: Metering data are only collected when this is necessary for statutory obligations, market processes or system operation.

3.57.2 Bij ministeriële regeling worden regels gesteld over: (English: Rules are laid down by ministerial regulation regarding:)
a. welke meetgegevens worden verzameld, gevalideerd of vastgesteld; (English: which metering data are collected, validated or determined;)
b. de frequentie waarmee meetgegevens worden verzameld, gevalideerd of vastgesteld, waarbij: (English: the frequency with which metering data are collected, validated or determined, whereby:)
1°. de intervalfrequentie van verbruiks- invoedgegevens niet hoger is dan een kwartier; en (English: 1°. the interval frequency of consumption and injection data is not higher than fifteen minutes; and)
2°. verbruiks- en invoedgegevens ten hoogste één maal per dag worden verzameld; (English: 2°. consumption and injection data are collected no more than once per day;)
c. de wijze waarop meetgegevens worden verzameld; (English: the manner in which metering data are collected;)
d. nauwkeurigheidseisen bij het verzamelen van meetgegevens; (English: accuracy requirements for the collection of metering data;)
f. methoden voor het herleiden en berekenen ten behoeve van het valideren en vaststellen van meetgegevens (English: methods for deriving and calculating metering data for the purposes of validation and determination.)
Explanation: These rules ensure uniform, accurate and transparent processing of metering data and set limits on the level of detail and frequency of data collection.

✎ **Artikel 3.114** ***tarieven beheerder gesloten systeem*** (English: Article 3.114 tariffs of the closed system operator)

3.114.1 Een beheerder van een gesloten systeem brengt voor het uitvoeren van de bij of krachtens paragraaf 3.5.5 aan hem opgedragen taken of verplichtingen bij aangeslotenen op zijn systeem een tarief in rekening dat is vastgesteld met inachtneming van een vooraf door hem opgestelde en bekendgemaakte berekeningsmethode, die leidt tot tarieven die de kosten in verband met de uitvoering van zijn taken of verplichtingen reflecteren en transparant en niet-discriminerend zijn. (English: For performing the tasks or obligations assigned to it by or pursuant to Section 3.5.5, a closed system operator charges connected users on its system a tariff determined in accordance with a calculation method drawn up and published in advance, which leads to tariffs that reflect the costs associated with the performance of its tasks or obligations and are transparent and non discriminatory.)
Explanation: Tariffs must be based on pre defined, transparent calculation methods, reflect actual costs and may not result in unfair discrimination or distort competition.

3.114.2 De Autoriteit Consument en Markt bepaalt dat een beheerder van een gesloten systeem de door hem toegepaste berekeningsmethode of een door hem in rekening gebracht tarief aanpast, indien de Autoriteit Consument en Markt naar aanleiding van een klacht als bedoeld in artikel 5.4, eerste lid, vaststelt dat deze berekeningsmethode of dit tarief niet in overeenstemming is met de vereisten, bedoeld in het eerste lid. (English: The Authority for Consumers and Markets determines that a closed system operator must adjust the calculation method it applies or a tariff it charges if, following a complaint as referred to in Article 5.4, paragraph 1, the Authority for Consumers and Markets finds that this calculation method or tariff does not comply with the requirements referred to in paragraph 1.)
Explanation: The ACM supervises the fairness and legality of tariffs and can require operators to amend their tariff methodology or tariffs in response to justified complaints.

✎ **Artikel 3.105** ***aansluiten en transporteren gesloten systeem*** (English: Article 3.105 connection and transport in a closed system)

3.105.1 Een beheerder van een gesloten systeem kan op verzoek een aanbod doen tot aanleg of wijziging van een aansluiting op zijn systeem. (English: At the request of a party, a closed system operator may make an offer for the construction or modification of a connection to its system.)
Explanation: The operator is not under a general obligation to connect, but may choose to construct or modify a connection when requested.

3.105.2 Een beheerder van een gesloten systeem doet op verzoek een aanbod tot: (English: At the request of a party, a closed system operator makes an offer to:)
a. het in gebruik geven, beheren en onderhouden van een aansluiting op zijn systeem; en (English: a. put a connection to its system into service and operate and maintain it; and)
b. het verzorgen van transport van elektriciteit of gas over zijn systeem. (English: b. provide for the transport of electricity or gas over its system.)
Explanation: When a party asks to be connected, the operator must offer both connection services and transport services over the closed system.

3.105.3 In afwijking van het tweede lid, kan een beheerder van een gesloten systeem weigeren een aanbod te doen, indien er redelijkerwijs onvoldoende transportcapaciteit beschikbaar is op zijn systeem. De beheerder van een gesloten systeem voorziet een weigering van een deugdelijke onderbouwing. (English: By way of derogation from paragraph 2, a closed system operator may refuse to make an offer if there is, reasonably, insufficient transport capacity available on its system. The closed system operator must provide a proper justification for such a refusal.)
Explanation: Only in case of substantiated capacity constraints may the operator refuse to connect or transport, and any refusal must be properly reasoned.

✎ **Artikel 4.6** ***register beheerder gesloten systeem*** (English: Article 4.6 register of the closed system operator)

4.6.1 Een beheerder van een gesloten systeem, met uitzondering van de beheerder bedoeld in artikel 1 van de Spoorwegwet, houdt een register bij waarin hij bij ministeriële regeling te bepalen gegevens opneemt die hij op grond van deze wet verzamelt of bewerkt over: (English: A closed system operator, with the exception of the operator referred to in Article 1 of the Railway Act, keeps a register in which it records, in accordance with what is determined by ministerial regulation, the data that it collects or processes under this Act concerning:)
a. aansluitingen, overdrachtspunten en allocatiepunten; (English: a. connections, transfer points and allocation points;)
b. aangeslotenen; (English: b. connected users;)
c. installaties; (English: c. installations;)
d. transport; (English: d. transport;)
e. meetinrichtingen; (English: e. metering devices;)
f. metingen; (English: f. measurements;)
g. onderwerpen, genoemd in artikel 3.79, onderdelen a tot en met c. (English: g. the subjects referred to in Article 3.79, parts a to c.)
Explanation: The operator is required to maintain a complete overview of all relevant technical and contractual data in a central register.

4.6.2 Indien een aangeslotene geen deel uitmaakt van het bedrijf van de beheerder en de beheerder geen energie levert aan die aangeslotene, houdt hij een register bij met gegevens die hij ontvangt en bewerkt over:

(English: If a connected user does not form part of the operator's business and the operator does not supply energy to that user, it keeps a register of the data it receives and processes concerning:)
a. leveranciers, aggregatoren, balanceringsverantwoordelijken en meetverantwoordelijken; (English: a. suppliers, aggregators, balance responsible parties and metering responsible parties;)
b. installaties; (English: b. installations;)
b. meetinrichtingen; (English: b. metering devices;)
c. metingen; (English: c. measurements;)
e. de contractperiode en opzegtermijn tussen marktdeelnemer en eindafnemer of actieve afnemer. (English: e. the contract period and notice period between a market party and an end-user or active customer.)
Explanation: This provision applies to external customers and ensures transparency regarding market roles, installations, metering and contractual arrangements.

4.6.3 De beheerder bedoeld in artikel 1 van de Spoorwegwet houdt een register bij van gegevens verzameld op grond van deze wet en EU-verordening 1301/2014 inzake interoperabiliteit van het subsysteem energie: (English: The operator referred to in Article 1 of the Railway Act keeps a register of data collected under this Act and EU Regulation 1301/2014 on the interoperability of the energy subsystem concerning:)
a. aansluitingen, overdrachtspunten en allocatiepunten; (English: a. connections, transfer points and allocation points;)
b. aangeslotenen; (English: b. connected users;)
c. metingen. (English: c. measurements.)
Explanation: Railway operators are subject to additional requirements under European legislation and must align their registers with those interoperability rules.

4.6.4 Bij ministeriële regeling worden regels gesteld over de frequentie waarmee en de termijn waarbinnen gegevens worden verzameld, bewerkt en geregistreerd. (English: Ministerial regulations lay down rules on the frequency with which and the period within which data are collected, processed and recorded.)
Explanation: This ensures that information remains up to date and that there is standardisation between different operators.

4.6.5 Gegevens worden niet langer bewaard dan noodzakelijk is voor het doel van gebruik. (English: Data are not retained longer than is necessary for the purpose for which they are used.)
Explanation: This promotes data protection and minimises the risks associated with unnecessary data storage.

✎ **Artikel 4.10** ***gebruiken en verstrekken gegevens beheerder gesloten systeem*** (English: Article 4.10 use and provision of data by the closed system operator)

4.10.1 Een beheerder van een gesloten systeem gebruikt de bij ministeriële regeling te bepalen gegevens die in zijn register zijn opgenomen voor de uitvoering van zijn wettelijke taken of verplichtingen met betrekking tot het: (English: A closed system operator uses the data determined by ministerial regulation and included in its register for the performance of its statutory tasks or obligations relating to:)
a. beheren en onderhouden van zijn systeem; (English: a. operating and maintaining its system;)
b. bepalen van tarieven; (English: b. determining tariffs;)
c. uitvoeren van aansluit- en transportovereenkomsten; (English: c. performing connection and transport agreements;)
d. transporteren; (English: d. providing transport;)
e. beheren en onderhouden van zijn meetinrichtingen; (English: e. operating and maintaining its metering devices;)
f. uitvoeren van artikel 3.79, onderdelen a tot en met c. (English: f. performing Article 3.79, parts a to c.)
Explanation: The operator may use the data in its register only for operational and statutory purposes that are directly related to system operation, tariffs and market processes.

4.10.2 In het geval een aangeslotene op een gesloten systeem niet behoort tot het bedrijf van de beheerder van het gesloten systeem en die beheerder niet aan die aangeslotene elektriciteit of gas levert, verstrekt een beheerder van een gesloten systeem aan leveranciers, marktdeelnemers die aggregeren, balanceringsverantwoordelijken, meetverantwoordelijke partijen, Onze Minister en andere systeembeheerders de bij ministeriële regeling te bepalen gegevens die in zijn register zijn opgenomen ten behoeve van het: (English: If a user connected to a closed system does not form part of the closed system operator's business and that operator does not supply electricity or gas to that user, the closed system operator provides suppliers,

aggregating market parties, balance responsible parties, metering responsible parties, the Minister and other system operators with the data determined by ministerial regulation and recorded in its register for the purposes of:)
a. sluiten, uitvoeren en beëindigen van een overeenkomst; (English: a. concluding, performing and terminating a contract;)
b. overstappen; (English: b. switching supplier;)
c. verstrekken van facturen, factureringsinformatie, opwekkingsgegevens en verbruiksgegevens; (English: c. providing invoices, billing information, generation data and consumption data;)
d. uitvoeren van de balanceringsverantwoordelijkheid; (English: d. fulfilling the balancing responsibility;)
e. uitvoeren van metingen; (English: e. carrying out measurements;)
f. uitgeven van garanties van oorsprong. (English: f. issuing guarantees of origin.)
Explanation: Where third parties are active in the system, the operator must share the relevant data with them so that market processes, settlement and supply can be carried out correctly.

4.10.3 Indien het tweede lid van toepassing is, verstrekt een beheerder van een gesloten systeem ter uitvoering van artikel 4.1, tweede lid, onderdelen b, c, d en e, de bij ministeriële regeling te bepalen gegevens die hij in zijn register heeft opgenomen aan de verzoekende partij of aan een ander zoals bepaald door de verzoekende partij. (English: If paragraph 2 applies, a closed system operator provides, for the purposes of implementing Article 4.1, paragraph 2(b), (c), (d) and (e), the data determined by ministerial regulation and recorded in its register to the requesting party or to another party designated by the requesting party.)
Explanation: The connected user or its authorised representative can obtain access to the relevant data, for example for insight, verification or switching, provided that this is permitted by law.

4.10.4 Een beheerder van een gesloten systeem verstrekt de gegevens, bedoeld in het eerste en tweede lid, middels een faciliteit van de gegevensuitwisselingsentiteit en geeft de gegevensuitwisselingsentiteit ter uitvoering van artikel 4.16 toegang tot zijn register. (English: A closed system operator provides the data referred to in paragraphs 1 and 2 via a facility of the data exchange entity and grants the data exchange entity access to its register for the purposes of implementing Article 4.16.)
Explanation: Data exchange takes place via a central data exchange facility, which ensures a standardised, transparent and secure way of sharing data between market parties and authorities.

D

Stakeholder Interview and Survey Findings on the Themes

This appendix presents a consolidated summary of stakeholder interview findings, covering judgements over the themes that might be present within the prioritisation framework, and the outcomes of the joint consultation with stakeholders in the Amsterdam case.

A detailed overview of the results of the stand-alone interviews have been omitted from the appendices in this public version. These are available from the author upon request.

D.1. Overview of Survey Results on the Technical Theme

General overview

Respondents were asked how soon their network would be stable and ready for new connections. Most do not consider their network ready at present, many expect readiness within a year, while only one respondent indicated that their network is immediately ready, see Figure D.1.

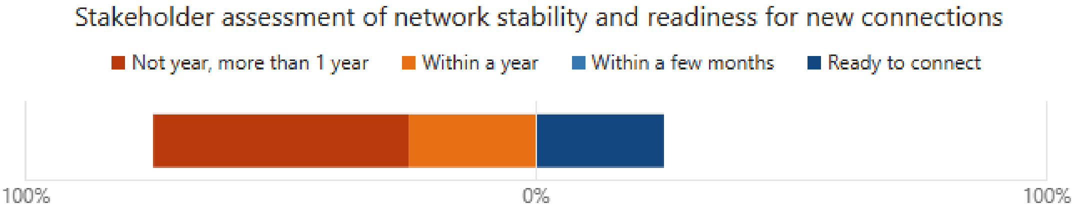

Figure D.1: Stakeholder assessment of network stability and readiness for new connections.

The respondents supplemented their reasoning with these statements:

- Limited experience and case by case: Some applications can be connected without issues, while for others the technical effect is still uncertain.
- DC grid is broadly stable: The binding constraint is the risk of exceeding contracted capacity, which is sensitive due to congestion. Applications that reduces net energy use, are expected to be connected within about a year.

Respondents also indicated which measures their organisation currently employs to alleviate grid congestion. Most report *reducing energy consumption*, with some also indicating that they focus on *reducing simultaneous power* or *adding local generation*. No responses were recorded for formal congestion management or renegotiation toward lower Connection and Transport Agreement (ATO) contracts, see Figure D.2. In addition, it was also stated that they provide insight into when exceedances occur by supplying real-time information about energy consumption to traffic control.

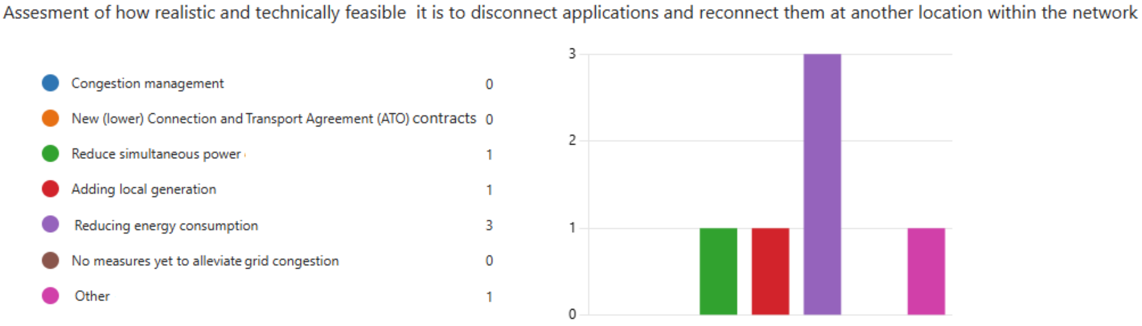

Figure D.2: Measures employed to alleviate grid congestion. Counts per measure as reported by respondents.

Grid impact

The survey highlights that the awareness that new applications may affect the regional or national electricity grid, DSO or TSO, is uneven. Several respondents reported limited awareness, while others indicated they are quite or fully aware of this, see Figure D.3.

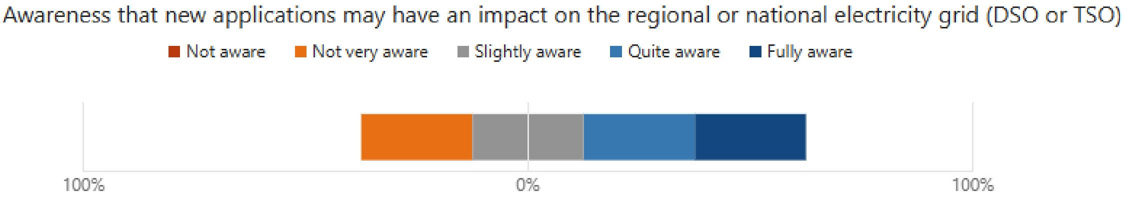

Figure D.3: Awareness that new applications can affect the DSO or TSO grid.

Figure D.4 summarises how respondents rate the importance of specific power system aspects. While all aspects matter, voltage fluctuations are viewed as the most important, followed by current variations, increased loading, and energy losses, with reduced power factor rated least important. Yet it underscores that all items should be minimised or actively controlled when applications are connected.

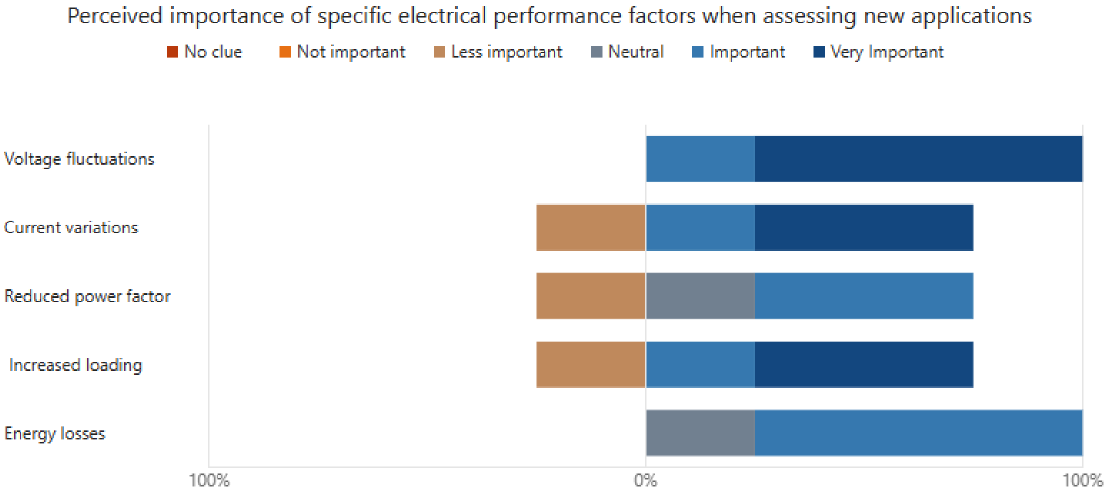

Figure D.4: Perceived importance of specific electrical performance factors when assessing and prioritising new applications on the PTO electrical network.

The survey revealed that all stakeholders consider it important to incorporate the *grid impact* component in the prioritisation framework when assessing and prioritising new applications that might be connected to the PTO electrical infrastructure, as can be seen in Figure D.5.

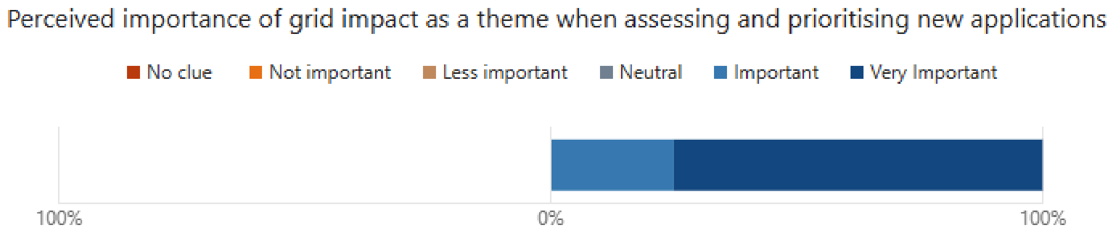

Figure D.5: Perceived importance of grid impact as component when assessing and prioritising new applications.

When asked about the reasoning behind this, the main points that emerged were:

- Contracted capacity is binding: Higher loading is acceptable provided the aggregate demand remains well below the contracted value with the DSO, exceeding the contracted power leads to penalties and can trigger disconnection, tighter DSO protection settings and maximum current limits make load control decisive.
- Continuity of service is dominant: New applications must not hinder traction operations, voltage fluctuations that cause trips are unacceptable.
- Protections are voltage and current driven: Stability of voltage and avoidance of overcurrent are the first checks at the point of connection, coordination with DSO settings is required.
- Big current variations are unlikely: Traction already causes large current swings, additional applications are unlikely to exceed these.
- Power quality must be kept within limits: Poor power factor and harmonic distortion can damage existing equipment.
- Efficiency matters: Energy losses should be avoided for sustainability and cost control, monitor and minimise conversion and cable losses.

When was questioned how applications could help and which positive technical effects they expect that connecting applications could have when those applications are connected to the electrical infrastructure of the PTO, the main points were that:

- Storage to stabilises: Applications with storage can help store surplus energy in ESS and used later, which stabilises the load profile and reduces stress on protections.
- Local generation offsets demand: Solar PV can cover part of the demand at certain times, lowering net withdrawals from the grid.
- Optimisation of consumption: Well controlled applications smooth the profile and shave peaks, improving operational efficiency.
- Better use of tram/metro infrastructure: Co-located loads make better use of existing traction power network capacity and reduce losses.

Figure D.6 shows how respondents rank preferred connection locations within the PTO electrical infrastructure, based on a technical point of view. The respondents most often select either a direct connection to the overhead line (OHL) or third rail, or an available AC transformer field. The DC rectifier field is typically the second preference, while cable pooling is generally ranked last on technical grounds.

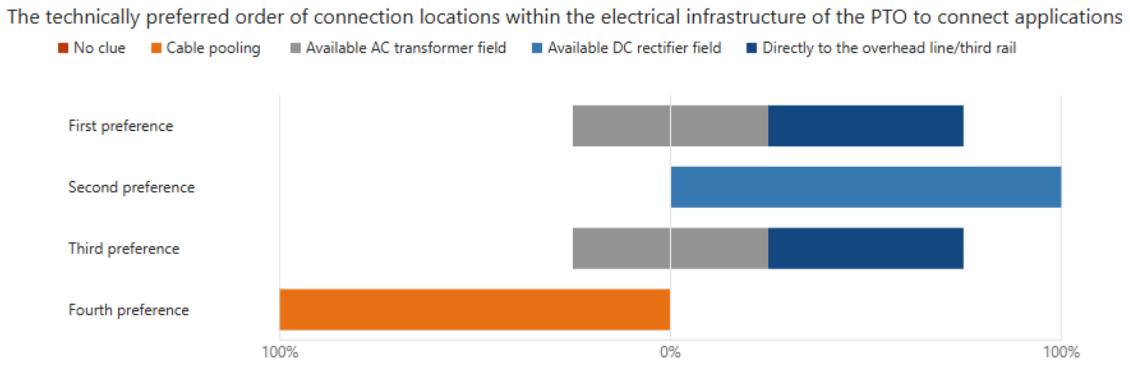

Figure D.6: Ranked technical preference for connection locations within the PTO electrical infrastructure.

The respondents supplemented their reasoning with these statements:

- Context dependent: The realistic location depends on the site, the connection type, and the application's current.
- Direct to OHL or third rail: Some view this as the simplest and lowest cost option, while others note the need for additional isolators and space which makes it less obvious, although still feasible.
- DC is more challenging: With a DC connection, it is often more difficult because the security/safety requirements are more specific. Furthermore, there are few or no fields available, either AC or DC.

According to them, cable pooling is more difficult in practice, because the intake substation is in the DSO domain, however under the new Energy Act it becomes a serious option since the primary connected party (which is the PTO) may choose with whom to share the intake connection, see *Cable Pooling.*

Efficiency

Respondents were asked to assess the impact of energy losses and the network's capacity to accommodate them. Responses are mixed. However, most do not regard losses as a major concern, they consider them limited and manageable, see Figure D.7.

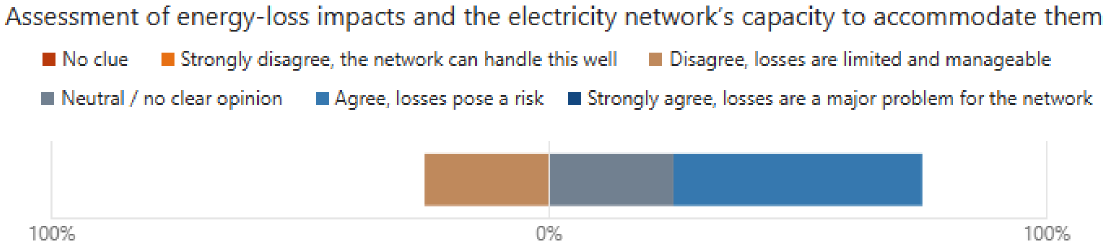

Figure D.7: Assessment of energy-loss impacts and the network's capacity to accommodate them.

The biggest part of the respondents rate *efficiency* as an important component to include in the prioritisation framework, while also some view it as less important, see Figure D.8.

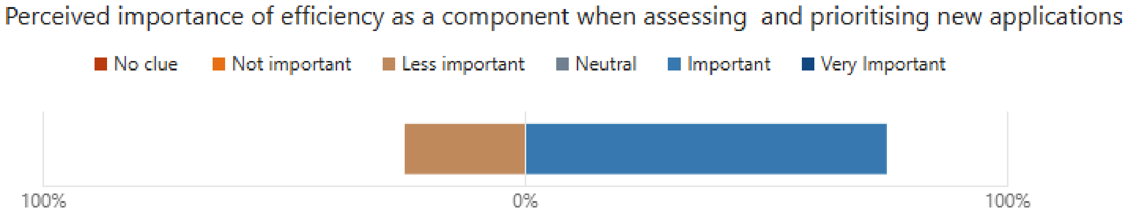

Figure D.8: Perceived importance of efficiency as a component when assessing and prioritising new applications.

The perceived importance aligns with the views on losses. Several respondents noted:

- Efficiency should be valued: It sensible to include efficiency, and to focus on reducing transport, conversion, and usage losses, but it is application dependent.
- Other components prevail: Even though efficiency is important, other aspects are more important.

Scalability

Respondents generally see opportunities, while also some see risks when scaling up applications, as can be seen in Figure D.9.

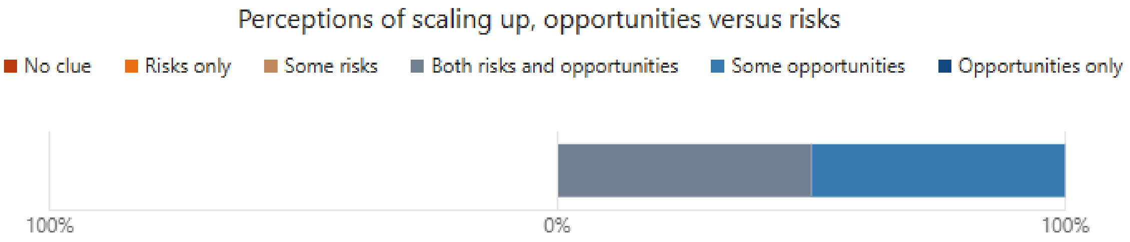

Figure D.9: Perceptions of scaling up, opportunities versus risks.

Scalability itself is rated as an important component when assessing and prioritising new applications, see Figure D.10.

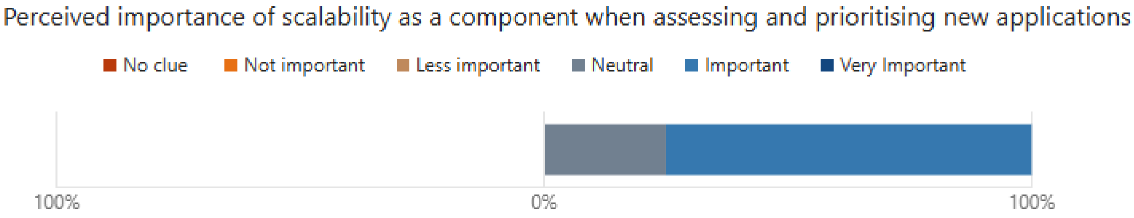

Figure D.10: Perceived importance of scalability as a component when assessing and prioritising new applications.

Mainly, the respondents prefer and see opportunities:

- Simple, clearly defined mechanisms: Solutions with a straightforward implementation path that can be replicated are favoured, provided they deliver a significant, demonstrable benefit.
- Standardise to scale: To scale up; design, construction, and operations and maintenance should be as uniform as possible, this reduces cost and complexity and speeds roll out.

Controllability

According to the respondents it is important that the application can be precisely controlled, this is rated from important to very important, as can be seen in Figure D.11.

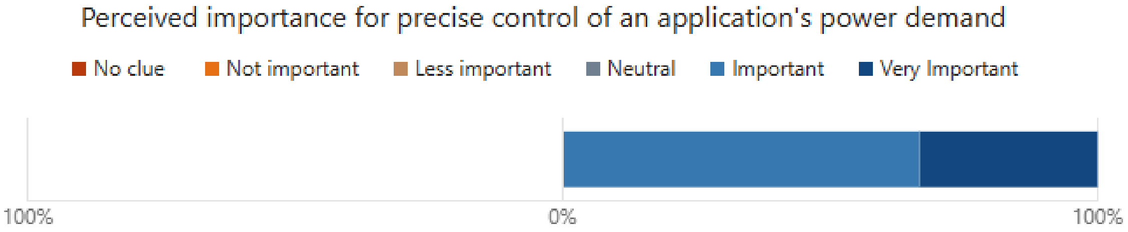

Figure D.11: Perceived importance of precise control of an application's power demand.

Next to that, they also indicate that it is important to be able to control the import or export direction, see Figures D.12.

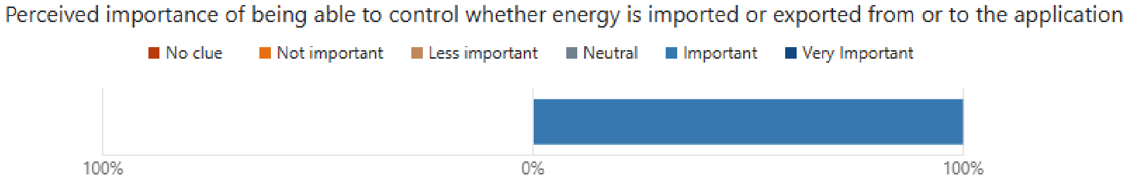

Figure D.12: Perceived importance of being able to control whether energy is imported or exported to or from the application.

In worst-case scenario's, the respondents also express that their need to be the ability to disconnect applications when that is required, see Figure D.13.

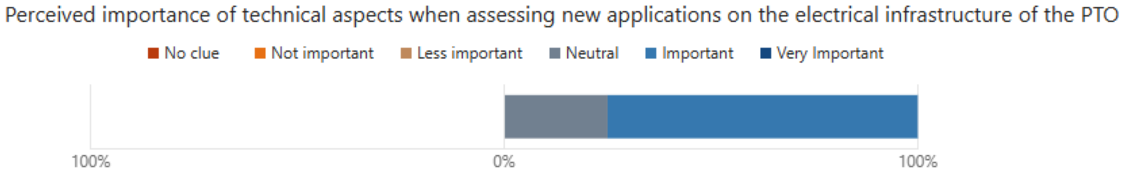

Figure D.13: Assessment of the necessity to temporarily disconnect applications from the PTO electrical infrastructure.

All in all, the respondents therefore also rate *controllability* as an important component when assessing and prioritising new applications, see Figure D.14.

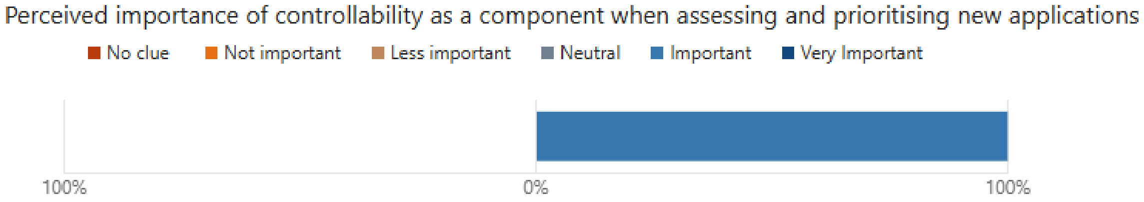

Figure D.14: Perceived importance of controllability as a component when assessing and prioritising new applications.

The perceived importance of the controllability components aligns with the views on controllability elements itself, and the respondents noted:

- Higher load, higher control: The larger the expected demand on the network, the more important controllability becomes.
- Energy management is essential: Energy Management Systems are needed to coordinate applications, optimise set points, and keep the aggregate demand within technical and contractual limits.
- Operational control at all times: Operators want control over power usage, including the ability to select import or export and disconnect temporarily when required for safety or service continuity.

Installation and maintenance

Figure D.15 shows that most respondents currently rely on external support for the installation, operation, and maintenance of new applications, whereas one respondent reports performing these activities mostly in-house with occasional external assistance.

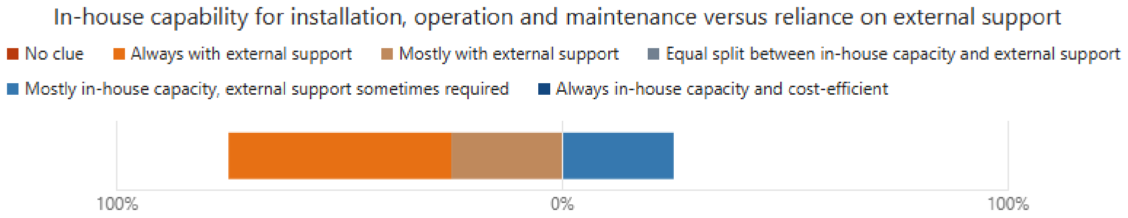

Figure D.15: In-house capability for installation, operation, and maintenance versus reliance on external support.

Respondents rated the *installation and maintenance* component from neutral to very important when prioritising new applications, as shown in Figure D.16.

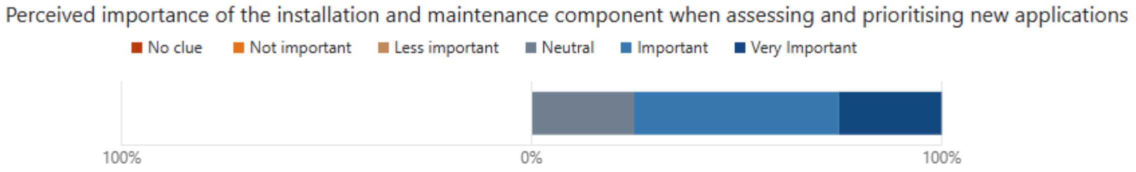

Figure D.16: Perceived importance of the installation and maintenance component when assessing and prioritising new applications.

In general, the statements they made for these claims came down to:

- Familiar technologies: Where the organisation is already familiar with a technology, it can undertake installation and maintenance more easily in-house.
- Use external specialists where efficient: Outsourcing can be cheaper or safer when specialist skills are required.

Relocatability

Respondents were asked how realistic and technically feasible it would be to disconnect applications and reconnect them elsewhere in the network. Many indicate that they do not have an idea whether this is feasible or not, while someone also noted that it might be feasible, see Figure D.17.

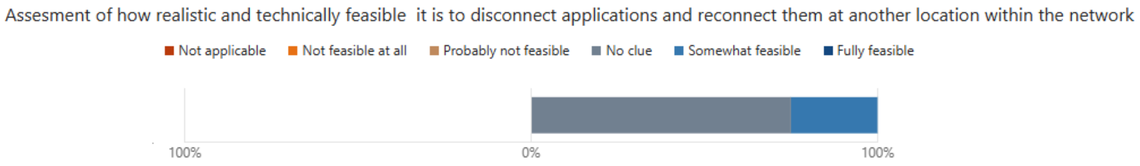

Figure D.17: Feasibility of disconnecting applications and reconnecting them at another location within the network.

As a component in the prioritisation framework, *relocatability* is typically rated between neutral and not important, see Figure D.18.

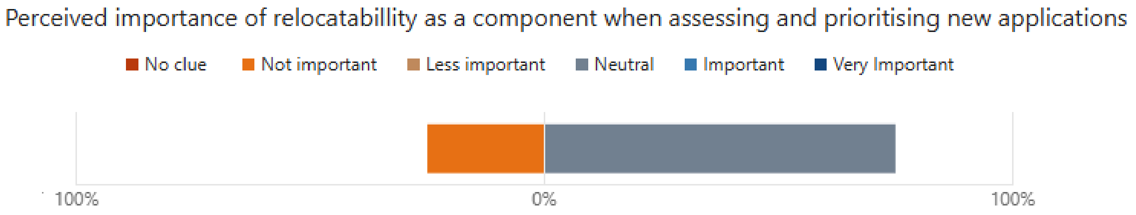

Figure D.18: Perceived importance of relocatability as a component when assessing and prioritising new applications.

The explaining statements of the respondents:

- Application dependent: The feasibility and desirability of relocating strongly depend on the type of application.
- Technically possible but costly: Relocation is usually feasible, however for most applications it is expensive and not preferred.
- Operations can change: Route plans and timetables may shift over time, which can make relocation necessary in specific cases.

D.2. Overview of Survey Results on the Societal Theme

General overview

When respondents were asked what primary objectives their municipality or province seeks to achieve by enabling third-party connections to the public transport electricity infrastructure, the following answers were given:

- Energy transition and CO_2 reduction: The main objective is to contribute to the energy transition and reduce CO_2 emissions.
- Relieving grid congestion via existing assets: Alleviate regional grid congestion by making optimal use of existing energy infrastructure and PTO assets.
- Supporting operator decarbonisation: Facilitate with the decarbonisation of other local (private) bus operators at depots.
- Not yet ready: Some stakeholders are not yet ready to connect applications and first want to focus on the operations of the public transport itself.
- No active policy: Some parties report that they do not have an active policy for third-party connections.

These responses indicate that the primary focus of these parties is to relieve grid congestion, preferably while also reducing CO_2 emissions, and in some cases to support other operators in meeting sustainability requirements.

When respondents were asked how these objectives should be realised and what role division they envisage between the municipality, province, PTO, DSO, concession grantor, and PTA, the following responses were given:

- Provincial coordination, municipal delivery: The province coordinates toward a coherent, future-proof energy and mobility infrastructure, municipalities are responsible for local implementation, management of the PTOs and operate/maintain the infrastructure.
- Pilots and knowledge-sharing: Close national cooperation with municipalities, PTA's, and peer infrastructure managers to share knowlegde and explore pilots.

These responses imply that the provinces and, where applicable, the PTA should assume the coordinating role, while municipalities that own the PTO or the electrical infrastructure should be closely involved as the implementing party and engage directly with the PTO.

When respondents were asked how these objectives should be realised and which parties should contribute to a prioritisation framework for applications, the following aspects were mentioned:

- Inclusive co-development: It is important that all involved parties can contribute to the prioritisation framework.
- In discussion: Discussions are ongoing, however some actors are not directly involved because their organisation does not have an active role.

These responses show broad support for inclusive participation, yet in practice not all actors are actively involved. Reasons could be that there is uncertainty about roles and expectations, limited clarity on how each party is connected to the process, insufficient knowledge of one another's mandates and activities, and an incomplete understanding of the system's functioning.

Stakeholders were also asked which application types they would prefer to see connected to the PTO electricity network. Preferences concentrate at the top on *EV chargers* and *Energy Storage Systems (ESS)*, followed by *Zero emission Equipment*. Mid-tier preferences include *PTO depots, offices, workshops* and *Local generation*. Lower ranked items are *Street lighting and Public space*, *Building services systems*, *Bidirectional inverters*, *Event and Temporary installations*, and *Industry*, see Figure D.19. Note that the application type *Business parks & commercial* was not included in the list, therefore no conclusions can be drawn for this category.

These preferences align with the pilots currently underway, which may indicate that limited exploratory studies and cross-stakeholder consultations have been conducted on other potential application types. While the rankings reflect perceived impact and deliverability, they do not substitute for a location-specific feasibility assessment.

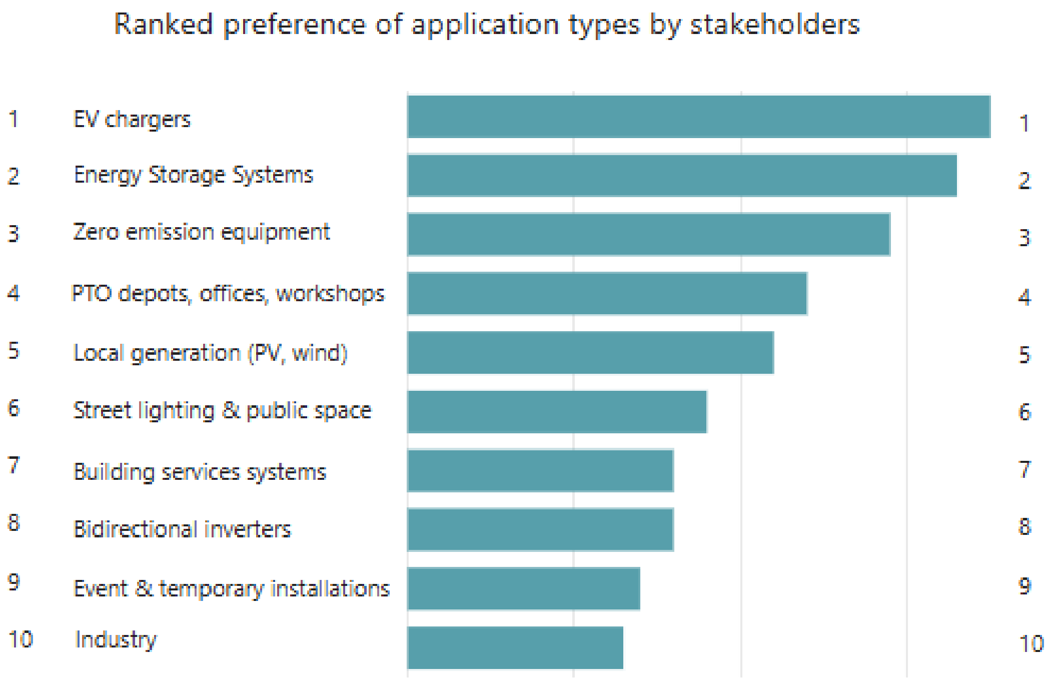

Figure D.19: Ranked preference of application types by stakeholders.

In addition, the stakeholders stated that:

- Existing connections for PTO-related assets: Street lighting and public-space assets that are under provincial/municipal ownership (for example, tram stops) are often already connected to the PTO electrical infrastructure.
- Limited control over connection: Some respondents do not manage their own electrical networks for public transport, so these type of choices rest with other parties.

Technical knowledge within the stakeholder set

When respondents were asked whether their municipality or province is aware of possible technical downsides of third-party connections, the following aspects were reported:

- Awareness is present: Several respondents indicated that they are aware of potential technical risks/issues and recognise that there these risks and potential consequences must be understood and managed.
- Unknown which problems: Some respondents reported they do not specifically what the possible technical risks/issues are, however colleagues are more closely involved hold the detailed expertise.

Social value

One stakeholder could not provide ratings for the social questions, noting that such assessments are made case by case across multiple departments, with final decisions taken by the council and influenced by national policy. They emphasised that choices should first be made through democratic consultation.

Impact within the organisation (PTO)

When stakeholders were asked to rate the *Impact within the organisation (PTO)*, most considered the items within this component important to very important. Improving employee safety, reducing occupational exposure to harmful emissions, and reducing noise exposure score consistently high. Involving employees in decision-making is also valued, although responses show a little bit more variation across organisations, see Figure D.20.

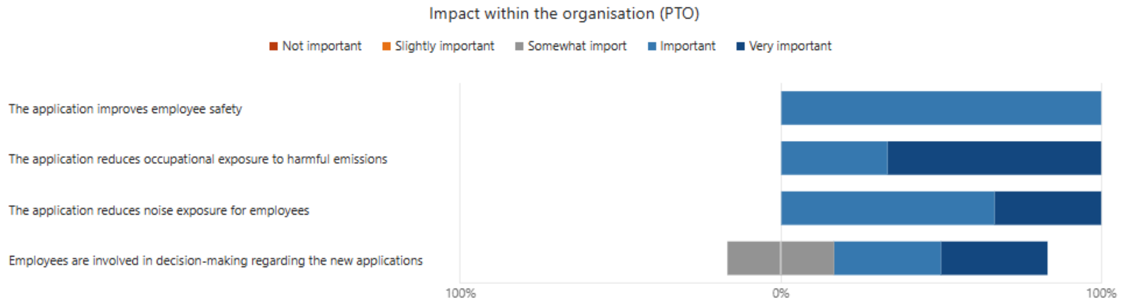

Figure D.20: Perceived importance of internal social aspects for the PTO workforce.

Passenger and customer impact

When stakeholders were asked to rate the *Passenger and customer impact* component, no consensus among stakeholders was achieved, as can be seen in Figure D.21. All items were ranked from not important to (very) important. Therefore, it is not possible to draw a clear judgement here.

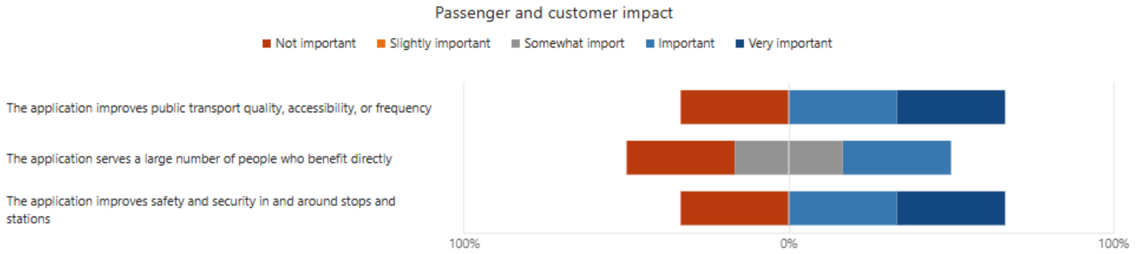

Figure D.21: Perceived importance of passenger and customer aspects.

Community and society impact

When stakeholders were asked to rate the *Community and society impact* component, the highest importance is placed on applications that help to improve local air and water quality, applications that are located at places where grid congestion is most severe. After that, an application that helps to reduce ambient noise is scored third. Limited spatial impact, positive effects on employment and the local economy, and applications that feed local generation are then considered to be the most important. All the aspects after those have limited to no importance in general, see Figure D.22.

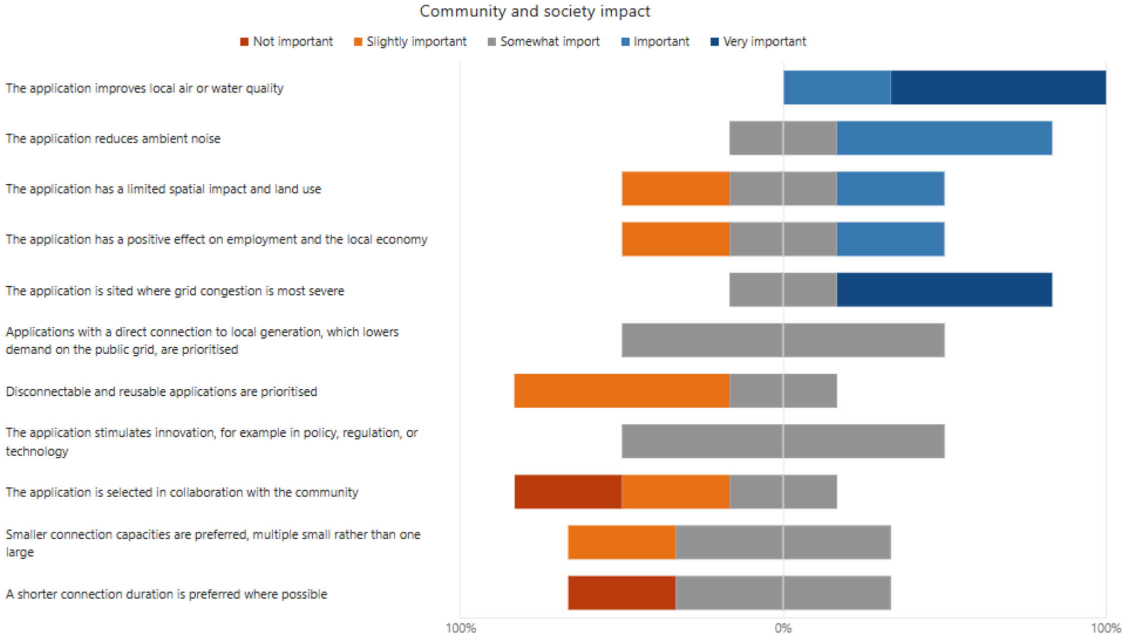

Figure D.22: Perceived importance of community and society aspects.

Sustainability value

The same stakeholder could also not provide answers for the sustainability related questions for the same reason noted as for the social related questions; assessments are made case by case across departments, with final decisions taken by the council and influenced by national policy.

Prevention of pollution

When stakeholders were asked to rate the *Prevention of pollution* component, reducing local air pollution has been judged the most important over the other two. The prevention of heavy metal emissions and water pollution prevention is generally viewed as somewhat important to important, see Figure D.23.

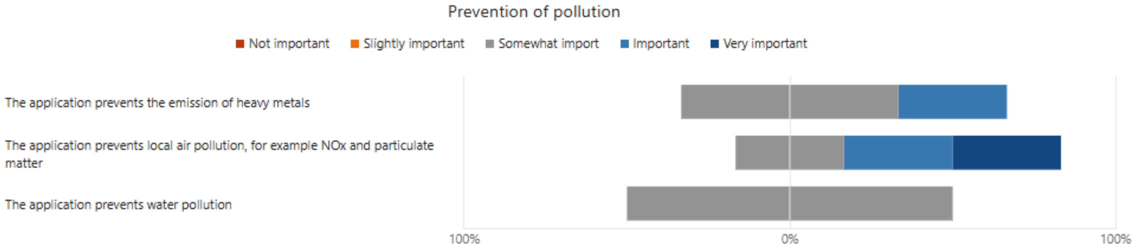

Figure D.23: Perceived importance within the sustainability component: prevention of pollution.

Sustainable resource use

For the *Sustainable resource use* component, improvements in energy efficiency and direct coupling to on site renewables are rated from important to very important by the respondents. Recyclability or use of recycled materials is typically rated from somewhat important to important, see Figure D.24.

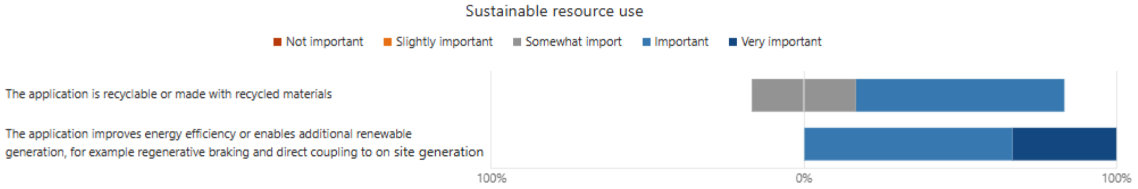

Figure D.24: Perceived importance within the sustainability component: sustainable resource use.

Climate change mitigation

The *Climate change mitigation* component receives consistently high scores, most respondents rate a comparatively large reduction in greenhouse gases as important to very important, see Figure D.25.

Figure D.25: Perceived importance within the sustainability component: climate change mitigation.

Protection of the local environment

Within *Protection of the local environment*, contributions to sustainable area development attract the strongest importance ratings, biodiversity and ecosystem health shows more mixed responses from slightly important to very important, while minimising land use relative scores a little bit lower with scores varying between slightly important to somewhat important, see Figure D.26.

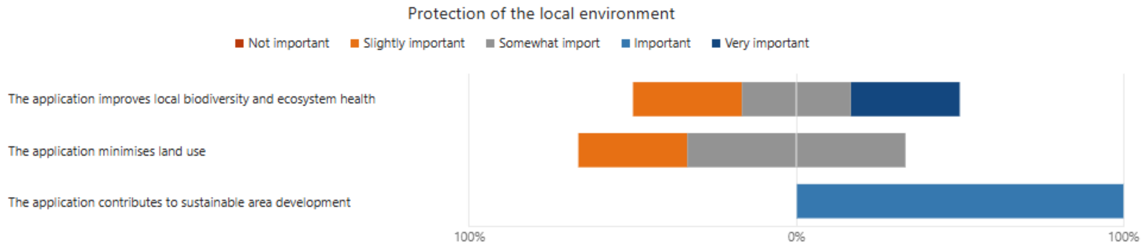

Figure D.26: Perceived importance within the sustainability component: protection of the local environment.

Alignment with development goals

For *Alignment with development goals*, respondents largely rate consistency with municipal or provincial objectives as very important, and contribution to the UN Sustainable Development Goals as somewhat important to very important, with a small neutral share, see Figure D.27.

Figure D.27: Perceived importance within the sustainability component: alignment with development goals.

D.3. Overview of Survey Results on the Legal questions

The respondents from the technical survey

The respondents from the technical survey most often pointed out that a Closed System is the most effective way to relieve congestion, followed by connecting application via the installation construction. Nevertheless, several respondents did emphasise that it is easier in practice to connect only self-owned applications or non-WOZ objects and to use the Installation construction, but they don't see this is as very effective. It should also be noted that none of the stakeholders indicated that the most effective solution would be to connect the application via the Cable Pooling construction.

Figure D.28 summarises stakeholder views on the most effective legal construct to connect applications and relieve grid congestion.

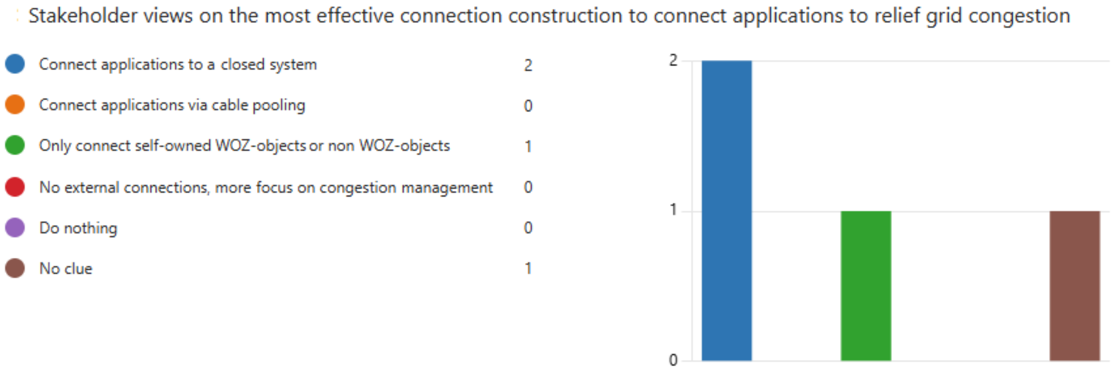

Figure D.28: Stakeholder views on the most effective legal construction to connect applications and relieve grid congestion.

The explaining statements of the respondents:

- Closed System timeline: Obtaining recognition for a Closed System is estimated to take about 1.5–2 years.
- Uncertain duration: Other respondents indicated they had no clear view of how long the process for the recognition of a CS would take.
- Possible faster: Due to preparatory work that has already been done by RET and HTM, some expect that subsequent CS recognition requests by other PTOs could proceed faster, potentially within a few months.
- Cable Pooling and Congestion Management: One respondent noted that, in addition to a CS, Cable Pooling and Congestion Management could offer opportunities to alleviate grid congestion.

The respondents from the societal survey

When respondents were asked whether their municipality or province is aware of legal possibilities and challenges, and, whether they know what the implications and additional burdens are for PTOs, the following highlights were reported:

- Uncertain and partial awareness: Some respondents do not know, others indicate that they are aware of the implications and additional burdens.
- Tracking new developments: The respondents tracking and orientating on new developments, including the new Energy Act.
- Recognised implications for PTOs: Some are concerned that third-party use can affect the acquisition of HBE (Renewable Fuel Units (HBEs) which offer entrepreneurs opportunities to earn extra money with sustainable transport) certificates linked to zero emission operation.
- Additional workload: The extra workload is dependent on forthcoming policy, and legal choices, for example whether to become a Closed System according to respondents.

Based on the ranking of application types that municipalities or provinces would most like to connect, respondents primarily prefer applications that are feasible via the installation construction. The application in sixth place is the first that would not be possible via the installation construction, see Figure: Ranked preference of application types by stakeholders.

D.4. Joint Consultation Amsterdam

In a joint consultation between the Municipality of Amsterdam, GVB, the Vervoerregio Amsterdam (VRA & PTA), and Liander (DSO), stakeholders discussed perspectives, knowledge, and expectations regarding third-party connections to GVB's electricity network and the role of the PTO in mitigating grid congestion in and around Amsterdam. The main insights are summarized below.

Profile

Participants included representatives from GVB, the Vervoerregio Amsterdam (VRA), the Municipality of Amsterdam, and Liander [106].

Focus and key insights

Near term capacity constraints and internal optimisation:

In the consultation, GVB explained that they are struggling with near-term capacity constraints and there is insufficient available power to realise its operational ambitions under temporary grid congestion. Internal optimisation across modes, that is bus, tram, and metro, is therefore required, combined with the potential addition of renewable energy sources (RES) on GVB's network. If optimisation is implemented effectively, GVB expects to meet its own demand.

Limited mutual system understanding and targeted relief:

The discussion also highlighted limited mutual understanding of each other (electrical) systems and objectives. PTO traction power networks can absorb high power peaks and, under certain circumstances, could function as a transport network where DSO transport capacity is constrained. Conversely, GVB has limited visibility of the DSO's specific congestion locations and types. If GVB wants to assist, it would make sense to target the areas with the greatest congestion relief value.

Divergent municipal views on the PTO's role:

Within the Municipality, views diverge on the desired role of the PTO. Some departments prioritise a future-proof public transport operation and consider third-party connections only if the core operation remains fully safeguarded. Others argue that the PTO's network should actively facilitate additional third-party connections and support congestion relief, and focus on flexible, capacity-limiting arrangements with Liander, see *Flexible contracts*, with compensation from the DSO.

DSO perspective:

Liander expressed concerns about GVB supplying electricity to third-parties, while their own demand is low. Current transport contracts to other applicants and capacity allocations reflect GVB's existing usage profile, and backfilling the contract of GVB with external loads may be undesirable. Liander's current priority is to flatten peaks on its own network, and there may be opportunities for GVB to contribute to that objective. Liander also noted that GVB is among the most complex customers in the Amsterdam area, which reinforces the need for close coordination on any third-party connections and on a prioritisation framework. Mutual learning about system characteristics is required to identify where networks can complement each other and where GVB could facilitate. Technically, GVB can feed regenerative braking energy back to Liander's grid through bidirectional substations, since Liander does not impose capacity limits on feed-in. At the same time, Liander indicated it is not desirable for GVB to act as a "light" network operator, since it is preferred that those tasks rest with the licensed DSOs. Finally, Liander requested early and comprehensive sharing of GVB's long-term plans, including expected demand, route extensions, and new depots or workshops, given the DSO's multi-decade planning horizons.

VRA expectations:

VRA would like GVB to support decarbonisation of neighbouring regional operators, for example by sharing bus charging sites. VRA's concession conditions already direct that GVB should prepare its network to enable potential third-party connections.

GVB perspective:

GVB indicated willingness to assist, after safeguarding its own operation, for example by offering recuperation energy to third parties or using its network as a transport corridor where DSO capacity is insufficient. Proposals to store regenerative braking energy in stationary energy storage systems (ESS) are not preferred by GVB at present due to an unconvincing business case. Anyway, for GVB it is important that third-party connections have a viable business case, for example through subsidies or revenues associated with connections. It was also mentioed thar regenerative braking energy can be fed to applications when they are located at the right place in the network, thereby helping to reduce grid congestion and making the PTO system more energy efficient.

Metro versus tram suitability:

From a system perspective, the metro network appears the more suitable platform for third-party facilitation. Metro demand is more predictable, regenerative energy volumes are higher, nominal voltages are higher, and a 20 kV ring is planned, which allow more and stable third-party connections. The tram network operates at lower voltage, has more substations, and displays less predictable profiles due to urban operations, braking and acceleration cycles, and re-routings. Legally, using tram networks for a closed distribution system is also more complex and less favourable, see *Interview with a colleague of the transition expert*

Temporary congestion and long lived assets:

Participants further underscored that current congestion is temporary, roughly on the order of ten to fifteen years, whereas substations and electro-technical installations are designed for lifetimes of fifty to one hundred years. Consequently, the focus should not be limited to facilitating third-party connections in the short run, but also on ensuring robust long-term asset design and future-proofing of the public transport electricity system.